Una reunión educativa con el bambú

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Showcase of the structural and sustainable possibilities of laminated Guadua bamboo as a material for a multiple story residential building in Guayaquil, Ecuador.
Research question

“How to design a residential building (complex) of multiple floors in Guayaquil, Ecuador, showcasing structural and sustainable possibilities and consequences of laminated Guadua bamboo?”

• Is the world, and especially Ecuador capable of building a laminated Guadua multi floor buildings? In other words: Is the world Ready?
• How to create a building that shows the possibilities of laminated bamboo, but at the same time complies with the current expectations of a building. In other words: How could it look like (and be excepted)?
• What are the decisive structural and technical limitations of a residential building with multiple floors in Laminated Guadua bamboo and how high the building can be according to those limitations. In other words: Can it be done?
• In what way does it contribute to the three spheres of sustainability and how does the building preform compared to similar sized buildings regarding environment. In other words: Is it sustainable?
Motivation

“The Future Depends on what we do in the Present” (Mahatma Gandhi 1869-1948)

- Reduce human impact now go positive in the future
- Bamboo could be the timber of the 21st century.
- To show the world the potential of laminated bamboo
- Help solving the housing shortage in Guayaquil (50%)
- Dense context asks a high building
Motivation

Larger scale
- Use of local natural resources helping a developing country develop
- Majority of buildings in the 21st. Will be building the developing world
Is the world ready?
Ecuador is ready (in a few years)

Yes in a few years

9 Story building Rome Italy

10 story building London England
Wood products (Ecuador is ready)

CLT

LVL

Glulam

Future recommendations
Bamboo products (Ecuador is ready)

Cross core

Cross laminated bamboo veneer (LVB)

Strandwoven

Scrimber

Physical testing

Conclusion

Laminated bamboo veneer (LVB)

Future recommendations
How could it look like?
Urban work models (It would look like)
Sketches (It would look like)
Urban plan  (It would look like)
Urban plan (It would look like)
Urban plan (It would look like)
Urban plan (It would look like)
Urban plan (It would look like)
Restaurant plan (It would look like)
Apartment plan (It would look like)

2 apartments per floor
BVO +/-109m² per apartment
Elevations (It would look like)

Front
Elevations (It would look like)

Right side
Elevations (It would look like)
Elevations  (It would look like)

Left side
View inside  (It would look like)
View inside (It would look like)
View inside (It would look like)
How could it be done?
Section: Structural system (How it could be done)
Structural system (How it could be done)
**Structural system** (How it could be done)
Structural system  (How it could be done)
Combining systems (How it could be done)

Internal dissipative system

Normal situation

Movement in earthquakes

Movement in earthquakes

Physical testing  Conclusion  Future recommendations
Energy absorption (How it could be done)

- Self Centring
- Energy dissipation
- Hybrid system

Pre-compressed Lamboo + Dissipative = Proposal

Physical testing  Conclusion  Future recommendations
Structural system (How it could be done)
Floor build-up (How it could be done)
Floor plate build-up (How it could be done)

- 30mm bamboo panels 1,660mm wide
- 30mm bamboo panels 1,460mm wide
- 30mm bamboo panels 1,660mm wide
- Reused pallet wood, serves as fire protection
- 10mm bamboo panel Finish
- Bearing cam

Span direction

Existing laminated bamboo panels glued and pressed together
Floor plate build-up (How it could be done)
Floor connection (How it could be done)

- Cap of recycled plastic
- Bold M10 HoH 500mm
- Holes drilled on site
- Internal LBV spline
- Pre-drilled holes
- Slot for the internal spline 5mm larger on all sides than the spline
- Recycled wood 2 layers of 30mm
- Bearing cam
- Nut M10
- Cap of recycled plastic

Physical testing  Conclusion  Future recommendations
Wall element build up it could be done

Physical testing Conclusion Future recommendations
Wall element build up (How it could be done)
Wall element build up (How it could be done)
Floor (How it could be done)
Floor build-up (How it could be done)
Floor build-up (How it could be done)
Core build-up (How it could be done)
Core build-up (How it could be done)
Core build up (How it could be done)

- Staircase wall LV8 6 layers of 3-ply bamboo
- Rockwool sound isolation 40mm
- Top cover plate 10mm lamboo 1400x340mm
- Inner opening height: 820, Width: 1400mm, Depth: 340mm, allowing post tensioning
- Location of cover strips to cover isolation
- Circular opening with a diameter of 1200mm
- Window frame with fire coating and thermo glass
- Steel plate 10mm 150x1340mm acts as force distributor
- Steel tendon 20mm before tensioning
- Two steel plates spreading pressure and allowing placement
- Bottom connection pin part of decoration
- Air tight rubber
- LV8 spacers 40x40 t.h. 300(vertical) and 510mm(horizontol)
- Apartment wall LV8 6 layers of 3-ply bamboo
Core build up  (How it could be done)

- Modular green roof system 130mm thick
- Waterproof membrane
- Pressure resistant isolation layer on slope
- Concrete topping
- Floor element 250mm high with bearing cam
- Steel tension cable (horizontal)
- Corbel 90mm with 440mm height
- UFP energy dissipator 100mmx100mmx8mm
- Open stair 850mm wide
- Ornamented window with fire coating and thermo glass
- Click on covers trip fire resistant
- Platform
- Elevator shaft, executed in LVB (kept transparent in this image to show elements behind it)
- Concrete topping with Electra piping 50mm

Physical testing  Conclusion  Future recommendations
How Sustainable is it?

Physical testing

Conclusion

Future recommendations
Sustainability

Sustainability for me is:
“Improving the world for tomorrow, based on the three pillars: Social, Economic and Environmental.”

Looking at only one pillar is lying to yourself.

Example: “Something can be a 100% environmental but not affordable or drastically reduce the standard of living.”
The Questions  Motivation  Ecuador is ready  It would look like  How it could be done  The sustainability

Education  (Social Sustainability)

Typical traditional organisation

Drawbacks:
- Financial control near impossible.
- Large amount of misinforming.
- Large amount of misinforming.
- Everyone (except the client) is only interested in their own part and disension will hinder others leading to overall cost increase.
- Little to no feedback of consequences of decisions in the design face to the experts.

Pro's:
+ Architect has larger degree of freedom
+ Fast and cheap
+ Invested time of different parties is minimized

Proposed organisation

Drawbacks:
- All parties have to be fully committed.
- Most information is irrelevant to different parties, but all have to attend for that small part that is relevant leading.
- Vast amount of decisions have to be made in an early stage.
- Time consuming meetings.
- Goals can differ.
- Industry will not like to share knowledge.

Pro's:
+ Allows better cost control
+ Reduces miscommunication
+ Increases understanding the building process for all parties.
+ Involving the executing parties to the design table allows them to optimize the design to their specialties and helps them understand the overall goals of the project.
+ Would boost the entire industry.

Physical testing  Conclusion  Future recommendations
Interaction (Social Sustainability)
Standard of living/Equalization (Social Sustainability)

Increased jobs for woman from 31% (raw culm industry) to 49% (premium processing)

Research also shows an increase in education of area’s with a developed bamboo industry.

Typical western approach, building cheap houses with culms, keeping people poor.

Physical testing

Conclusion

Future recommendations
Prize comparison (Economic Sustainability)

Earthquake proof building system NZ cost overview 2010 +Press-LBV

Early estimation: 30% more expensive than concrete buildings
Critical notes (Economic Sustainability)
Environmental Sustainability

- Total Eco-cost
  - Addition (no weighting)
  - Endpoint
    - Normalization factors
  - Midpoints
    - Characterization factors
      - Substances
        - Metals + rare earth
        - Wood + Food
        - Oil + Gas
  - Inorganic depletion
  - Water scarcity
  - Land-use
  - Waste
  - Fossil fuels
  - Climate change
    - Emissions of substances to: air, water, ground
  - Eco-cost of resource depletion
  - Eco-cost of carbon footprint
  - Eco-cost of Eco-systems
  - Eco-cost of human health
  - External ecological cost "P of Planet"
  - External Social-economic costs "P of people"

Physical testing
Conclusion
Future recommendations
C2G vs. C2C (Environmental Sustainability)

C2G = Cradle to Gate

C2C = Cradle to cradle

Physical testing Conclusion Future recommendations
**KG/m² + Life span** (Environmental Sustainability)

Concrete is a heavy building material.

Life time of a single structure less than a 100 years.
Eco-cost (Environmental Sustainability)

Concrete is more "sustainable" because about 3x less material is used than in the case of LVL.

Without EOL included a tall laminated biotic building is less sustainable than a concrete building.

With EOL included a tall laminated biotic building is more sustainable than a concrete building.

Table 16: Eco-cost for each structure

Physical testing Conclusion Future recommendations
Carbon + Energy (Environmental Sustainability)
The Questions  |  Motivation  |  Ecuador is ready  |  It would look like  |  How it could be done  |  The sustainability

**Systems compared (Land-Use)**

Hybrid structure (wood)  

LVB structure

- Physical testing  
- Conclusion  
- Future recommendations

+-1.950m3  
+-1.250m3
Fundamentals (Land-Use)

Guadua matures in 4-5 years and can be harvested.

Plantation is Mature after 9 years.

Source: http://www.guaduabamboo.com/blog/guadua-bamboo-growing-habits
Fundamentals (Land-Use)

The hole plant except the roots can be used.
The roots are needed to regenerate.

Source: http://www.niceep.pdt.gov.ph/admin/img/industry/FulUtilizationOfBamboo-part-1.jpg
Yield rate (Land-Use)

CLT 15m³/ha/year

LBV 15m³/ha/year
Results (Land-Use)

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Regular multistory CLT building

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Recycled wood (forest)
135ha

Guadua Forrest
84.3ha

Wood Forest
908ha

6.7x

+/- 1160m

+/- 1160m

+/- 920m

+/- 3010m

+/- 3010m
Adhesives (Adhesives)

- Adhesives have to be used
- There are no sustainable structural adhesives only less bad ones
- Wood can use more ‘sustainable’ structural adhesives
- No good sustainable alternative at the moment but there is hope
- Structural adhesives based on soybeans and other organic material
- PF adhesives are NO danger to the health of human occupants
Impact (Adhesives)

LCA (C2G) - Greenhouse gasses (carbon analysis)

Process: Laminated Guadua (bamboo) panel in Ecuador

- Production of insecticide
- Transport of culms
- Transport of preservation water
- Production of boric acid
- Steel sponges production
- Rest of processes
- Production of Boric oxide
- Electricity for pressing
- Transport of preserved culms to plant
- Production of Vinyl acetate
- Production of Urea formaldehyde

Influence on overall result

Physical testing
Conclusion
Future recommendations

The Questions  Motivation  Ecuador is ready  It would look like  How it could be done  The sustainability
Physical tests
Physical testing

Conclusion

Future recommendations
Physical testing
Physical testing

**Formula's Mechanical**

**Modules of Elasticity**

\[ E(x) = -\frac{\Delta Fx}{\Delta Vb(h)^3} \left(3l_1l_{h.o.h.} - 3l_1^2 - x^2\right) \]

**Stress caused by bending (bending strength)**

\[ \sigma_M = \frac{3F l_1}{b h^2} \]

**Formula's Statistics**

**Mean**

\[ \bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \]

**Standard deviation**

\[ \sigma_{SD} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n}} \]

**Standard error of the mean**

\[ \sigma_{\bar{x}} = \frac{\sigma_{SD}}{\sqrt{n}} \]
## Physical testing

<table>
<thead>
<tr>
<th></th>
<th>Lamboo</th>
<th></th>
<th>Moso</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>MOE (MPa)</td>
<td>$\sigma_m$ (MPa)</td>
<td>MOE (MPa)</td>
<td>$\sigma_m$ (MPa)</td>
<td></td>
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<tr>
<td>Mean:</td>
<td>9446</td>
<td>48.1</td>
<td>9688</td>
<td>56.8</td>
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<td>SD($\sigma$):</td>
<td>516</td>
<td>5.4</td>
<td>650</td>
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<tr>
<td>$\sigma_x$:</td>
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<td>1.13</td>
<td>174</td>
<td>1.18</td>
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<tr>
<td>CV:</td>
<td>8569</td>
<td>39.2</td>
<td>8620</td>
<td>49.5</td>
</tr>
</tbody>
</table>

Values claimed by **Moso** fit in standard error of the mean.

Values **Lamboo** can not be confirmed or disclaimed.

The wrong material was obtained.
Conclusion

A 12 story building in Lamboo seems technically possible. Although more research is needed, it can meet fire, sound and structural demand.

If the right context is applied it can be sustainable and could provide multiple story buildings for dense cities allowing a more sustainable alternative to concrete and steel

However there are still some issues to solve (adhesives, cost, local cooperation)
Future recommendations

- Connections: **FEM** analysis structure
- Material: **Physical** testing: creep, delamination fire behaviour and gas emissions.
- Structural: **Physical** testing: vibrations, building system
- Analysing the building **Cost** within context.
- Sustainability: Possibilities of high-tech industry in Ecuador, Full Complete LCA study fully adapted to Ecuador, How to reduce the impact of adhesives,
Thank you