RE-LOOKING AT BAMBOO:
[A journey into exploration of bamboo components for structural possibilities]

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Research and explorations on bamboo

1930: Bamboo dome – Yona Friedman

1985 - 86: Bamboo grid shell – Frie Otto

2005: Bamboo Space frame – University of Aachen

2007: Bamboo school – Anna Heringer

2011: Bamboo school – John Hardy

2011: Wind and Water café - Vo Trong Nghia Architects

2011: Bamboo Pavilion - Hirokazu Toki

1997: Bamboo connection – Renzo Piano

1997: Bamboo furniture – Sandeep Sangaru

2000: ZERI Pavilion – Simon Velez

Overview

Research on bamboo

Methodology

Analysis

Inferences

Conclusion

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Aim:
To explore various possibilities of deriving components in bamboo split sections for structural utilization.

Objectives:

- Understanding different parameters which form components of bamboo split section in various bamboo craft.
- Deriving a method for explorations of various bamboo components.
- Exploring different components/modules/systems, using the derived methodology.
- Testing of a particular component/module/system, using the derived methodology.

Parameter, in mathematics, a variable for which the range of possible values identifies a collection of distinct cases in a problem.
Component, a constituent part
Module, an independently operable unit that is a part of the total structure
System, a regularly interacting or interdependent group of items forming a unified whole
(source: Britannica Encyclopaedia)
According to Xiobing Yu -

Disadvantages of bamboo in two dimensions:
1. Material perspective
2. Designers perspective

Irregular structure and material properties

Lack of standardization
“Instead of industrialization, modernization should be the real solution for the problem of utilizing bamboo in the industrial context.” - Xiaobing Yu
Modernization of bamboo:

Building up a new identity of the material bamboo in industrial context.

Bamboo + Designer = Experimentation with bamboo
Methodology
Stage 1: A study to find out various bamboo components formed out of bamboo split sections, in various bamboo crafts, prevailing in traditional and contemporary architectural practices, till now.

Stage 2: Analyzing and organizing the collected data, to extract various parameters which form bamboo components and further can be used to derive a method for experimentation.

The extracted parameters:

1. Techniques used
2. The predetermined form
3. Connections between the split sections
4. Scale and proportions of different sections and their compositions

Stage 3: Derivation of methodology for further experimentations.
List of techniques:

- Tying
- Twisting
- Drilling
- Bending
- Weaving
- Heating
- Splitting
- Bundling
- Flattening
- Joining
- Cutting
- Nailing

Predetermined form:
The directions for propagations are limited to:
1. Horizontal
2. Vertical
3. Inclined
4. Curvilinear

Connections between the sections:
- Jute twine
- Nut, bolts and rivets
- Bamboo pin
Scale and proportions of different split sections:
Stage 4: Exploring different components/systems, using the derived methodology.

Stage 5: Analyzing different components/modules, as follows:

Structural virtuosity:

Structural behavior of the joint:
Rotation along any axes – if joinery allows rotation?

Behavioral pattern:
How a particular module behaves under compression and tension loading conditions?
What are the strengths and weaknesses of the module?

How does the load transfer?

Further scope of the research:

What are the future possibilities/ scope of the study?
What are the possible ways to modify the module?

Possible direction of propagation:

Horizontal, Vertical, Inclined and Curvilinear

Probable application:

What can be the future applications of the systems?
Stage 6: Further explorations on the selected combination of the technique and one of the iterations from the chart.

Constants: Combination of half bamboo with one node
          Bending technique

Variables: Angle of bending
          Width of the strips

Stage 7: Compression testing on a selected module/system.
Selected species: Bambusa Arundinacea:

- Commonly known as “Assam bamboo”
- Swollen nodes and long intranodes
- Medium wall thickness

Mechanical properties of the selected species:

<table>
<thead>
<tr>
<th>Green Condition</th>
<th>Dry Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density Kg/m³</td>
<td>663</td>
</tr>
<tr>
<td>Modulus of rupture N/mm²</td>
<td>80.1</td>
</tr>
<tr>
<td>Modulus of elasticity N/mm²</td>
<td>8.96</td>
</tr>
<tr>
<td>Max. Com. strength N/mm²</td>
<td>35.3</td>
</tr>
</tbody>
</table>

| Density Kg/m³   | 559           |
| Modulus of rupture N/mm² | 58.3          |
| Modulus of elasticity N/mm² | 5.95         |
| Max. Com. strength N/mm² | 35.3         |
Analysis and Documentation
Analysis and documentation

- Tying [Module 1 to 5]
- Splitting [Module 1 to 3]
- Cutting [Module 1 to 2]
- Bending [Module 1 to 4]
Overview

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Tying

Module 1

Module 2

Module 3

Module 4

Module 5

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Exploration 1:

- Orientation of the sections: All the three sections - vertical
- Structural behavior of joint: Pin joint – restraints translations
- The module will perform good under: Compression And tension
- Orientation of the module for better performance: Vertical
- Directions for propagation: Horizontal
- Probable application: For vertical support systems in various space making elements
- Further scope of research: Tying pattern and other split Sections

Propagation possibilities:

1. Module
2. Sub system
3. System
### Exploration 2:

| **Orientation of the sections:** | Two sections – Vertical  
|                                | Two sections – Horizontal |
| **Structural behavior of joint:** | Fix joint – restrains both rotations & translations |
| **Directions for propagation:** | Horizontal, vertical and inclined |
| **Better performance of the module:** | Under compression |
| **Better orientation of module:** | Vertical |
| **Manually or machine based process:** | Partially manual  
|                                | Partially machine based |
| **Further scope of research:** | Tying pattern, different angles and other split Sections |

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Propagation possibilities:

Maximum and minimum dimensions possible & Increment in layers of tying with respect to the changing dimensions
Exploration 3:

- **Orientation of the sections:**
  - Two sections – Vertical
  - Two sections – Horizontal

- **Structural behavior of joint:**
  - Fix joint – restrains both rotations & translations

- **Directions for propagation:**
  - Horizontal, vertical and inclined

- **Better performance of the module:**
  - Under compression and tension

- **Better orientation of module:**
  - horizontal

- **Manually or machine based process:**
  - Partially manual
  - Partially machine based

- **Further scope of research:**
  - Tying pattern, different angles and other split Sections

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Propagation possibilities:

Maximum and minimum dimensions possible & Increment in layers of tying with respect to the changing dimensions

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### Exploration 4:

| Orientation of the sections: | Two sections – Vertical  
| Structural behavior of joint: | Two sections – Horizontal 
| Directions for propagation: | Pin joint – restrains translations 
| Better performance of the module: | Horizontal 
| Better orientation of module: | Under compression 
| Manually or machine based process: | Vertical 
| Further scope of research: | Partially manual 
| | Partially machine based 
| | Tying pattern and other split Sections 

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**Overview**

**Methodology**

**Analysis**

**Inferences**

**Conclusion**
Propagation possibilities:

Component → Module → Sub system
## Exploration 5:

| Orientation of the sections: | One sections – Vertical  
|                            | One sections – Horizontal  
|                            | One section - inclined  
| Structural behavior of joint: | Fix joint – restrains both rotations & translations  
| Directions for propagation: | Horizontal, vertical and inclined  
| Better performance of the module: | Under compression and tension  
| Better orientation of module: | Vertical  
| Manually or machine based process: | Partially manual  
|                                    | Partially machine based  
| Further scope of research: | Tying pattern, different angles and other split Sections  

**Plan**

- **Perspective view**

**Perspective view**

**Perspective view**

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Propagation possibilities:

Module

Sub system

System

Maximum and minimum dimensions possible & Increment in layers of tying with respect to the changing dimensions
Cutting / Splitting

Module 1
Module 2
Module 3
Module 4

Analysis
Structure

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Exploration 6:

- Orientation of the sections:
  - Two sections – Vertical
  - Two sections – Horizontal

- Structural behavior of joint:
  - Pin joint – restrains translations

- Directions for propagation:
  - Horizontal and vertical

- Better performance of the module:
  - -

- Better orientation of module:
  - Horizontal

- Manually or machine based process:
  - Machine based

- Further scope of research:
  - Other ways of splitting and other split sections
Exploration 7:

Orientation of the sections: All three sections - vertical

Structural behavior of joint: Fix joint – restricts both rotations & translations

Directions for propagation: Vertical

Better performance of the module: Under compression

Better orientation of module: Vertical

Manually or machine based process: Machine based

Further scope of research: Other ways of splitting and other split sections

Plan

Perspective view

Module

Sub system

System

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Exploration 8:

Orientation of the sections:
- Two sections – horizontal
- One section - vertical

Structural behavior of joint:
- Fix joint – restrains both rotations & translations

Directions for propagation:
- Horizontal, vertical and inclined

Better performance of the module:
- Under compression

Better orientation of module:
- Horizontal

Manually or machine based process:
- Machine based

Further scope of research:
- Other shapes of bamboo pins and other split sections

Plan

Perspective view

Module

Sub system

System
Exploration 9:

**Orientation of the sections:**
- One sections – horizontal
- Two sections – vertical

**Structural behavior of joint:**
- Pin joint – restrains translations

**Directions for propagation:**
- Horizontal, vertical and inclined

**Better performance of the module:**
- Under compression

**Better orientation of module:**
- Horizontal

**Manually or machine based process:**
- Machine based

**Further scope of research:**
- Other shapes of bamboo pins and other split sections

Plan

Perspective view

Module

Sub system

System
Exploration 10:

- Number of vertices: 4
- Number of edges: 6
- Angle between strips: 60 degrees
  - Surfaces: Four equilateral triangle
- Structural behavior of joint:
  - Fix joint – restrains both rotations & translations
- Directions for propagation:
  - Horizontal
  - Vertical
- Better performance of the module:
  - Under compression
- Manually or machine based process:
  - Partially manual
  - Partially machine based
- Further scope of research:
  - Other angle between the sections and other split Sections
Propagation possibilities:

Component

Module

Sub system
Exploration 11 and 12:

Number of vertices: 5
Number of edges: 8
Angle between strips: 90
Surfaces: Four equilateral triangles, one square

Number of vertices: 6
Number of edges: 10
Angle between strips: 108
Surfaces: Five equilateral triangles, one pentagon
Propagation possibilities:

Component ➔ Module ➔ Sub system ➔ Sub system
Propagation possibilities:

Component ➔ Module ➔ Sub system
**Exploration 13:**

- **Number of vertices:** 3
- **Number of edges:** 3
- **Angle between strips:** 60°
- **Surfaces:** One triangle
- **Structural behavior of joint:**
  - Fix joint – restrains both rotations & translations
- **Directions for propagation:** Horizontal, Vertical and inclined
- **Better performance of the module:** Under compression
- **Manually or machine based process:**
  - Partially manual
  - Partially machine based
- **Further scope of research:**
  - Other angle between the sections and other split Sections

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Propagation possibilities:

Module → Sub system → System

Module → Sub system → System

Module → Sub system → System

Module → Sub system → System
Exploration 14 and 15:

Number of vertices: 4
Number of edges: 4
Angle between strips: 45
Surfaces: One square

Number of vertices: 4
Number of edges: 4
Angle between strips: 90
Surfaces: One square

Plan
Perspective view
Elevation

Structural behavior
Propagation possibilities:

Module → Sub system → System

Module → Sub system → System

Module → Sub system → System

Module → Sub system → System

Module → Sub system → System

Module → Sub system → System
Propagating possibilities:

- Module → Sub system → System
- Module → Sub system → System

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Exploration 16 and 17:

**Number of vertices:** 4

**Number of edges:** 12

**Angle between strips:** 90

**Surfaces:** One square

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**Number of vertices:** 4

**Number of edges:** 12

**Angle between strips:** 90

**Surfaces:** One square and two rectangles
Exploration 18 and 19:

Number of vertices: 10
Number of edges: 20
Angle between strips: 90
Surfaces: Nine rectangles

Number of vertices: 8
Number of edges: 12
Angle between strips: 90
Surfaces: Two squares and four rectangles
Exploration 19 and 20:

**Number of vertices:** 4

**Number of edges:** 4

**Angle between strips:** 60

**Surfaces:** Four equilateral triangles

**Number of vertices:** 6

**Number of edges:** 12

**Angle between strips:** 90

**Surfaces:** Eight equilateral triangles

Structural behavior
**Exploration 21 and 22:**

**Number of vertices:** 8
**Number of edges:** 12
**Angle between strips:** 90
**Surfaces:** Six squares

**Number of vertices:** 12
**Number of edges:** 20
**Angle between strips:** 90
**Surfaces:** Twelve equilateral triangles

**Structural behavior**
**Constants:**

Testing: compression testing  
Propagation direction: vertical  
Testing specimen  
Testing equipment

**Variables:**

Amount of the UDL

Selected option of testing equipment and specimen
**Inference:**

- **Total time duration for the experimentation** – 9:36 mins
- **Time duration for the failure – when the system fails** – 1:06 mins

**Strength to weight ratio of the system**

\[ \text{Strength to weight ratio} = \frac{\text{force}}{\text{unit area}} \frac{\text{density}}{\text{kg}} \]

= 704.57 N.m/kg

The strength to weight ratio, derived here exhibits the structural potential of the system, made using the tetrahedrons.

**Possible ways to modify:**

The failure can be traced out at the bent junctions of the modules, where the strips are not laminated or overlapped. So overlapping at the junctions can make the system stronger.

Increment in the values of the considered width and thickness can also make the system stronger.

**Further scope of the research:**

Other load testing can also be done to evaluate the performance of the system under different loading conditions. For example tension, shear, torsion and bending.
It is possible to use bamboo split section for various structural applications...
“Cocoon Structure” – A workshop organized by C.A.R.E. School of Architecture, Trichy, India and AARHUS School of Architecture, Denmark.
Interior of the structure
Interior of the structure
A Bus Stop Module - A workshop organized by C.A.R.E. School of Architecture, Trichy, India.
A Bus Stop Module
A Bus Stop Module
Thank you...