HYBRID TIMBER CONSTRUCTION
TECHNOLOGY AND DIGITAL-TOOL

Investigation in a hybrid building construction technique, that could be encoded in a digital tool, by maximizing the use of local building materials such as natural timber, in seismic zone of Meghalaya, India.

- P5 Graduation
Krittika Agarwal | 4742591
Seismotectonic map of the Shillong Plateau showing four seismic source zones, earthquake epicenters from the declustered catalogue, and active fault lines. Numbers in the figure represent significant EQs:
1. 832EQ (M 8.0);
2. 541EQ (M 7.7);
3. 156EQ (M 7.3);
4. 173EQ (M 7.3);
5. 176EQ (M 7.5);
6. 178EQ (M 7.8);
7. 186EQ (M 7.7);
8. 186EQ (M 7.5);
9. 189EQ (M 8.1);
10. 1915EQ (M 7.1);
11. 1918EQ (M 7.6);
12. 1923EQ (M 7.1);
13. 1930EQ (M 7.1);
14. 1938EQ (M 7.2);
15. 1940EQ (M 7.2);
16. 1947EQ (M 7.7);
17. 1954EQ (M 7.7);
18. 1957EQ (M 7.0). Image and data copied from (Baweja, Kumar, & Ismaeel Zadeh, 2018).
Context - Urbanisation

Image source: Alamy stock photos
The embodied carbon of building materials (kg CO2/kg)

- Aluminium: -11.5
- Fibreglass: -8.1
- Brass: -4.5
- Lead: -3.2
- Zinc: -2.9
- Plastic: -2.7
- Copper: -2.7
- Vyl: -2.6
- Insulation: -1.9
- Steel: -1.0
- Cement: -1.0
- Ceramics: -1.0
- Glass: -1.0
- Plasterboard: -0.4
- Timber: -0.3
- Bricks: -0.2
- Concrete: -0.1
- Straw: -0.1
- Stone: -0.1

Image source: shrinkthatfootprint.com
Context - Historical reference

- 1823 - 1831: Construction of Cheria sanatorium, British influence
- 1864 - 1865: Construction of road Assam - Sylhet (now Bangladesh)
- 1887: Assam Earthquake
- 1903: 1st Motor car
- 1915: 1st Electric station
- 1947: Indian Independence
- 1972: Meghalaya, an autonomous state

11
The embodied carbon of building materials (kg CO₂/kg)

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Image source: shrinkthatfootprint.com
Research question

How can we develop a construction technology, for the seismic prone region of Shillong, comprising of a hybrid structural system by maximizing the quantitative use of local building materials such as timber, and how can the design logic of such a technique be made available for the local concerned professionals of the region?
Context analysis - Housing demands

60% of total master plan, Shillong = Residential

<table>
<thead>
<tr>
<th>Year</th>
<th>Residential Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991-2011</td>
<td>5095 hectares</td>
</tr>
<tr>
<td>2015-2035</td>
<td>3717 hectares</td>
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</tbody>
</table>

3388 hectares
Context analysis - Resource availability

Timber

Limestone

Bamboo

Authorities & professionals

Investors and land owners

Third party
Timber - Types

Types of structural timber

Natural solid timber

Engineered timber products

Logs

Sawing

Peeling

Stranding

Processing

Drying, planing & grading

Drying, cutting & sorting

Drying, sorting

Timber

Strands

Veneers

Cross-laminated timber

Shiplap panels

Scribner-sawed timber

Nail-laminated timber

Chemically treated timber

Plywood

Parallel-strand laminated panel and shutter

Laminated veneer lumber and panel

Oriented strand board

Laminated panel products and timber and planks

Structural insulating panels

Panelboard
Timber - Construction systems

Types of timber construction

Log construction
Timber frame construction
Light frame construction
Panel construction
Frame construction
Solid timber construction
Timber - Fire resistance

Active systems
- Automatic sprinklers
- Fire alarms
- Detection systems

Passive systems
- Charring method
- Encapsulation method
- Surface treatments (paints)
Timber - End of life scenarios

- Reuse
- Recycle
- Recover
- Dispose
Seismic design principles

Gravity force

Seismic force
Seismic design principles

**Terminology**
- Liquefaction
- Displacement
- Velocity
- Acceleration
- Inertia force
- Center of mass
- Return period

**Building properties**
- Weight
- Natural period of vibration
- Damping
- Ductility
- Strength
- Stiffness
- Torsion

**Force resistant systems**
- Shear walls
- Bracings
- Moment frames
- Diaphragms

**Design principles**
- Scale
- Proportions
- Corners
- Height
- Structure-plan density
- Symmetry
Overview

CONTEXT

BACKGROUND INFORMATION

DESIGN

CONTEXT ANALYSIS

TIMBER AS A MATERIAL

SEISMIC DESIGN PRINCIPLES

CASE STUDIES

TRADITIONAL JAPANESE

CONTEMPORARY CONSTRUCTION
Case studies - Traditional Japanese

Image source: Azby Brown, 2013
Case studies - Assam type

Combination of building materials - modern and traditional

Seismic performance by load distribution

Hybrid joineries
Case studies - Timber construction innovations

Height (metres)

Legend
- Completed
- In Construction
- Project

Case studies - Timber construction innovations

Tall timber tower concept
SOM

Tall timber tower concept
mgb Architecture + Design

Tamedia tower
Shigeru Ban Architects

The Stadhaus
Waugh Thistleton Architects

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Image source: https://images.adstcc.com/media/images/5304/7a5/4db4/4a8a/0a00/00c0/large.jpg?candidates=large,720,960,480,640,small,large,medium,small_square,large_square,landscape
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Overview

CONTEXT

BACKGROUND INFORMATION

DESIGN
Determining grid sizes

Habitable room

Lift shaft

Staircase

Final grid size - 3mx4m
Structural member sizing - criteria

Determining grid sizes

Material properties

Investigation criteria

Softwood
*Pinus kesiya*

Hardwood
*Shorea robusta*

Density

Mod. of elasticity

Bending strength

Max. lateral shear

Deflection

Secondary beam

Primary beam

Column

National building code of India
Structural sizing - Secondary beam

Determining load cases

Determining effective area

Structural validation

- Bending strength
- Max. lateral shear
- Deflection

Mechie Flooring, 125 mm plus
Plain concrete layer, 20 mm thick
Softwood floor joists, 25mm thick

Dimensions in mm:
- Width: 800
- Length: 2000
- Height: 100

Load applied in N/mm:
- W = 5.392

Deflections at R1:
- 15.90
- 6.80
- 52.95
Structural sizing - Primary beam & Column

Determining load cases

Determining effective area

Structural validation
Structural sizing - Primary beam & Column

Determining load cases

Determining effective area

Structural validation

Dedicated load:･
Hydrostatic soil -wood wall
Substantial thickness
Bamboo net panel with 2cm thich
sandstone plaster on each side
Vertical soft-wood wall
Supporting & frame

Secondary soft-wood
postament, supporting the floor.

Primary hard-wood beams, supporting the wall
and secondary beams.
Maximum load capacity per floor

- Ground floor: 0.6 kN
- First floor: 1281.4 kN
- Second floor: 1066.7 kN
- Third floor: 852.7 kN
- Fourth floor: 638.8 kN
- Fifth floor: 425.5 kN
- Roof: 212.8 kN

- 200 x 200 solid hard-wood cross-section
- 250 x 250 solid hard-wood cross-section
- 300 x 300 solid hard-wood cross-section
- 300 x 300 solid hard-wood cross-section
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<table>
<thead>
<tr>
<th>Grid size, mm</th>
<th>X axis (Secondary beam)</th>
<th>Y axis (Primary beam)</th>
<th>Primary beam cross-section, mm</th>
<th>Column solid cross section, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ground floor</td>
<td>1st floor</td>
<td>2nd floor</td>
<td>3rd floor</td>
</tr>
<tr>
<td>3000</td>
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</table>
### Structural sizes for various grids

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<tr>
<th>Grid size, mm</th>
<th>Secondary beam cross-section, mm</th>
<th>Primary beam cross-section, mm</th>
<th>Column solid cross section, mm</th>
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<tr>
<td></td>
<td>X axis (Secondary beam)</td>
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</tr>
</tbody>
</table>
DESIGN :D
Column design for visual integrity

- 200 x 200 solid hard-wood cross-section: 212.8 kN at +16000 m²
- 200 x 200 solid hard-wood cross-section: 425.5 kN at +12000 m²
- 250 x 250 solid hard-wood cross-section: 638.8 kN at +7000 m²
- 300 x 300 solid hard-wood cross-section: 1066.7 kN at +6000 m²
- 300 x 300 solid hard-wood cross-section: 1281.4 kN at +3000 m²
- 350 x 350 solid hard-wood cross-section: 0 kN at +0 m²

COLUMN DESIGN
Column design

Design criteria

- Psychological comfort
- Ease of joinery
- Symmetry
- Standardized parts
- Ease of fabrication
- Material saving
- Minimize surface expose (for fire)
## Column design

### Design criteria
- Psychological comfort
- Ease of joinery
- Symmetry
- Standardized parts
- Ease of fabrication
- Material saving
- Minimize surface expose (for fire)

### Inspiration

![Inspiration images](image-source)

### Design options

**Shapes**
- Metal plate connector
- Wooden dowels

**Connections**
- Glue
- Bolts

*Image source: scielo.conicyt.cl and researchgate.net.*
## Column design

### Design criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>✔️</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychological comfort</td>
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<td></td>
</tr>
</tbody>
</table>

### Proportions

- 2x3 - 2mm
- x/6 - 2mm

### Structural sizing

- Net cross-section dimensions
- Consideration of 25mm char layer
- Gross cross-section dimensions for structural calculations
Joinery Design
Overview

1. Background research
2. Concept design (1 joint)
3. Prototyping
4. Laboratory test
5. Result evaluation
6. Global seismic simulation (Structure validation)
7. Structural member sizing
8. Hybrid timber construction technology
9. User input:
   - Building footprint
   - Grid size
10. Design logic
11. Product catalogue
12. Digital tool
Joinery - Design criteria

Proportions
Symmetry
Balance
Material interaction

Joinery - Design

Proportions ✓ Symmetry Balance Material interaction

3/4 diameter

Small block width x 4

9.5

11

Joinery - Design

Proportions ✓
Symmetry ✓
Balance ✓
Material interaction ✓

Inspiration

Design

Joinery - Test process

Design → Prototype → Compression test → Evaluate

x 4 Repeat
Joinery - iterations
## Joinery - development

<table>
<thead>
<tr>
<th>Joinery design</th>
<th>First iteration</th>
<th>Second iteration</th>
<th>Third iteration</th>
<th>Fourth iteration</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Joinery design" /></td>
<td><img src="image2.png" alt="Joinery design" /></td>
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<td><img src="image4.png" alt="Joinery design" /></td>
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</table>

<table>
<thead>
<tr>
<th>Maximum Load</th>
<th>14 kN</th>
<th>13 kN</th>
<th>12.6 kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load paths</td>
<td>Limited</td>
<td>Limited</td>
<td>Increased surface area</td>
</tr>
<tr>
<td>Failure behaviour</td>
<td>-</td>
<td>Sudden breakage</td>
<td>Ductile behaviour</td>
</tr>
<tr>
<td>After test integrity</td>
<td>Central connector intact, primary beams broken</td>
<td>Stability dependent on the central dowel</td>
<td>Overall joinery intact, damage in the main bracket</td>
</tr>
<tr>
<td>Symmetry</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Standardization</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Repair facility</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
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<tr>
<th>Load paths</th>
<th>Limited</th>
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<th>Increased surface area</th>
<th>Increased area and contact bonding</th>
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<th>×</th>
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<th>✓</th>
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<thead>
<tr>
<th>Standardization</th>
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</table>

<table>
<thead>
<tr>
<th>Repair facility</th>
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</table>
Joinery - Fabrication in timber

Final design

Icon source: Nounproject
Timber Joinery - Load capacity test

Vertical compression test

Lateral cyclic load test

Results

Deformation [mm]

Normalized Force [N]

48kN

Normalized Stress [MPa]

Legend:
- 2.5 kN
- 5 kN
- 7.5 kN

Normalized Stress [MPa]

5kN
Timber Joinery - Load capacity test

Vertical compression test

Lateral cyclic load test

Cause of failure? Material or joinery?

Results
Timber Joinery - Cause of failure

Cause of failure?

Material or Joinery

Softwood pieces load test results

Vertical compression test results

Lateral cyclic load test results
Timber Joinery - Cause of failure

Cause of failure?

Material or Joinery?

Softwood pieces load test results

Vertical compression test results

Lateral cyclic load test results

Loading condition | Size (mm) | Results | Maximum load (N) | Average load (N)
--- | --- | --- | --- | ---
Parallel to grain | 44 x 43 x 42 | Specimen 1 | 43939 | 43303 N
| 43.5 x 43.5 x 38 | Specimen 2 | 42303 | 43 kN
Perpendicular to grain | 44 x 43 x 23 | Specimen 3 | 4988,8 | 4342,38
| 44 x 43 x 19 | Specimen 4 | 3686,75 | 5 kN

Legend:
- 2.5 kN
- 5 kN
- 7.5 kN

45 kN

5 kN
Timber Joinery - Load capacity for 1:1

Scaled model 1:5

Actual joinery 1:1
Timber Joinery - Scaling load capacity

Scale factor for force

$$\lambda_{\text{Force}} = \lambda_{\text{Mod. of elasticity (E)}} \times \lambda_{\text{length}}^2$$

Scaled model 1:5
Timber Joinery - Scaling load capacity

Scale factor for force

\[ \lambda_{\text{Force}} = \lambda_{\text{Mod. of elasticity (E)}} \times \lambda_{\text{length}}^2 \]

\[ \lambda_{E} = \frac{(\text{Modulus of elasticity of actual material})}{(\text{Modulus of elasticity of prototype})} = \frac{12.67 \text{ MPa}}{?} \]

Scaled model 1:5
Timber Joinery - Scaling load capacity

Scale factor for force

\[ \lambda_{\text{Force}} = \lambda_{\text{Mod. of elasticity (E)}} \cdot \lambda_{\text{length}}^2 \]

<table>
<thead>
<tr>
<th>Specimen properties</th>
<th>Results from lab test</th>
<th>Test setup</th>
<th>Young's modulus x E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>( E = \frac{\Delta P \cdot \alpha (\beta_1 - \alpha_2)}{\Delta \beta \cdot (\alpha_1^2 - \alpha_2^2)} )</td>
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<tr>
<td>specimen dimensions</td>
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<td>specimen area</td>
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<td>Second moment of area</td>
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<td>Load = P</td>
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</tr>
</tbody>
</table>

Scaled model 1:5

13.35 MPa
Timber Joinery - Scaling load capacity

Scale factor for force

$$\lambda_{\text{Force}} = \lambda_{\text{Mod. of elasticity (E)}} \times \lambda_{\text{length}}^2$$

$$\lambda_E = \frac{\text{(Modulus of elasticity of actual material)}}{\text{(Modulus of elasticity of prototype)}} = \frac{12.67 \text{ MPa}}{13.35 \text{ MPa}} = 1$$

$$\lambda_{\text{length}}^2 = 5^2 = 25$$

Scaled model 1:5
**Timber Joinery - Scaling load capacity**

Scale factor for force:

\[ \lambda_{\text{force}} = \lambda_{\text{Mod. of elasticity (E)}} \times \lambda_{\text{length}}^2 \]

\[ \lambda_{\text{force}} = 1 \times 25 = 25 \]

\[ \lambda_{E} = \frac{\text{(Modulus of elasticity of actual material)}}{\text{(Modulus of elasticity of prototype)}} = \frac{12.67 \text{ MPa}}{13.35 \text{ MPa}} = 1 \]

\[ \lambda_{\text{length}}^2 = 5^2 = 25 \]

1200 kN

Scaled model 1:5

125 kN

Actual joinery 1:1
## Timber joinery validation

<table>
<thead>
<tr>
<th>Load from structural calculation</th>
<th>Load capacity of proposed column-beam joinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>212.8 kN</td>
<td>&lt; 1200 kN</td>
</tr>
<tr>
<td>425.5 kN</td>
<td>&lt; 1200 kN</td>
</tr>
<tr>
<td>638.8 kN</td>
<td>&lt; 1200 kN</td>
</tr>
<tr>
<td>852.7 kN</td>
<td>&lt; 1200 kN</td>
</tr>
<tr>
<td>1066.7 kN</td>
<td>&lt; 1200 kN</td>
</tr>
<tr>
<td>1281.4 kN</td>
<td>&gt; 1200 kN</td>
</tr>
</tbody>
</table>
## Maximum no. of possible floors

<table>
<thead>
<tr>
<th>Grid size, mm</th>
<th>3000</th>
<th>3500</th>
<th>4000</th>
<th>4500</th>
<th>5000</th>
<th>4000</th>
<th>4500</th>
<th>5000</th>
<th>4000</th>
<th>4500</th>
<th>5000</th>
<th>4000</th>
<th>4500</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td>211,8</td>
<td>237,4</td>
<td>260,8</td>
<td>238,4</td>
<td>268,48</td>
<td>290,64</td>
<td>267,04</td>
<td>300,6</td>
<td>325,72</td>
<td>294,6</td>
<td>330,2</td>
<td>359,04</td>
<td>322,24</td>
<td>362,44</td>
</tr>
<tr>
<td>4500</td>
<td>423,72</td>
<td>474,92</td>
<td>521,72</td>
<td>476,92</td>
<td>537,08</td>
<td>581,4</td>
<td>534,2</td>
<td>601,32</td>
<td>651,56</td>
<td>589,32</td>
<td>660,52</td>
<td>718,2</td>
<td>644,6</td>
<td>725</td>
</tr>
<tr>
<td>5000</td>
<td>637</td>
<td>713,8</td>
<td>784,65</td>
<td>716,8</td>
<td>807,69</td>
<td>874,17</td>
<td>803,37</td>
<td>904,05</td>
<td>979,41</td>
<td>886,05</td>
<td>992,85</td>
<td>1079,37</td>
<td>968,97</td>
<td>1089,57</td>
</tr>
</tbody>
</table>

### Vertical Load on each column (kN)

<table>
<thead>
<tr>
<th>Vertical Load on each column (kN)</th>
<th>5th floor</th>
<th>4th floor</th>
<th>3rd floor</th>
<th>2nd floor</th>
<th>1st floor</th>
<th>Ground floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th floor 211,8</td>
<td>227,4</td>
<td>260,8</td>
<td>238,4</td>
<td>268,48</td>
<td>290,64</td>
<td>267,04</td>
</tr>
<tr>
<td>4th floor 423,72</td>
<td>474,92</td>
<td>521,72</td>
<td>476,92</td>
<td>537,08</td>
<td>581,4</td>
<td>534,2</td>
</tr>
<tr>
<td>3rd floor 637</td>
<td>713,8</td>
<td>784,65</td>
<td>716,8</td>
<td>807,69</td>
<td>874,17</td>
<td>803,37</td>
</tr>
<tr>
<td>2nd floor 850,93</td>
<td>953,33</td>
<td>1047,58</td>
<td>957,33</td>
<td>1078,3</td>
<td>1167,71</td>
<td>1072,54</td>
</tr>
<tr>
<td>1st floor 1064,86</td>
<td>1193,63</td>
<td>1311,28</td>
<td>1198,63</td>
<td>1349,68</td>
<td>1461,25</td>
<td>1342,48</td>
</tr>
<tr>
<td>Ground floor 1279,56</td>
<td>1433,93</td>
<td>1575,87</td>
<td>1439,93</td>
<td>1621,95</td>
<td>1755,68</td>
<td>1613,31</td>
</tr>
</tbody>
</table>

### Possible number of storeys

6 5 4 5 4 4 4 4 3 4 3 3 3 3
Column-primary beam joinery
All other joineries

- Facade
- Primary - secondary beam connection
- Eaves
- Beams to core
- Foundation
Global seismic simulation

1) Modelling system → 2) Model calibration → 3) Final simulation
### 1) Modelling system

<table>
<thead>
<tr>
<th>Element Order</th>
<th>2D Solid</th>
<th>3D Solid</th>
<th>3D Shell</th>
<th>Line Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>PLANE42, PLANE182</td>
<td>SOLID45, SOLID185</td>
<td>SHELL63, SHELL181</td>
<td>BEAM3/44, BEAM188</td>
</tr>
<tr>
<td>Quadratic</td>
<td>PLANE92/183</td>
<td>SOLID95/186</td>
<td>SHELL93</td>
<td>BEAM189</td>
</tr>
</tbody>
</table>

# Global seismic simulation

## 1) Modelling system

<table>
<thead>
<tr>
<th>Element Order</th>
<th>2D Solid</th>
<th>3D Solid</th>
<th>3D Shell</th>
<th>Line Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>PLANE42, PLANE182</td>
<td>SOLID45, SOLID185</td>
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<td>BEAM3/44, BEAM188</td>
</tr>
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<td>Quadratic</td>
<td>PLANE92/183</td>
<td>SOLID95/186</td>
<td>SHELL93</td>
<td>BEAM189</td>
</tr>
</tbody>
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Global seismic simulation

1) Modelling system → 2) Model calibration
Global seismic simulation

1) Modelling system → 2) Model calibration

Calibration sample models

<table>
<thead>
<tr>
<th>Model no.</th>
<th>DOF</th>
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<tbody>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
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<tr>
<td>3</td>
<td>2</td>
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<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
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</tbody>
</table>
Global seismic simulation

1) Modelling system

2) Model calibration

<table>
<thead>
<tr>
<th>Model no.</th>
<th>DOF</th>
<th>Analytical calculation</th>
<th>As per NBC India -2016</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inelastic displ. [mm]</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Reflection [mm]</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0.05</td>
<td>0.0</td>
</tr>
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<td>2</td>
<td>1</td>
<td>0.03</td>
<td>0.18</td>
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<td>4</td>
<td>2</td>
<td>0.07</td>
<td>3.23</td>
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Global seismic simulation

1) Modelling system

2) Model calibration

Types of joints/nodes

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<tr>
<th>Joint Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>Solid node</td>
<td>Component that represents solid material.</td>
</tr>
<tr>
<td>Rigid node</td>
<td>Component that represents rigid behavior.</td>
</tr>
<tr>
<td>Stitched node</td>
<td>Component that represents stitched behavior.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Joint No.</th>
<th>Joint Type</th>
<th>Description</th>
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</thead>
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<td>1</td>
<td>0.06</td>
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<tr>
<td>2</td>
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<td>0.09</td>
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<tr>
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<tr>
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<td>0.308</td>
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Dof: Degrees of Freedom

Reflection levels:
## Global seismic simulation

### 1) Modelling system

### 2) Model calibration

<table>
<thead>
<tr>
<th>Model no.</th>
<th>DOF</th>
<th>Analytical calculation</th>
<th>Numerical simulation</th>
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</thead>
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<td></td>
<td></td>
<td>Solid node</td>
<td>Point mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time (s)</td>
<td>Reflection (mm)</td>
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<td>1</td>
<td>1</td>
<td>0.05</td>
<td>0.8</td>
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<td>2</td>
<td>0.05</td>
<td>0.26</td>
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<tr>
<td></td>
<td>3</td>
<td>0.07</td>
<td>3.33</td>
</tr>
<tr>
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<td>4</td>
<td>0.07</td>
<td>3.23</td>
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<td>0.5</td>
<td>3.75</td>
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## Global seismic simulation

1) Modelling system  
2) Model calibration

<table>
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<th>Model no.</th>
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<th>Numerical simulation</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td>Total period (sec)</td>
<td>Reflection (mm)</td>
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<td>1 1</td>
<td>0.05</td>
<td>0.015</td>
<td>0.95</td>
</tr>
<tr>
<td>2 1</td>
<td>0.05</td>
<td>0.18</td>
<td>0.24</td>
</tr>
<tr>
<td>3 2</td>
<td>0.07</td>
<td>3.13</td>
<td>1.76</td>
</tr>
<tr>
<td>4 2</td>
<td>0.07</td>
<td>3.25</td>
<td>1.54</td>
</tr>
<tr>
<td>5 3</td>
<td>0.1</td>
<td>7.9</td>
<td>1.9</td>
</tr>
<tr>
<td>6 8</td>
<td>0.128</td>
<td>30.6</td>
<td>0.13</td>
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</tbody>
</table>
Global seismic simulation

1) Modelling system ➔ 2) Model calibration ➔ 3) Final simulation

1) Central core ➔ 2) Shifted core/extended core ➔ 3) Detached core
# Global seismic simulation

1) Modelling system  
2) Model calibration  
3) Final simulation

<table>
<thead>
<tr>
<th>Building core</th>
<th>Central core</th>
<th>Shifted core (extended)</th>
<th>Detached core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period for mode 1</td>
<td>0.046 sec</td>
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Global seismic simulation

1) Modelling system

2) Model calibration

3) Final simulation

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<tr>
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</tr>
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<td>Allowable deflection (0.004*building height)</td>
<td>72 mm</td>
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<td>72 mm</td>
</tr>
</tbody>
</table>

National building codes

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Hybrid timber construction technology
Digital tool - Target users

- Basic user
  - Digital tool
    - Controlled input parameters
    - Pre-coded design process
    - Quick output
  - Hybrid timber construction technology

- Advanced user
  - Research report
    - No control on parameters
    - Follow the research methodology
    - Calculations and simulations
Traditional building design process

- Step 1: Site
- Step 2: Building footprint
- Step 3: Determine the floor heights
- Step 4: Determine the grid size
- Step 5: Determine the floor heights
- Step 6: Architectural layout
- Step 7: Location of core
- Step 8: Location of the service shafts
- Step 9: Sizing of structural members, services and connection design
- Step 10: Fabrication and construction phase
Role of digital tool

Step 1 → Site

Step 2 → Building footprint

Step 3 → Determine the grid

Step 4 → Determine the floor heights.

Step 5 → Determine the structural dimensions.

Step 6 → Architectural layout.

Step 7 → Location of core

Step 8 → Location of the service shafts.

Step 9 → Facade design structure validation.

Step 10 → Fabrication and construction phase.

Digital tool

Input → Input

Output → Output
Defining inputs and outputs

1. Site
2. Building footprint
3. Determine the grid
4. Determine the floor heights
5. Determine the structural dimensions
6. Architectural input
7. Location of core
8. Location of the service shafts
9. Facade design / Structure validation
10. Fabrication and construction phases
Defining inputs and outputs

Step 1 → Site
Step 2 → Building footprint
Step 3 → Determine the grid
Step 4 → Determine the floor heights.
Step 5 → Determine the structural dimensions.
Step 6 → Architectural input.
Step 7 → Location of core
Step 8 → Location of the service shafts.
Step 9 → Refine and finalize design structure validation.
Step 10 → Fabrication and construction phase.

Digital tool

Input
Output
Input
Output

Design logic

Digital tool input

Post processing the digital tool output
### Grid size, mm

<table>
<thead>
<tr>
<th>Grid size, mm</th>
<th>Secondary beam cross-section, mm</th>
<th>Primary beam cross-section, mm</th>
<th>Column solid cross section, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>X axis (Secondary beam)</td>
<td>Y axis (Primary beam)</td>
<td>Ground floor</td>
<td>1st floor</td>
</tr>
<tr>
<td>3000</td>
<td></td>
<td>100x200</td>
<td>200x350</td>
</tr>
<tr>
<td>4500</td>
<td></td>
<td>125x200</td>
<td>225x350</td>
</tr>
<tr>
<td>5000</td>
<td></td>
<td>100x200</td>
<td>275x350</td>
</tr>
<tr>
<td>3500</td>
<td></td>
<td>150x200</td>
<td>225x350</td>
</tr>
<tr>
<td>4500</td>
<td></td>
<td>175x200</td>
<td>250x350</td>
</tr>
<tr>
<td>5000</td>
<td></td>
<td>150x200</td>
<td>250x375</td>
</tr>
<tr>
<td>4000</td>
<td></td>
<td>150x200</td>
<td>250x350</td>
</tr>
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<td></td>
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Specifying member sizes
Nomenclature system

Column-Primary beam joinery

Joinery series 3

Center location - a
- 3ax
- 3ay
- 3az

Edge location - b
- 3bx
- 3by
- 3bz

Corner location - c
- 3cx
- 3cy
- 3cz

Digital tool

Product catalogue
Final research output

Hybrid timber construction technology

Digital tool
Final research output

Hybrid timber construction technology

Assembly sequence
Assembly sequence

Concrete slab and steel connectors for columns.

Steel connector for timber column. Detail J1.

Reinforced concrete slab.

Steel connector embedded into the concrete foundation during casting.

Threaded rods welded to the reinforcement bars of the foundation.

Detail J1: Steel connector to foundation.
Assembly sequence

Detail 12: Installation of timber column.

Timber column installation & filling the foundation pit.

Detail 12: Timber column to concrete foundation.

Hardwood timber column, crafted and placed on the steel connector.

Timber column fastened by steel bolts.
Assembly sequence

Detail J5 - Installation of timber primary beams.

Primary beam installation.

Detail J5a - Primary beam to column to column installation

Primary beam to column connection fastened with nail and bolts.

Detail J5b - Primary beam to column to core installation

Steel connector embedded in concrete core, with a layer of hysteretic material.

Primary beam connected to column.
Assembly sequence

Detail J6: Steel connectors for secondary beams.

Secondary beam steel connector installation.

Detail J6: Steel connector to primary beam.

Secondary beam steel connector mounted on primary beam and fastened with nuts and bolts.
Assembly sequence

Detail 7
Supplementary timber columns for supporting intermediate beams for toilet shafts.

Timber supports for intermediate secondary beams.

Steel brackets for supporting intermediate secondary beams.

Timber columns for supporting secondary beams.

Detail 7: Steel connector to primary beam
Assembly sequence

Floor planks installation.

Detail J9: Flooring installation

25mm softwood timber planks for flooring, installed on the secondary beams.

Interlocking timber planks.
Assembly sequence
Assembly sequence

Construction progress.
Assembly sequence
Assembly sequence

2 bedroom apartment M1G, 3x4m grid, 60m² area.

2 bedroom apartment M1G, 3x4m grid, 60m² area, with gypsum board exterior and interior cladding.

Gypsum board cladding
Replacing primary beam

Replacing by removing floor

Replacement by removing flooring of top floor. One piece primary beam installation.

Replacing from below (not removing floor)

Replacement by without removing flooring. 3 piece primary beam installation with additional steel plate supports.
Conclusion

**Proposed:**

*Hybrid timber technology:*

**Current practice:**

*Reinforced cement concrete*

Conclusion

Proposed:

Hybrid timber technology:
- Timber structure
- Steel connectors

Current practice:

Reinforced cement concrete
- Concrete
- Steel reinforcement
- Wood shuttering

Seismicity

| Mass (kg) | 83.3% |

Sustainability

| Embodied Energy (MJ) | 5% |
| CO₂ footprint (kg) | 41.2% |

Image source: https://www.linkedin.com/pulse/basic-construction-process-rcc-column-majdi-ayeb, data source: CES
Conclusion

GLOBAL APPLICABILITY

Proposed:

Hybrid timber technology:
1. Timber structure
2. Steel connectors

Current practice:

Reinforced cement concrete:
1. Concrete
2. Steel reinforcement
3. Wood shuttering

Seismicity

Mass (kg)
- Proposed: 83.3%
- Current practice: 1000 kg

Energy (MJ)
- Proposed: 5%
- Current practice: 17500 MJ

CO₂ (kg)
- Proposed: 41.2%
- Current practice: 1800 kg

Future works

- Detail all other joineries and facade
- Seismic simulation with friction and damping
- Compression test using original proposed species
- Cost and energy savings analysis
- Moisture problem analysis in proposed joineries
- Digital tool refinement, more liberty to user
- Digital tool: more choice options
- Digital tool: inclusion of other joineries and facade
- Digital tool: Public availability
HYBRID TIMBER CONSTRUCTION
TECHNOLOGY AND DIGITAL-TOOL