Una reunión educativa con el bambu

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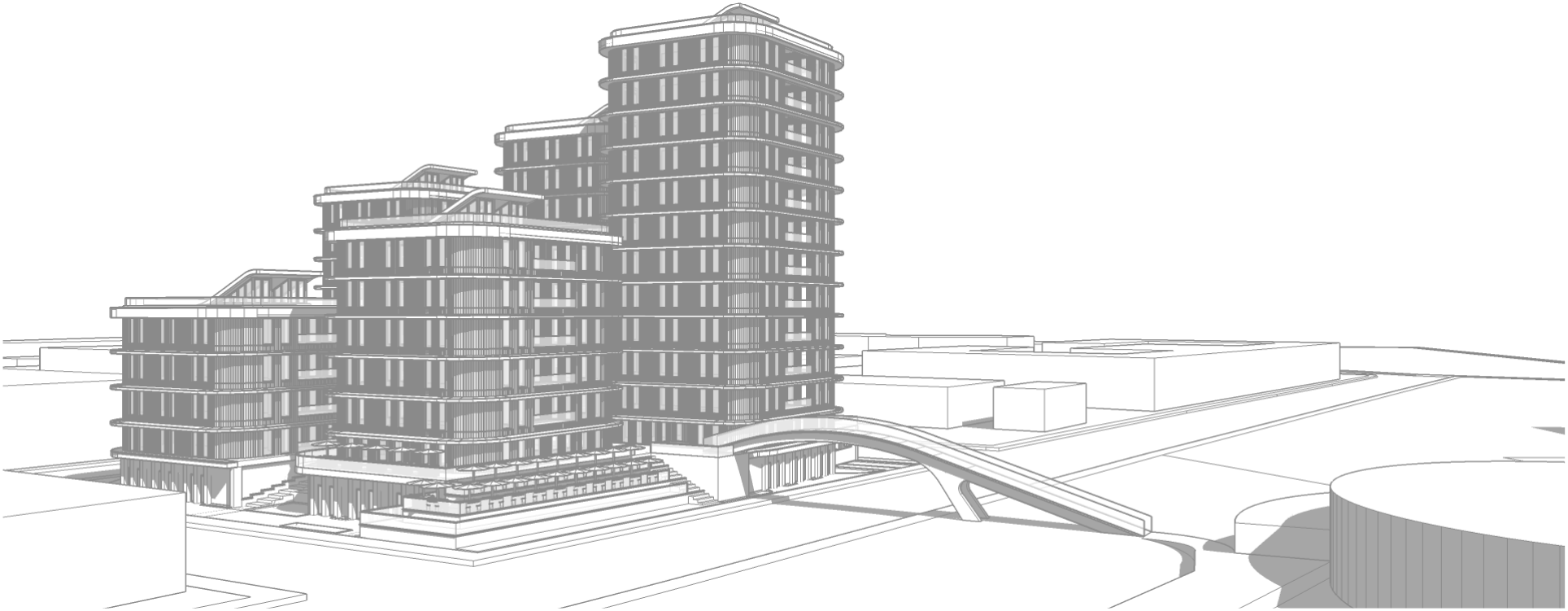
TU Delft

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?"

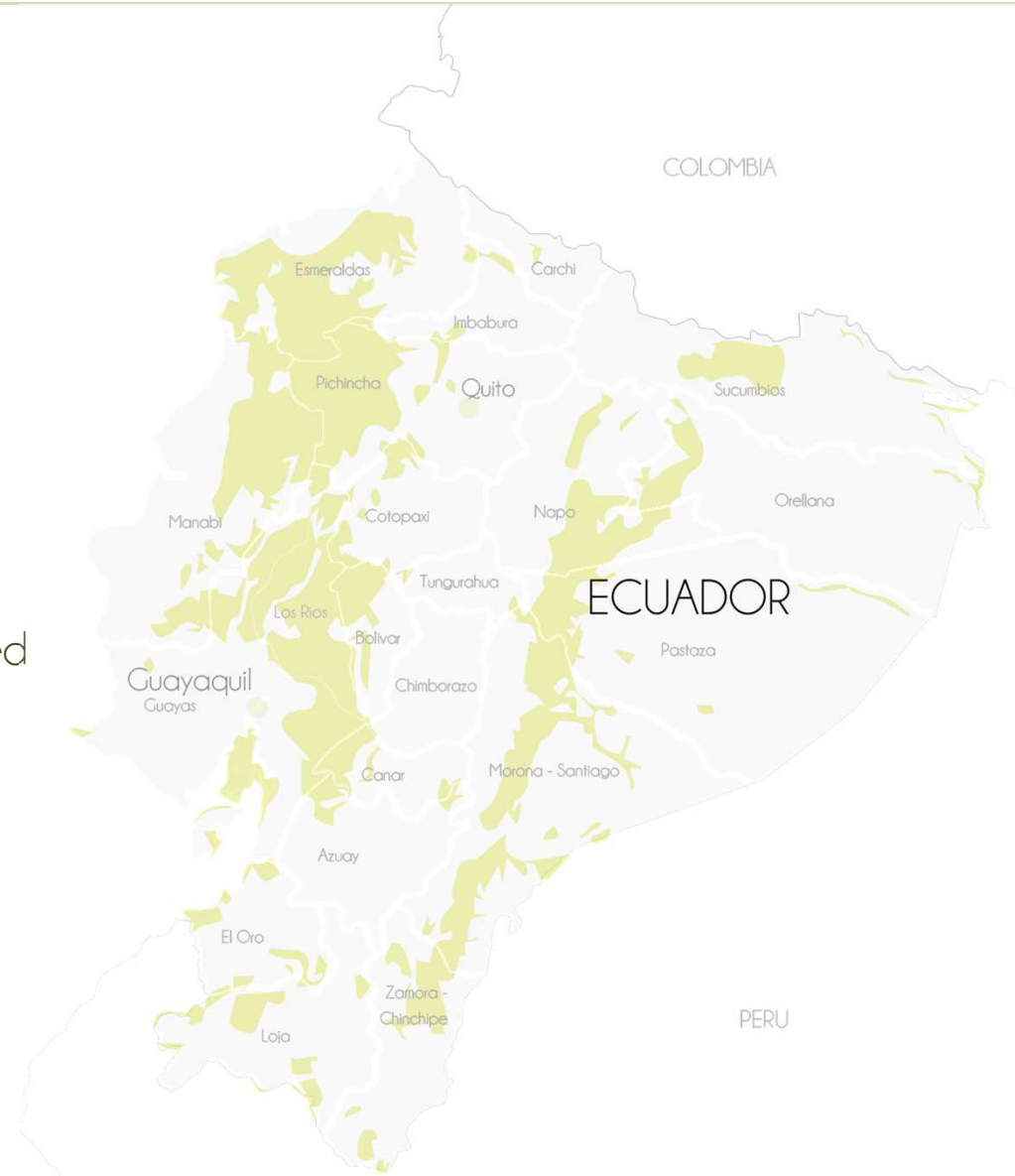
- Is the world, and especially Ecuador capable of building a laminated Guadua multi floor buildings? In other words: Is the world Ready?
- How to create a building that shows the possibilities of laminated bamboo, but at the same time complies with the current expectations of a building. In other words: 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

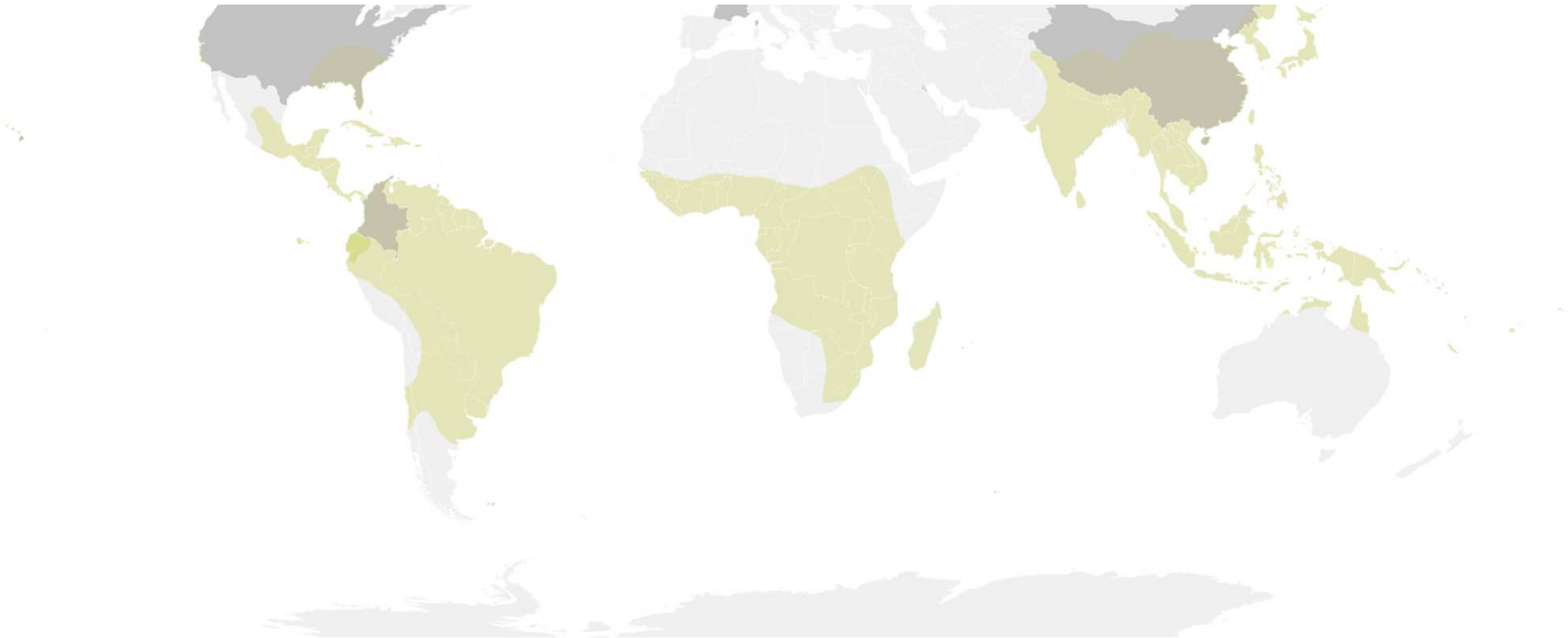
- Help solving the housing shortage in Guayaquil (50%)
- Dense context asks a high building



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

Glulam

LVL

Bamboo products (Ecuador is ready)

Cross core

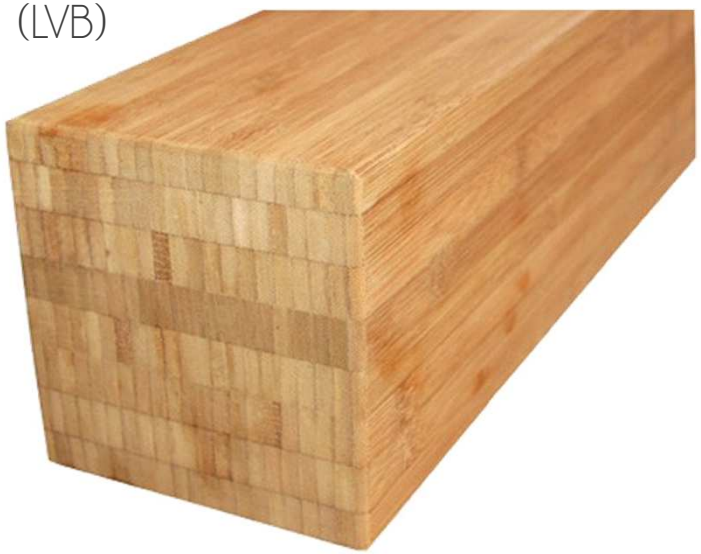
Strandwoven

Strandwoven

Cross laminated bamboo veneer (LVB)

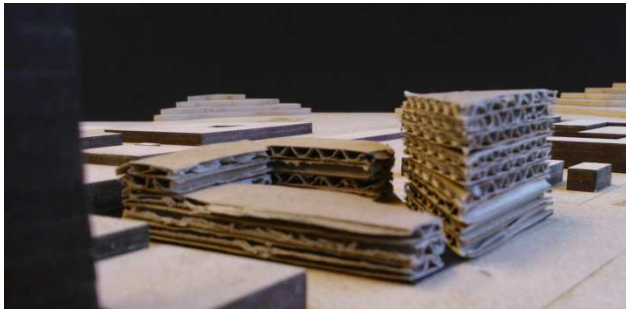
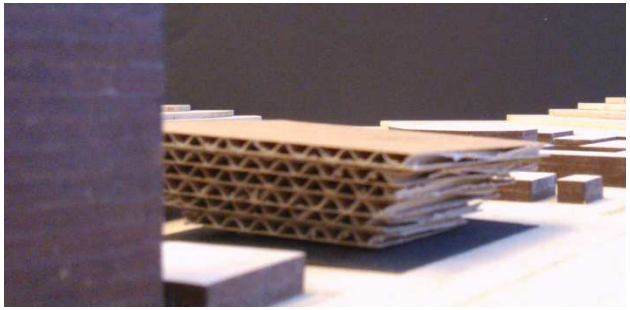
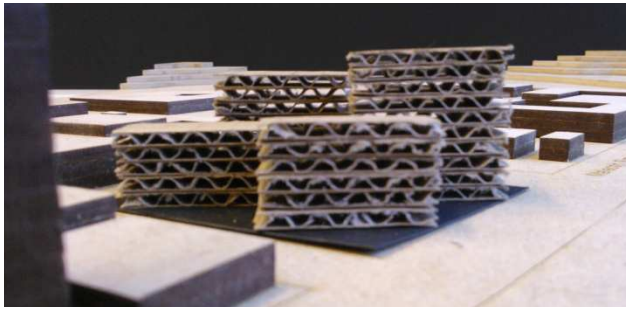
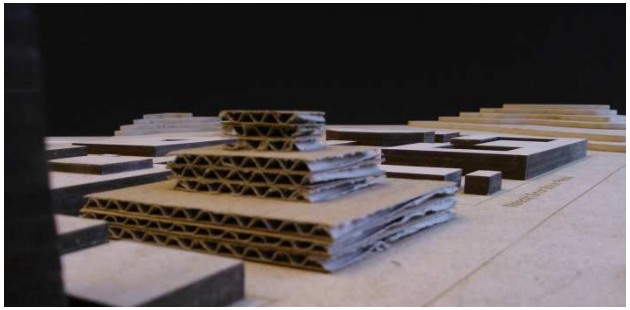
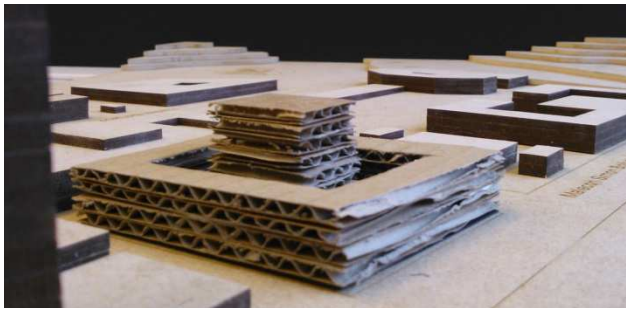
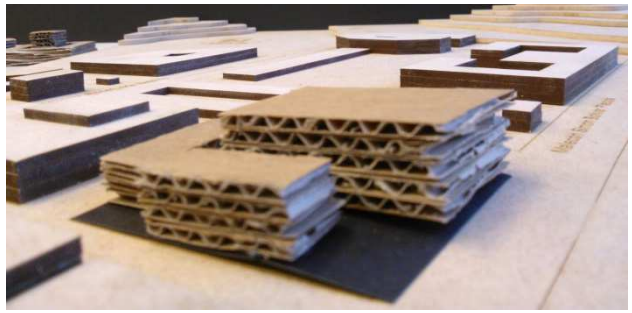
Scrimber

Laminated bamboo veneer (LVB)



How could it look like?

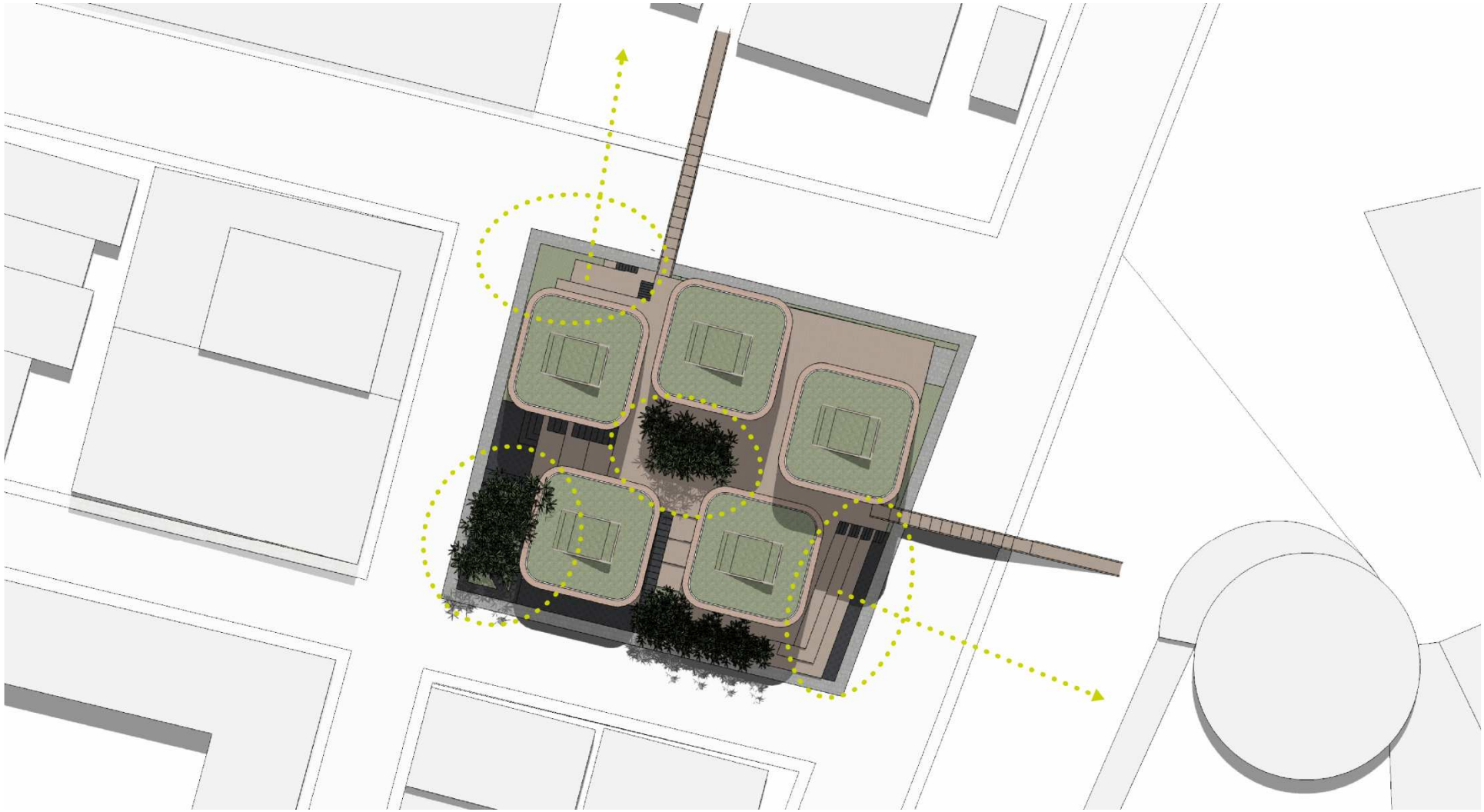
Urban work models (It would look like)

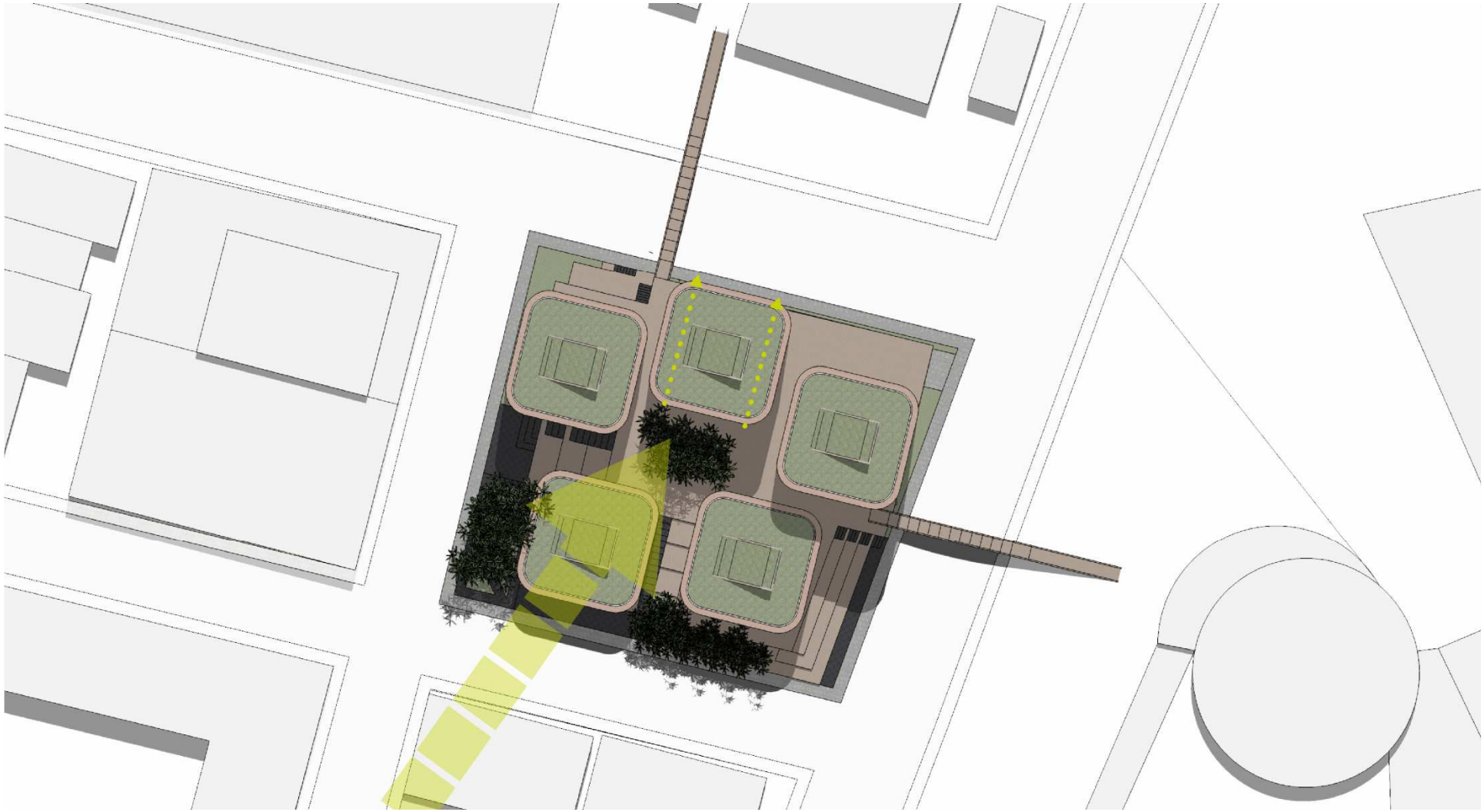
Sketches (It would look like)

Urban plan (It would look like)

Urban plan (It would look like)

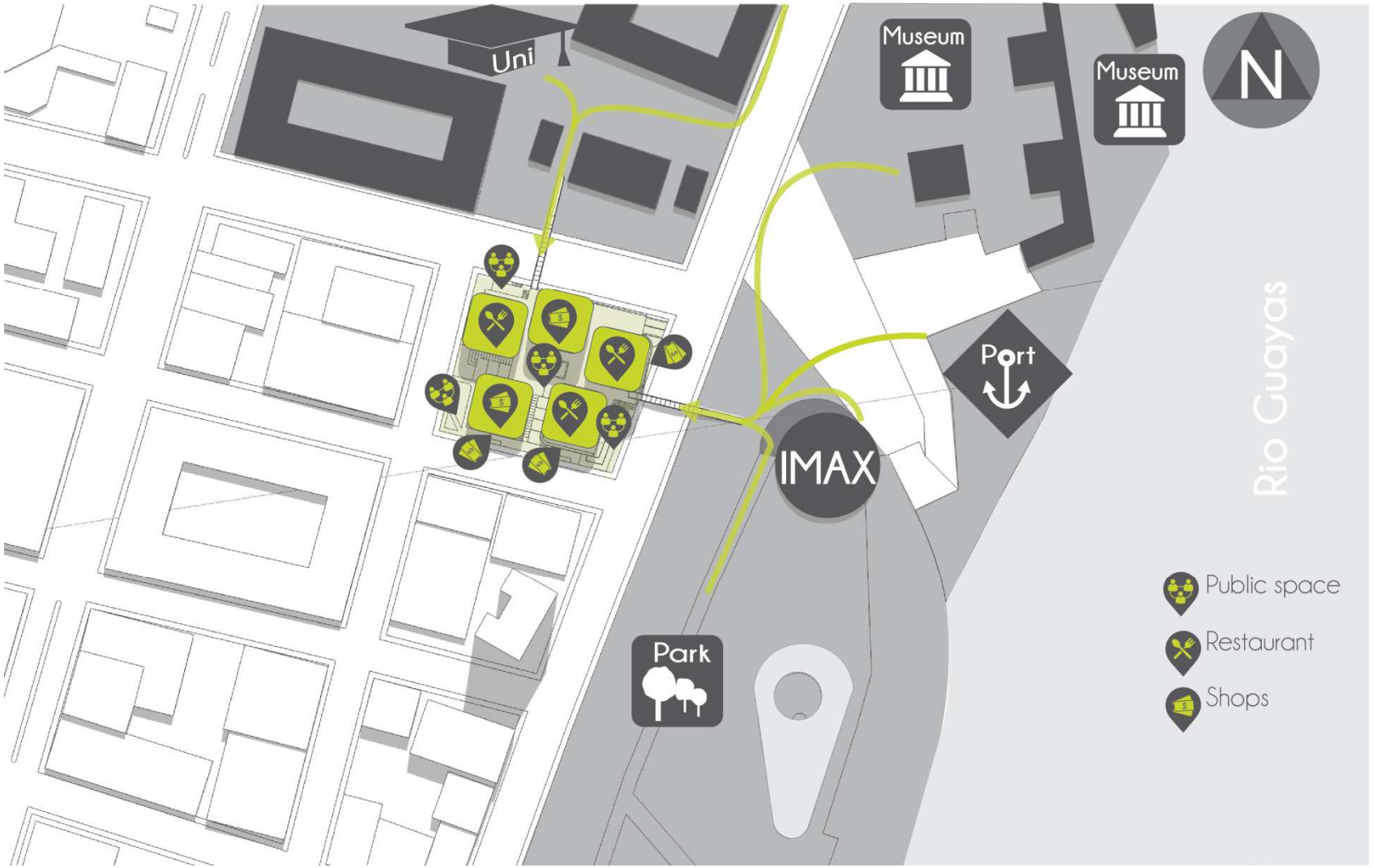


Urban plan (It would look like)

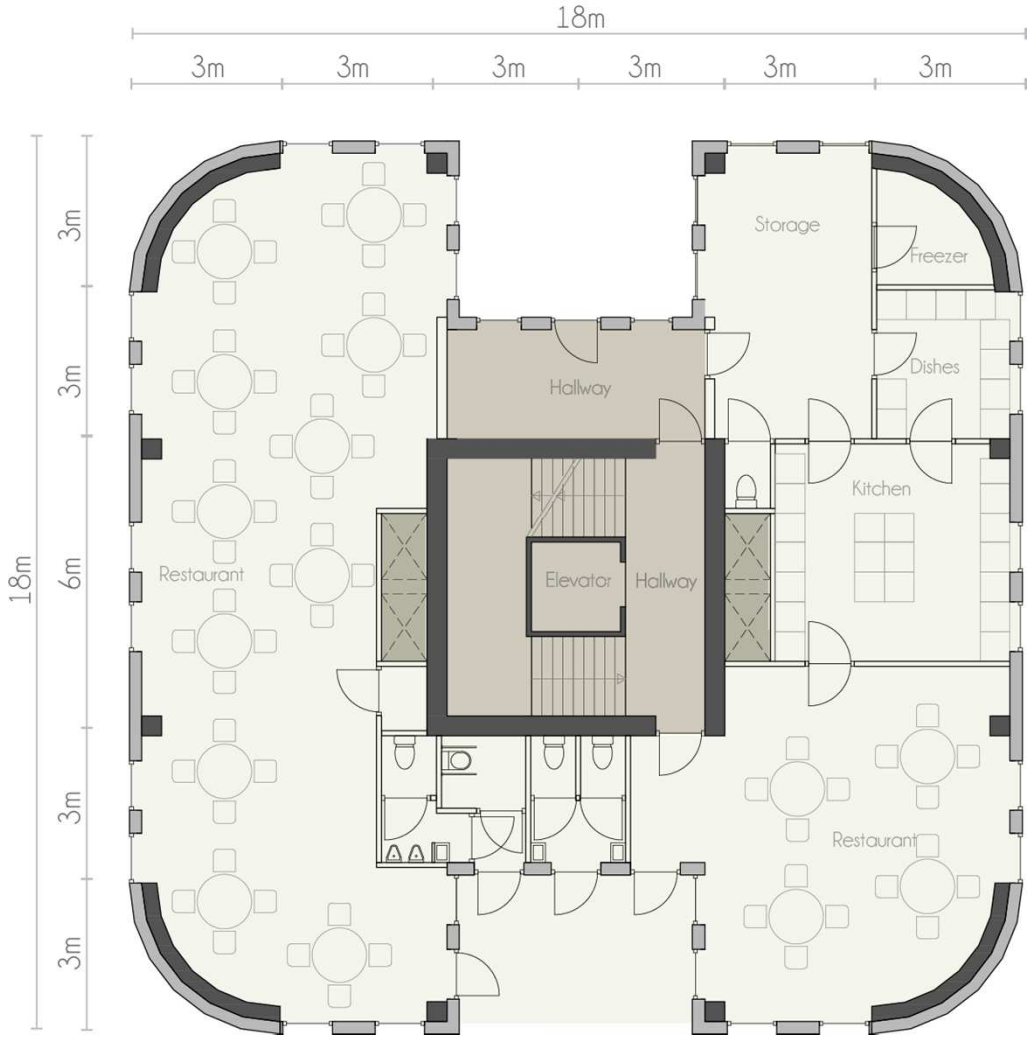


Urban plan (It would look like)

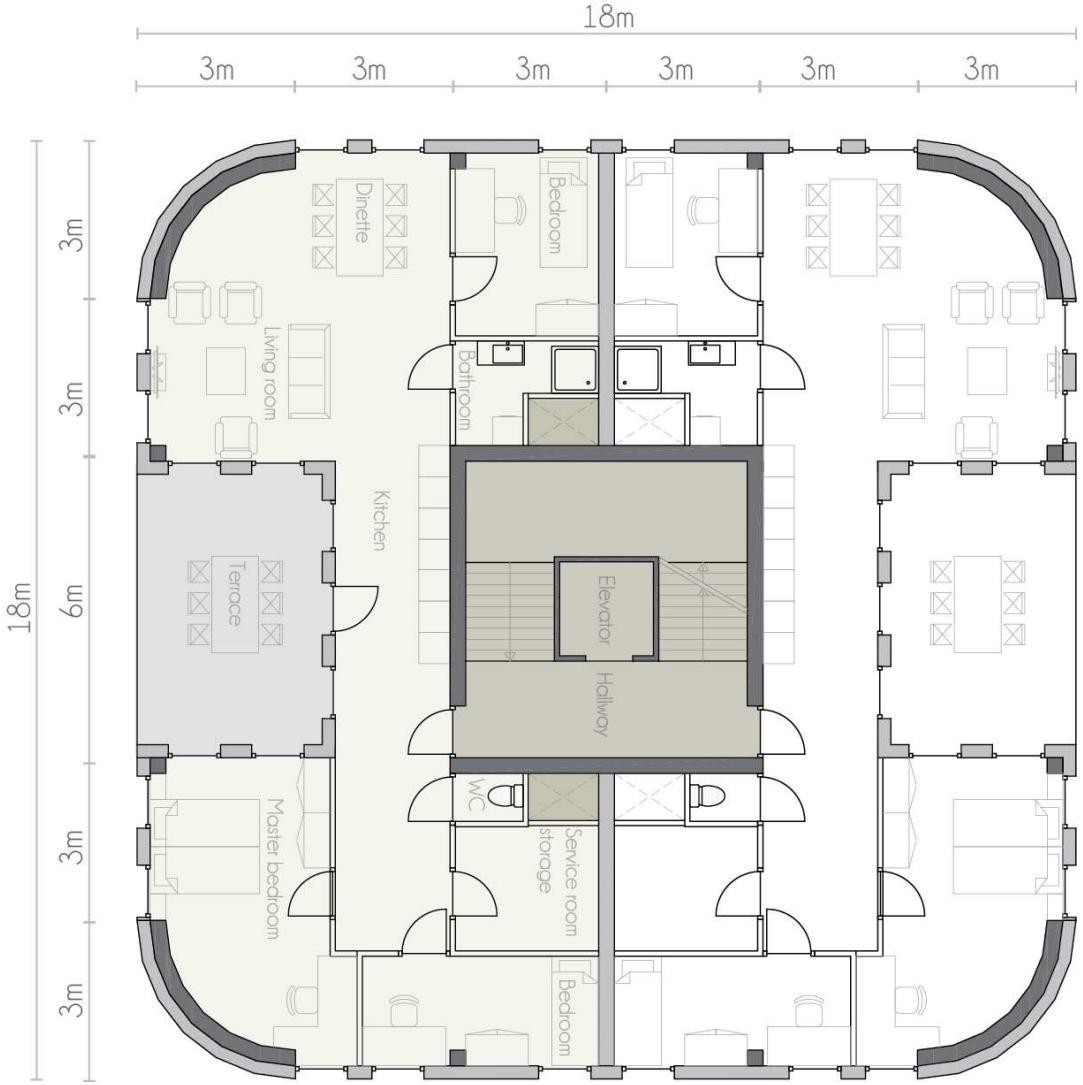
Urban plan (It would look like)



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)

Back

Elevations (It would look like)

Left side

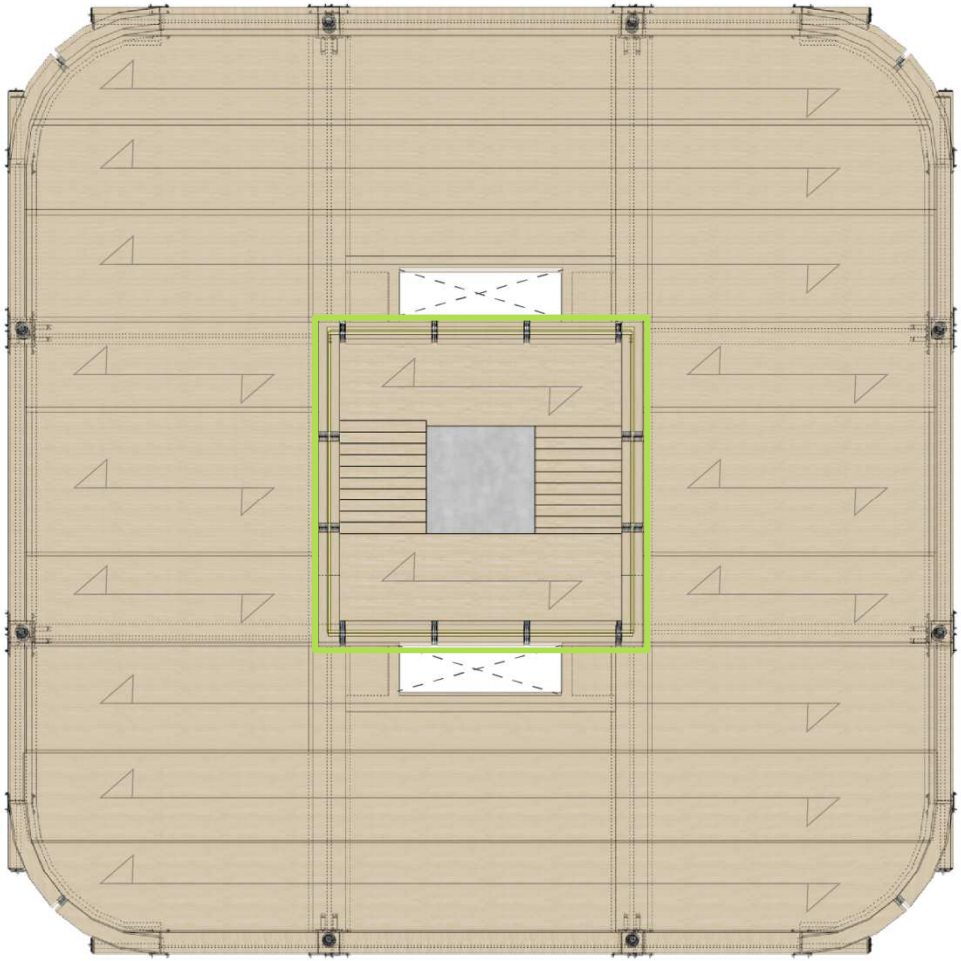
View inside (It would look like)

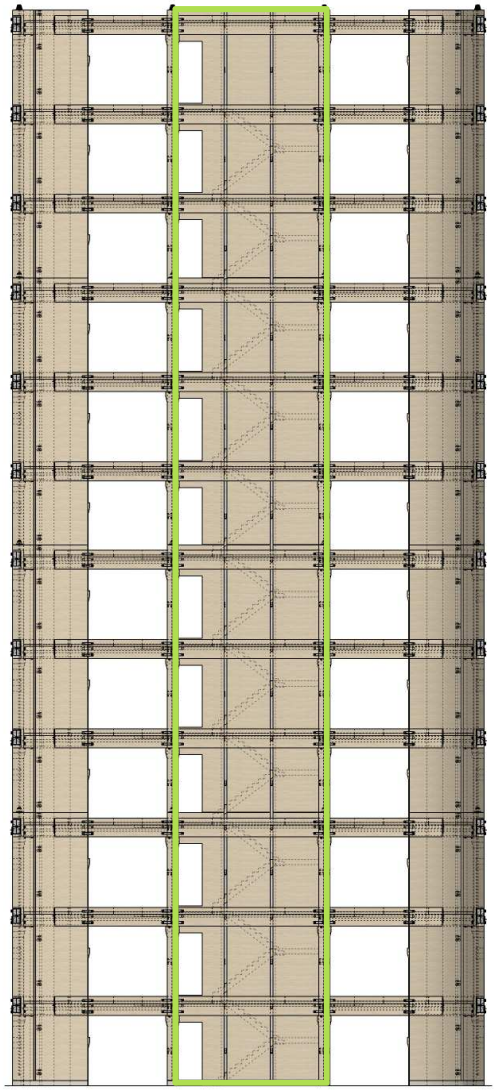
View inside (It would look like)

View inside (It would look like)

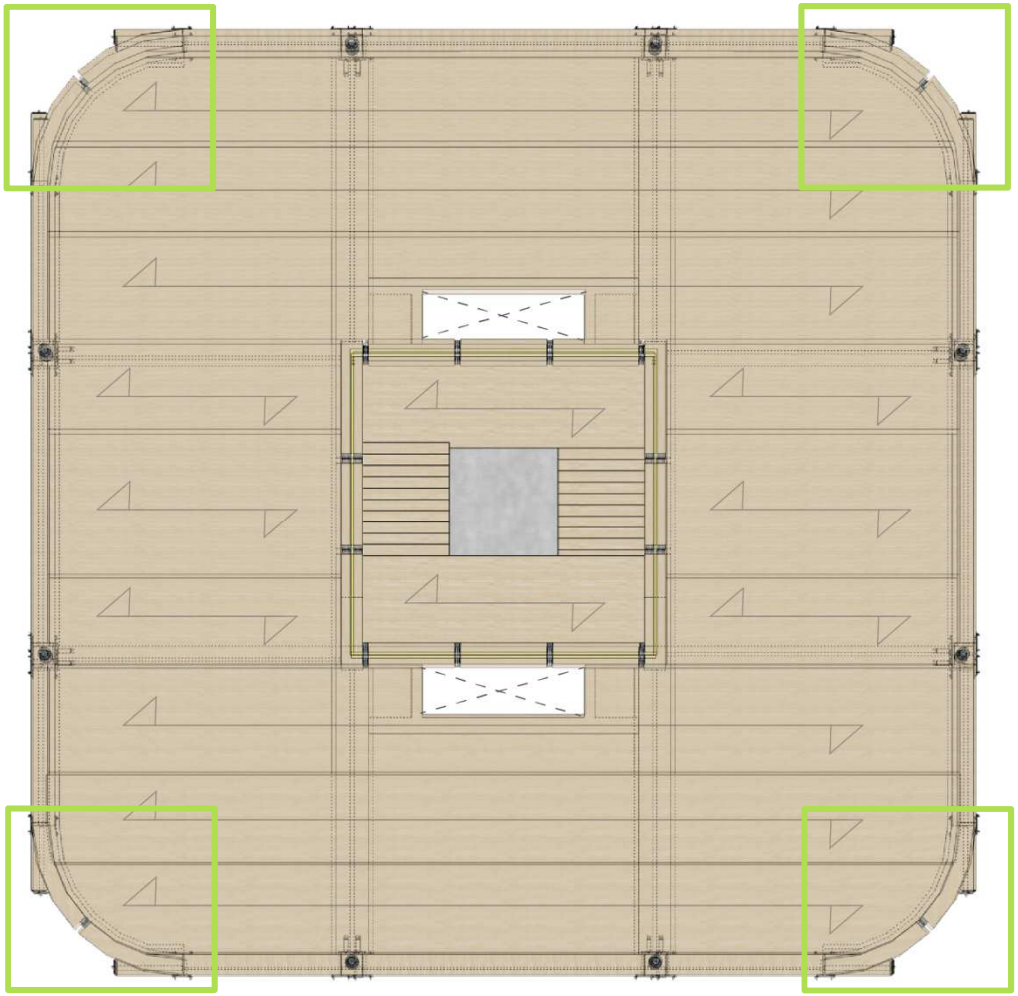
How could it be done?

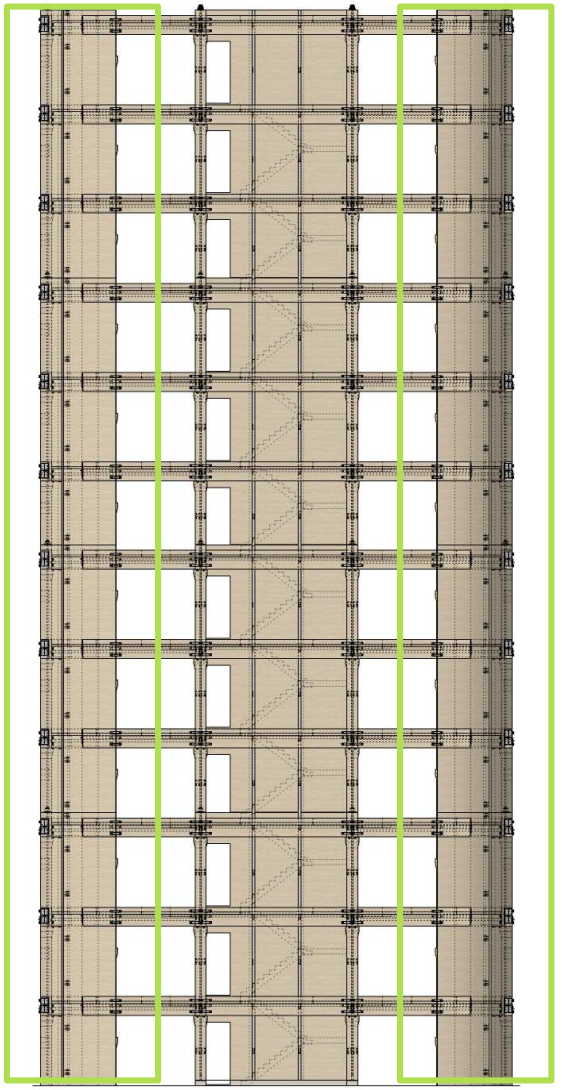
Structural system (How it could be done)



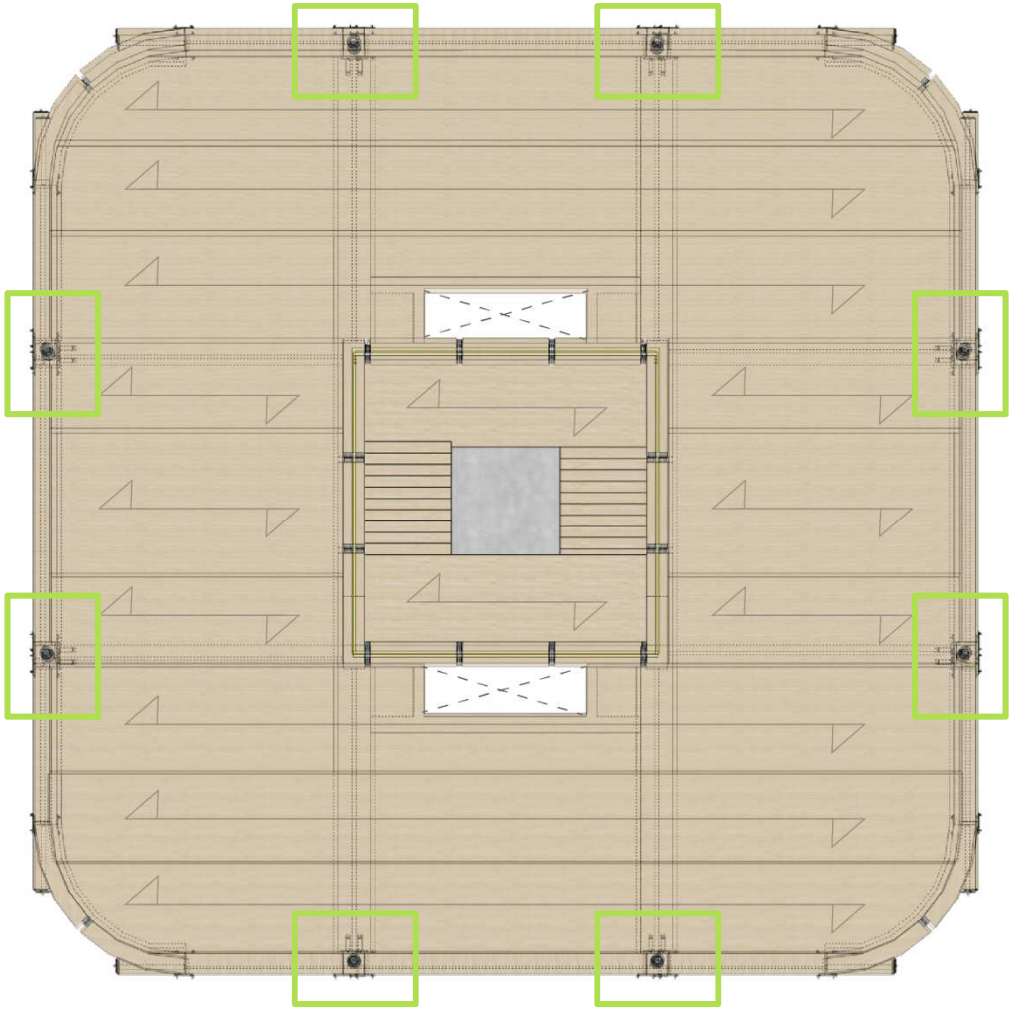


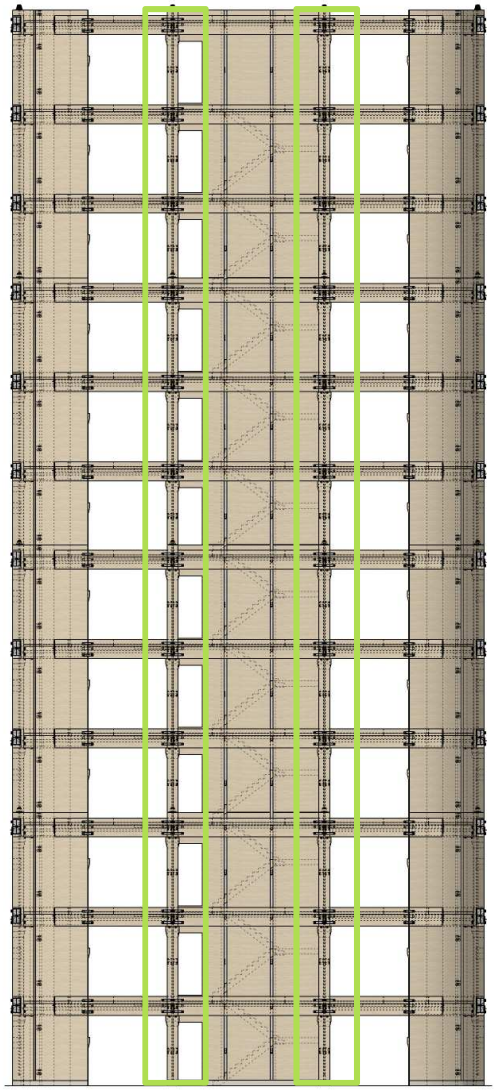
Structural system (How it could be done)



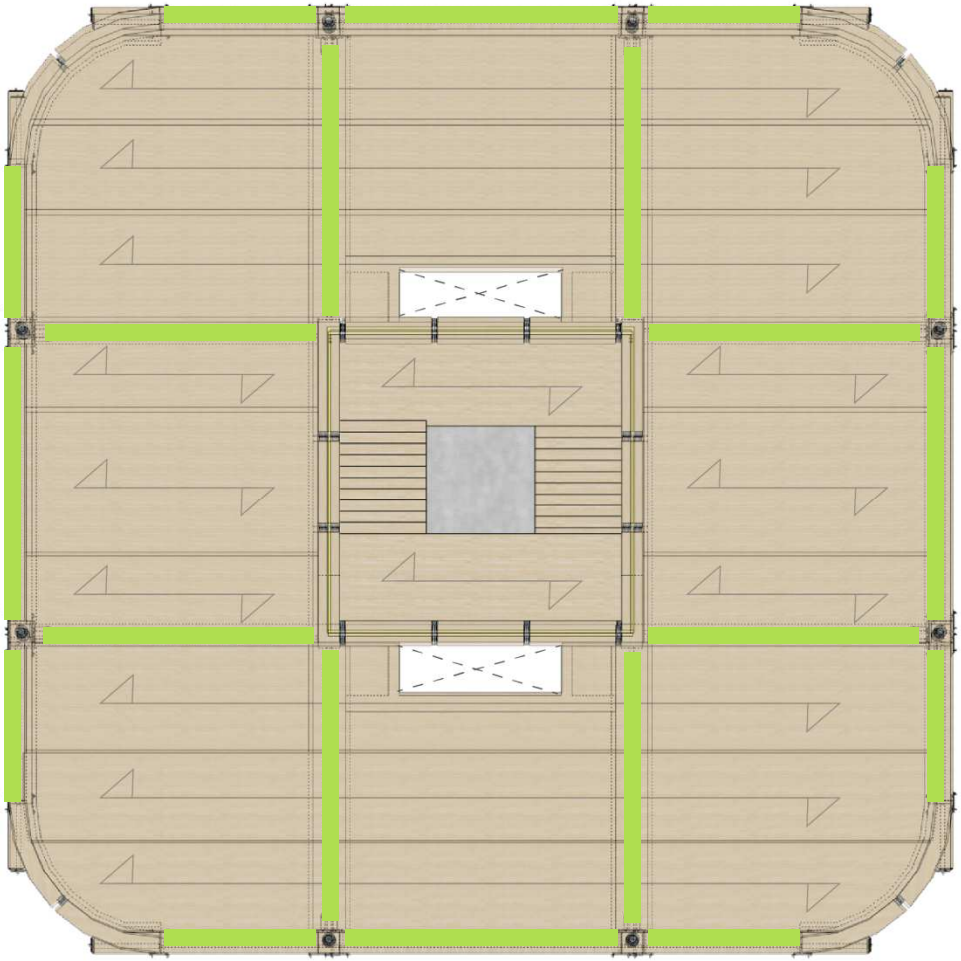


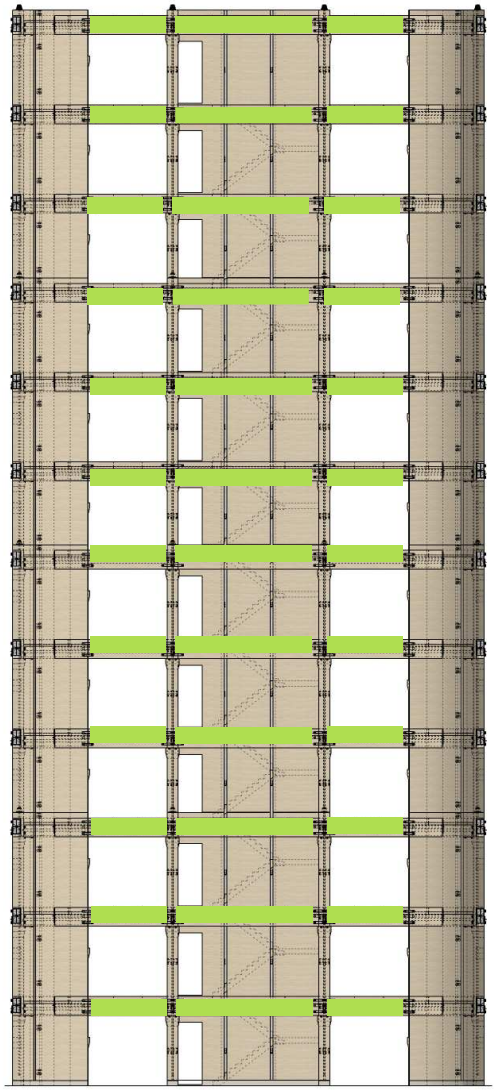
Structural system (How it could be done)





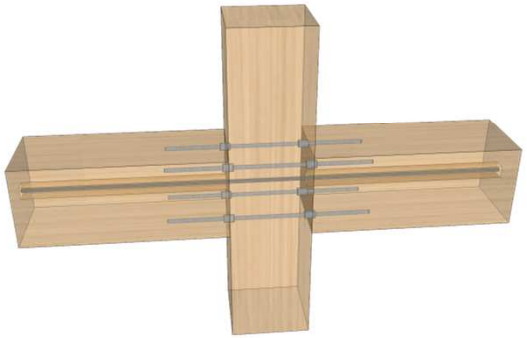
Structural system (How it could be done)



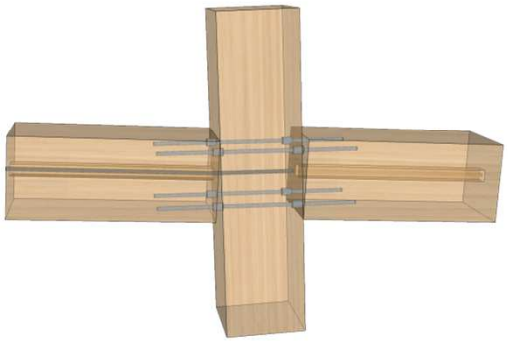


Combining systems (How it could be done)

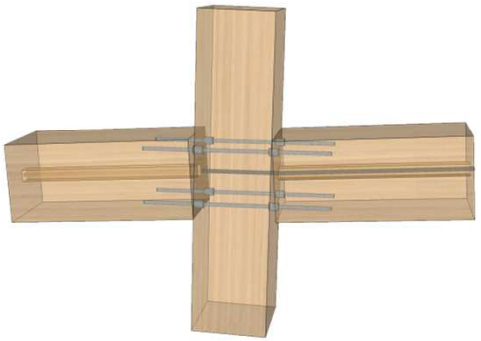
Internal dissipative system



Normal situation



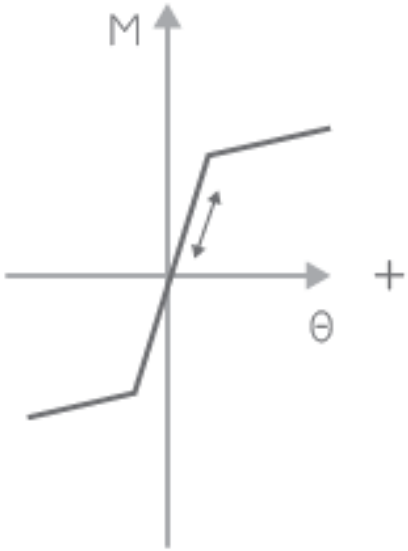
Movement in earthquakes



Movement in earthquakes

Energy absorption(How it could be done)

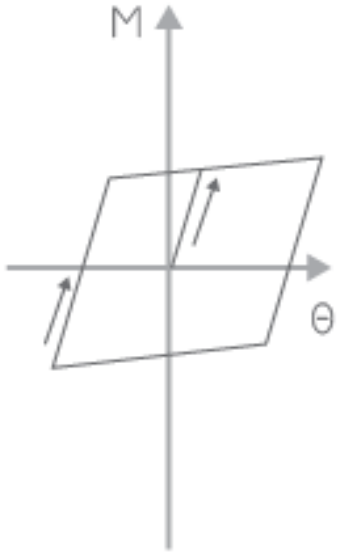
Self Centring



Pre-compressed Lamboo

+

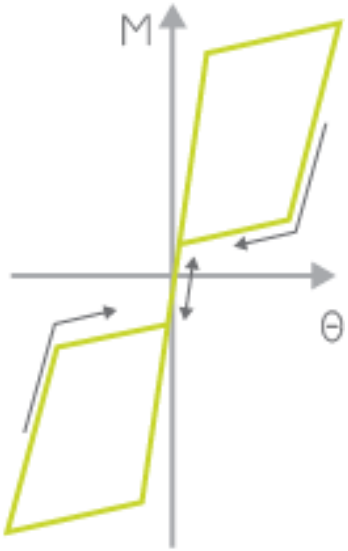
Energy dissipation



Dissipative

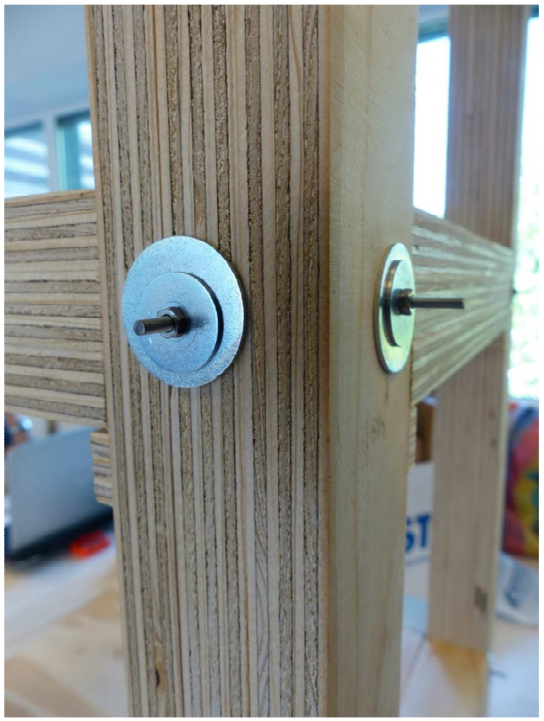
=

Hybrid system

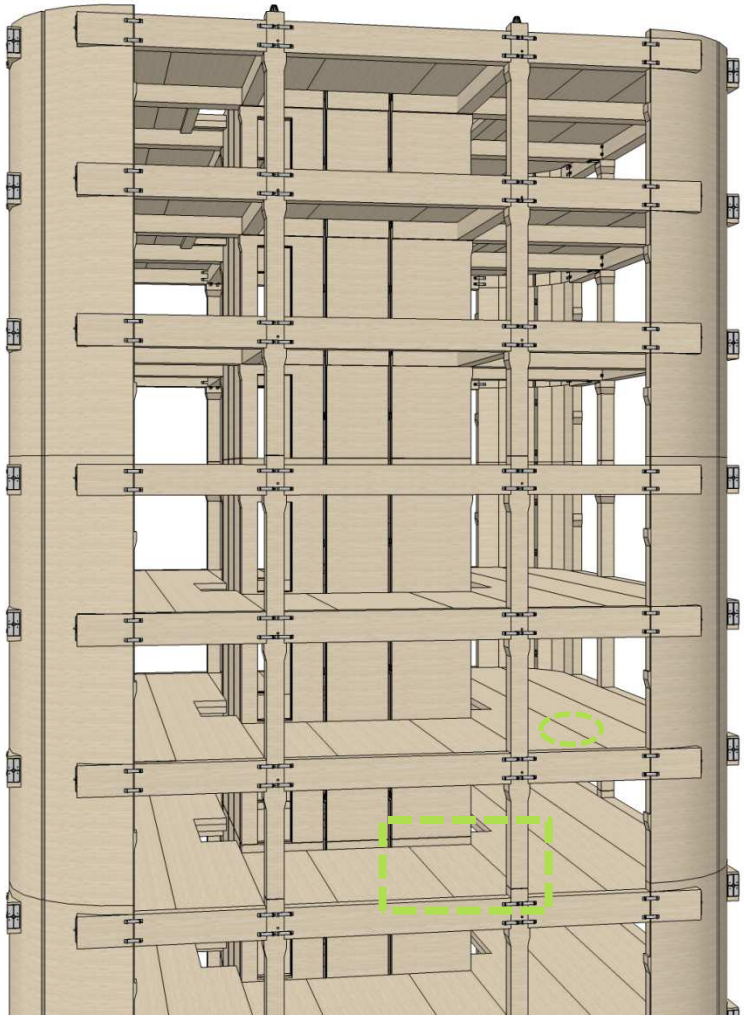


Proposal

Structural system (How it could be done)



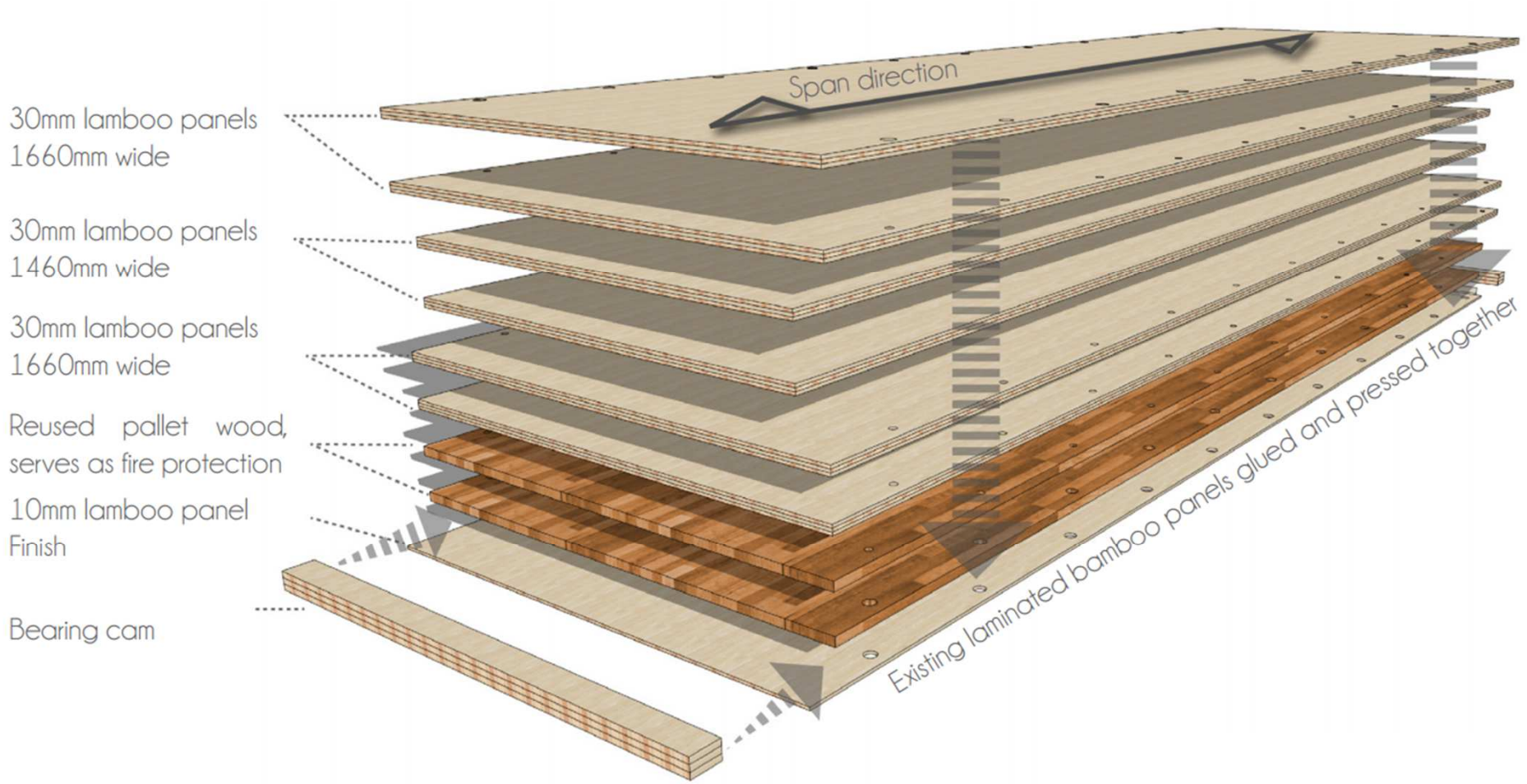
Floor build-up (How it could be done)



A

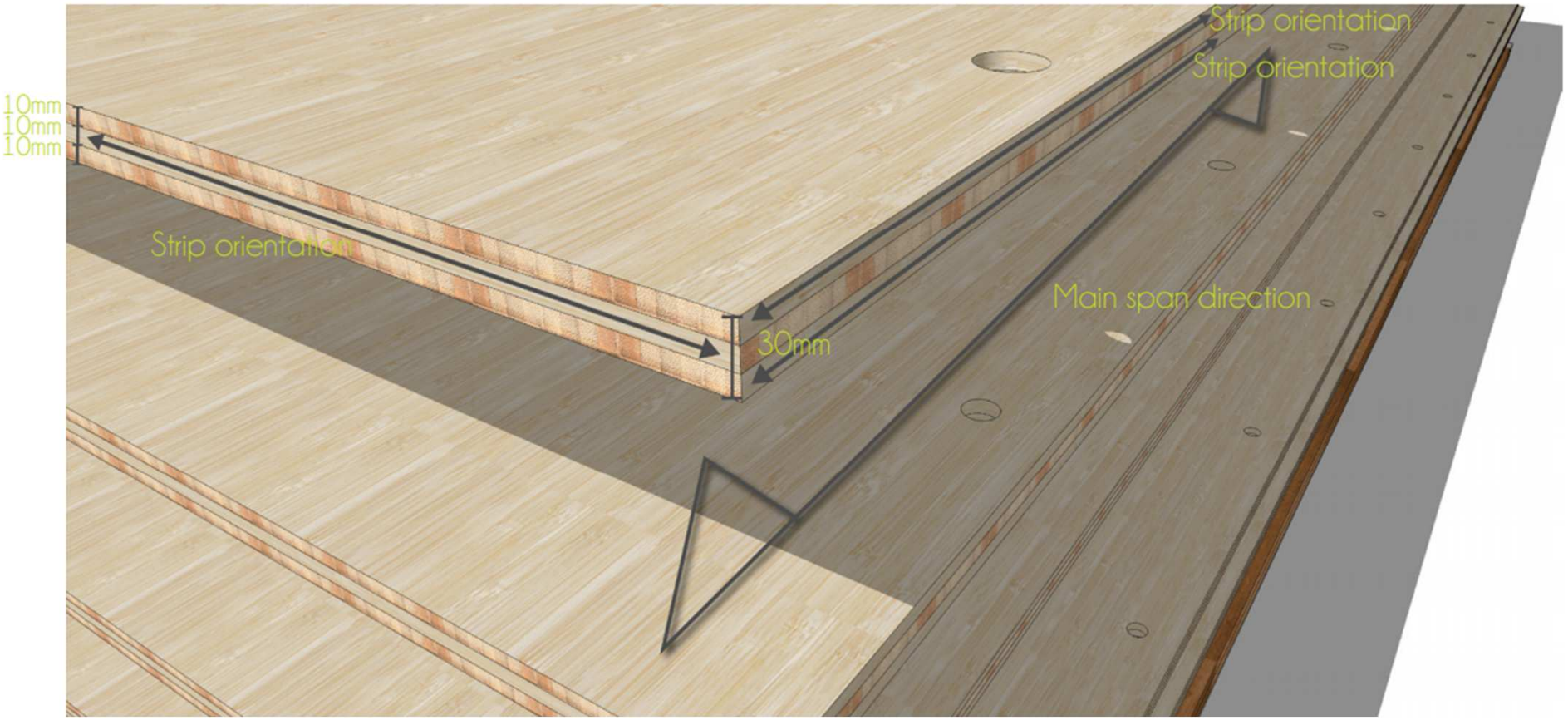
Floor plate build-up (How it could be done)

1

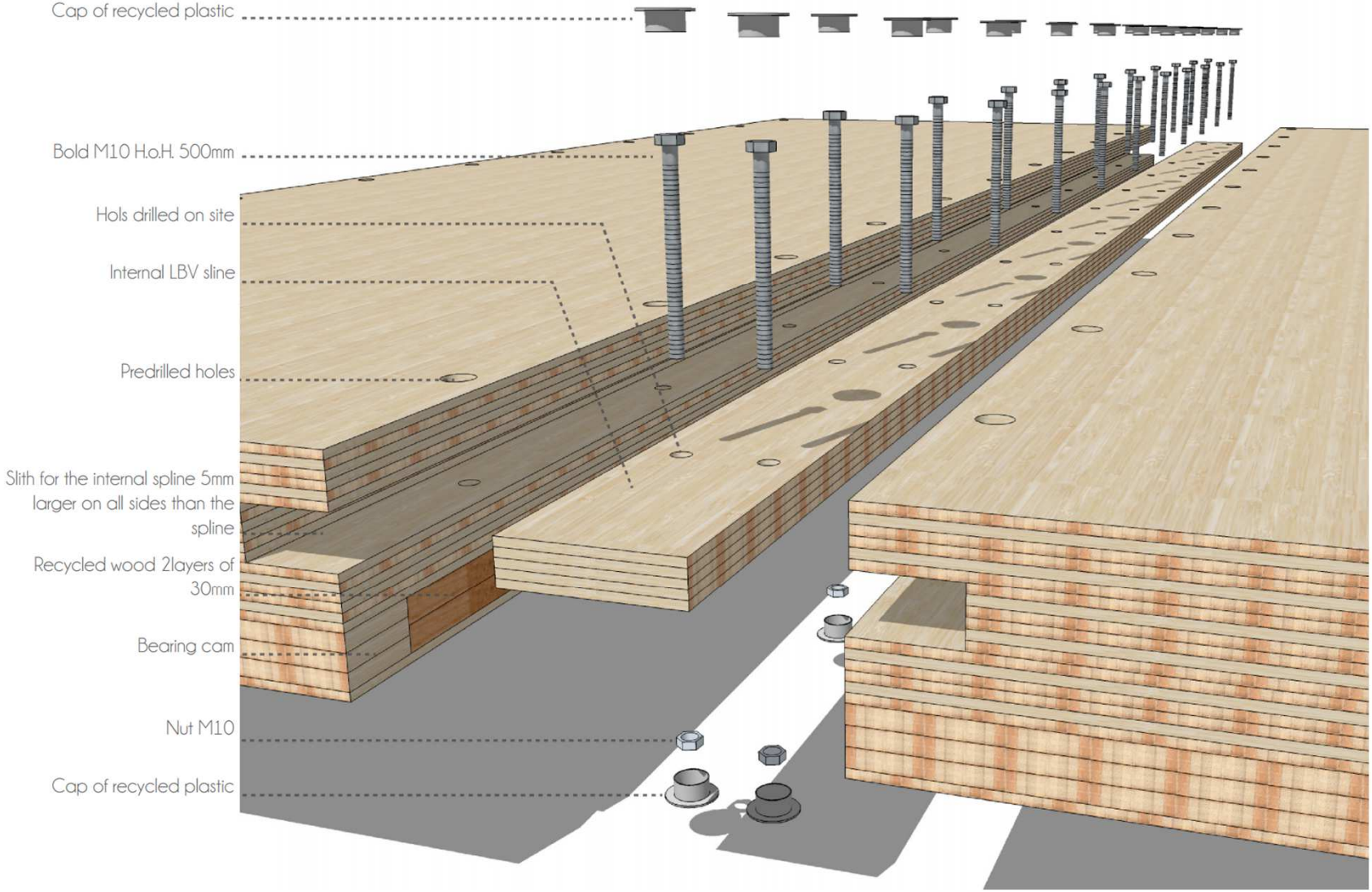


Floor plate build-up (How it could be done)

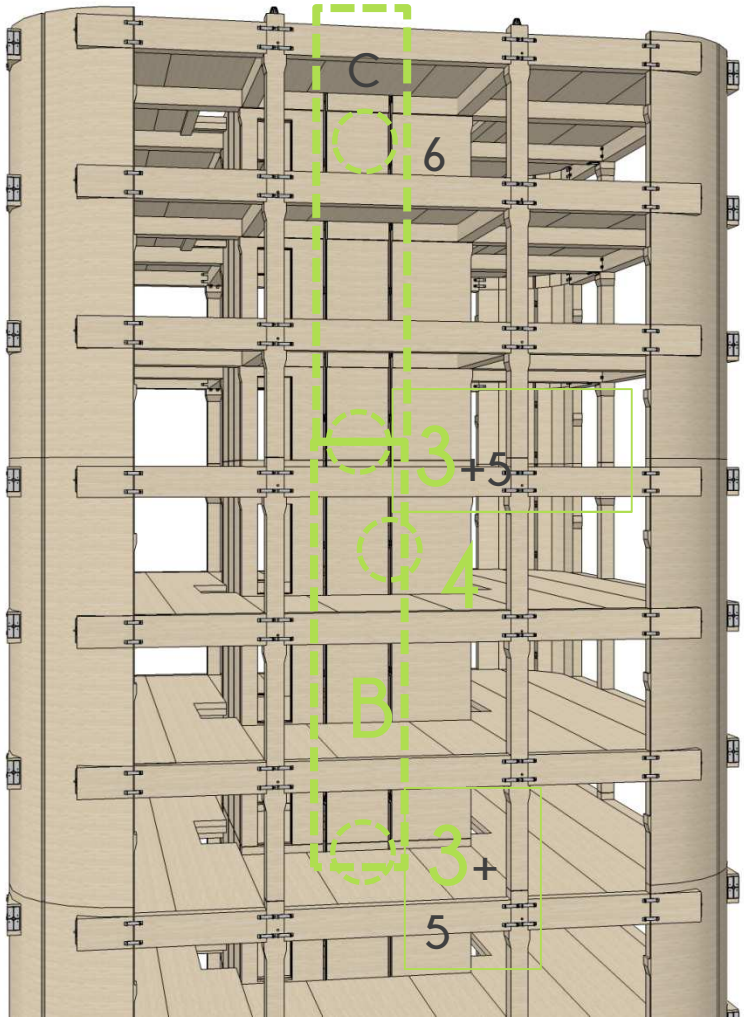
2

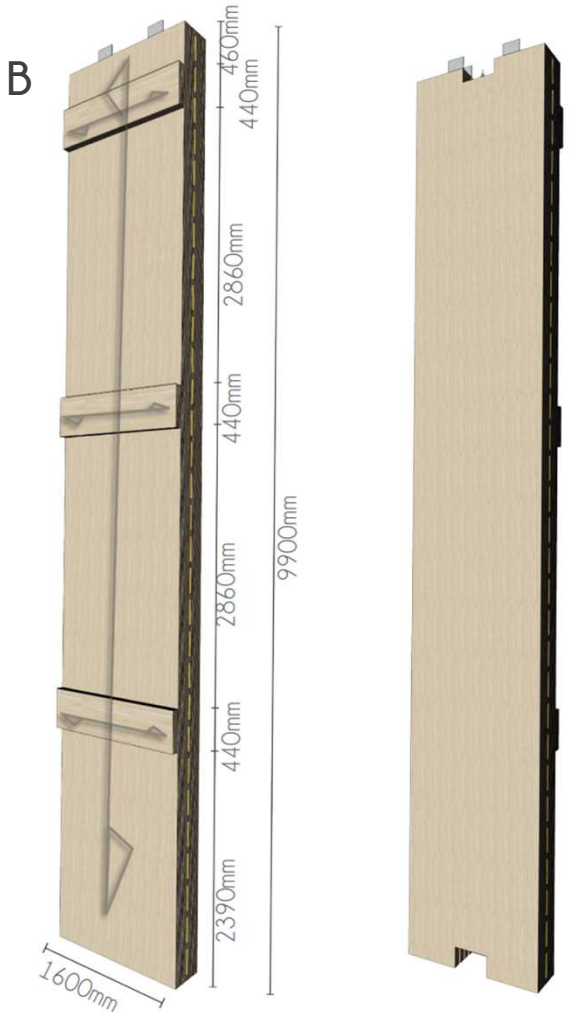


Floor connection (How it could be done)

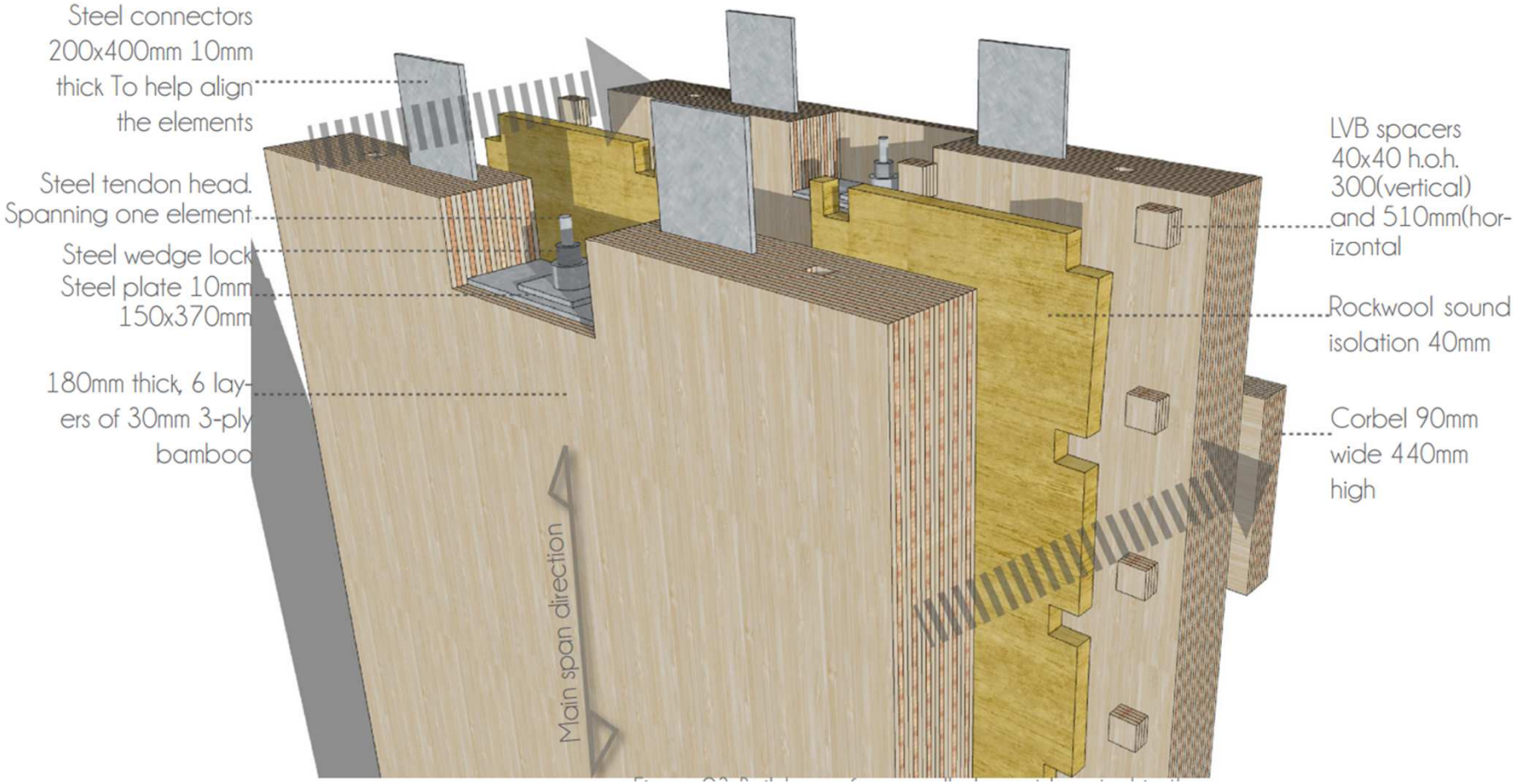


Wall element build up it could be done)

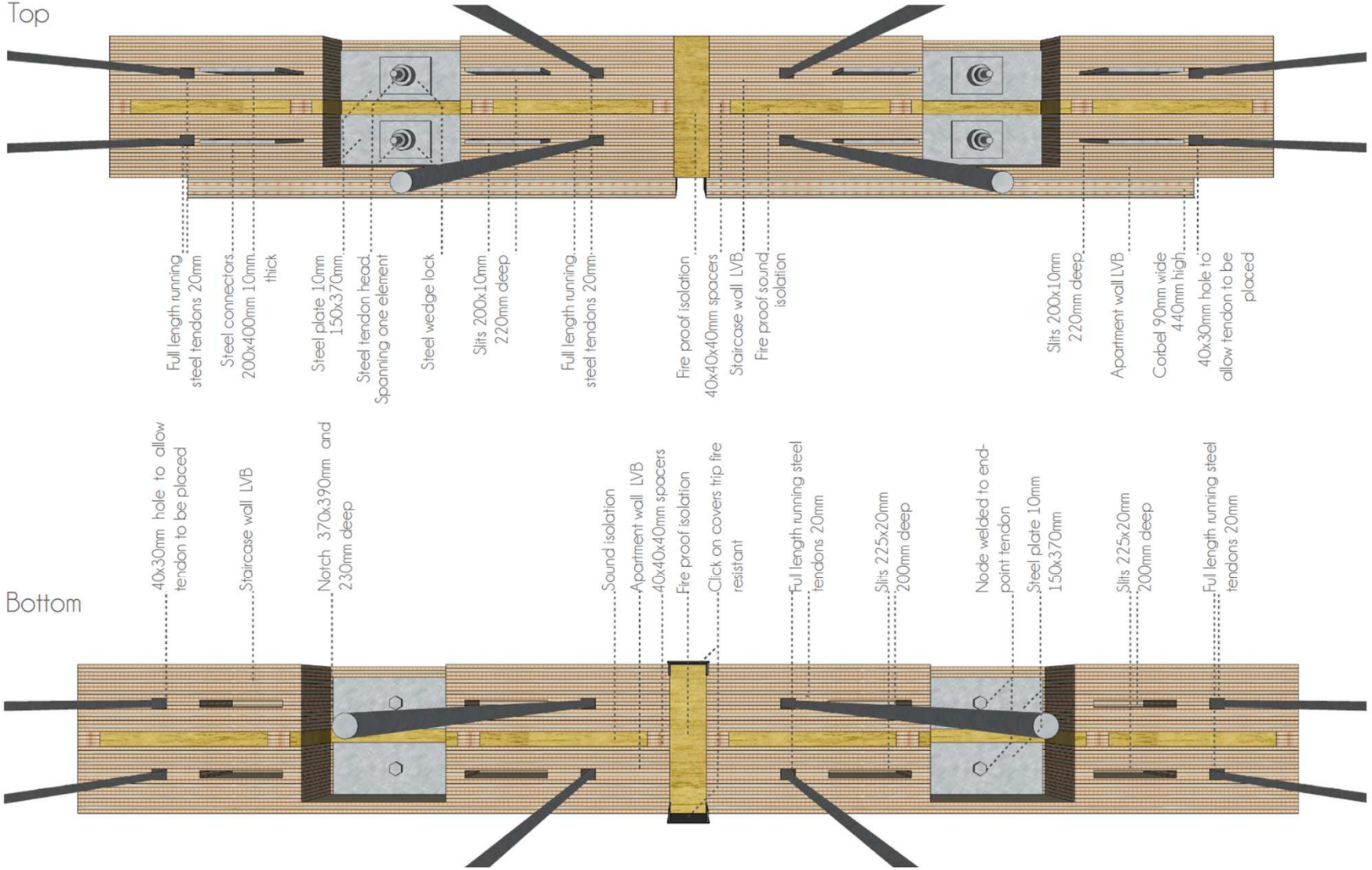




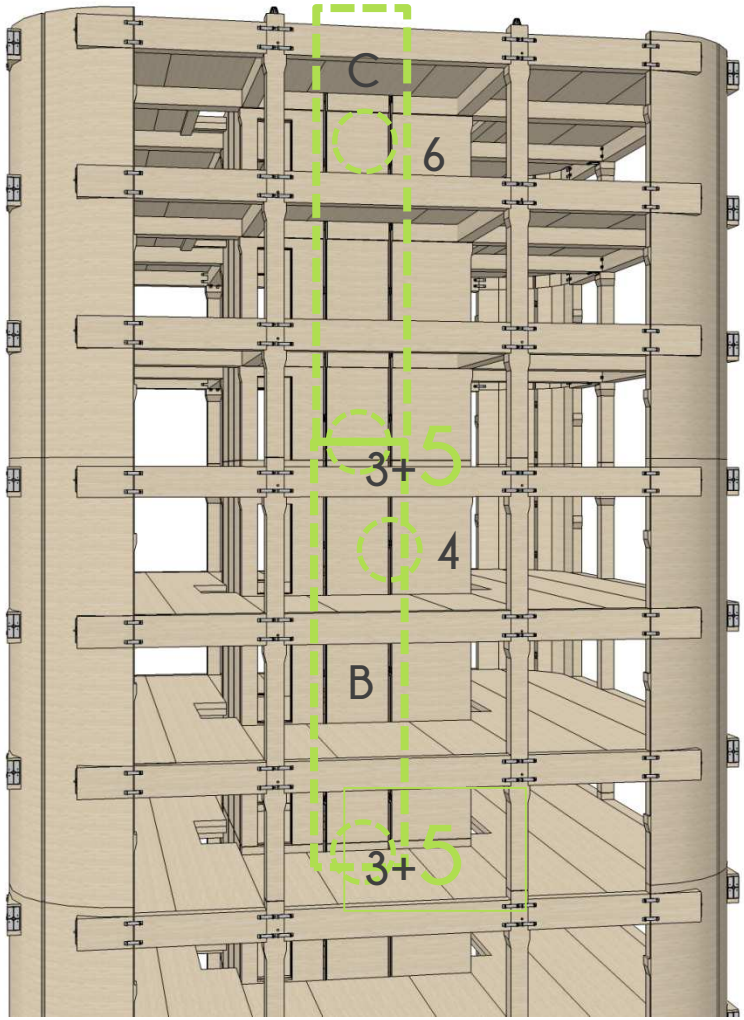
Wall element build up (How it could be done)



Wall element build up (How it could be done)



Floor(How it could be done)



Floor build-up (How it could be done)

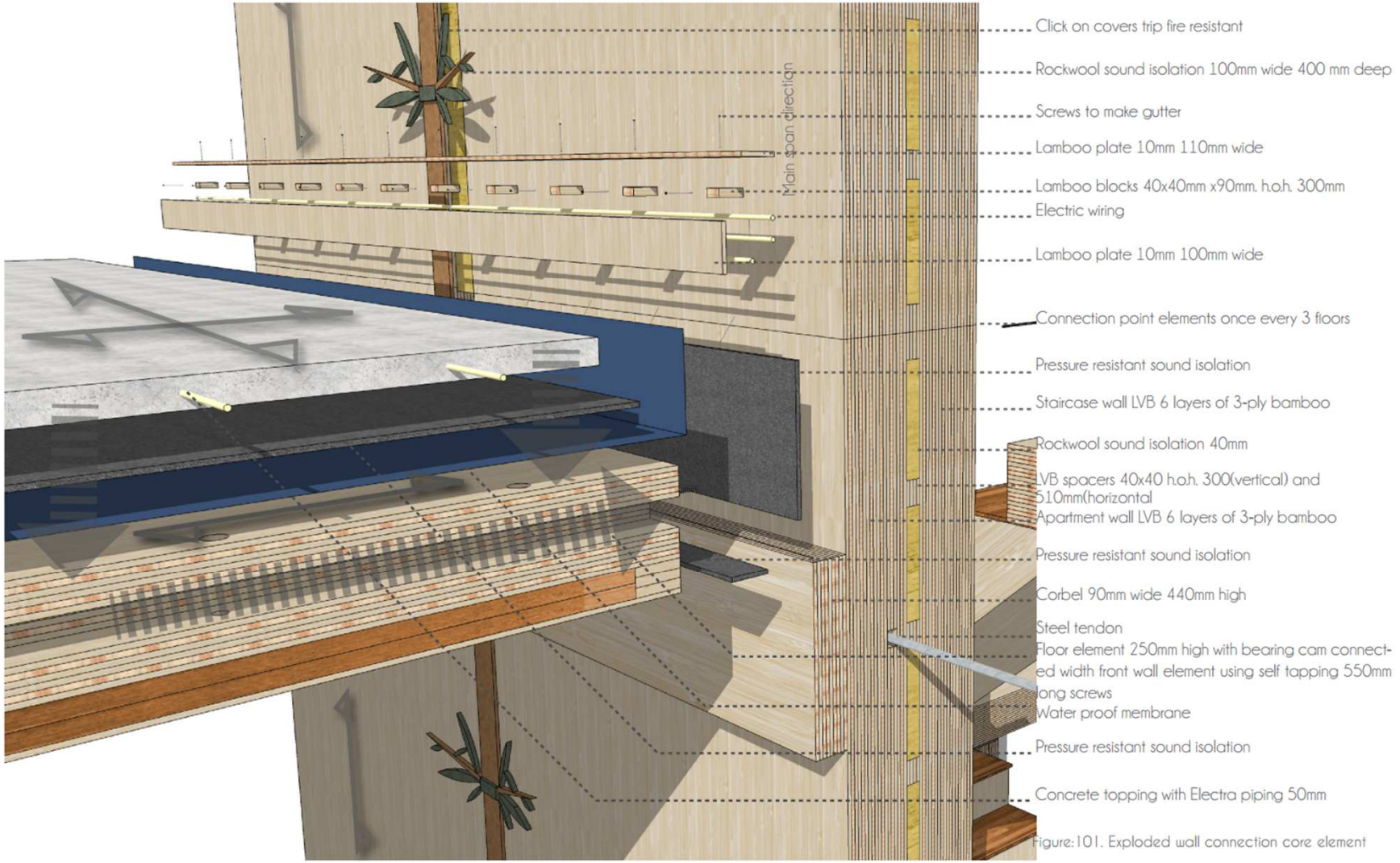
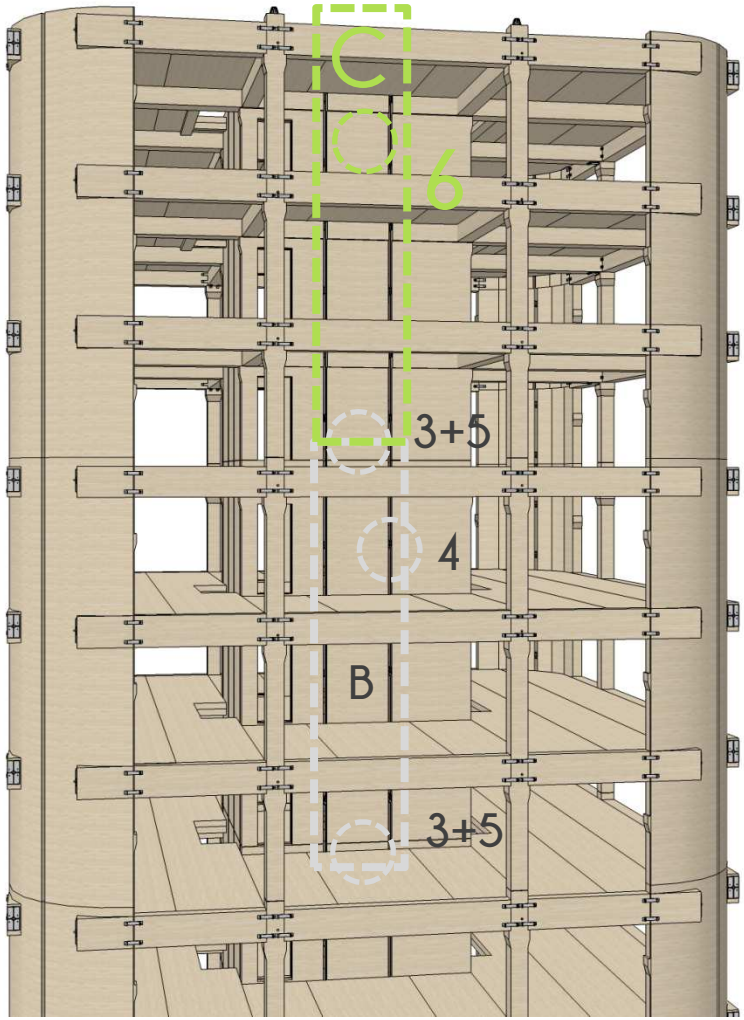
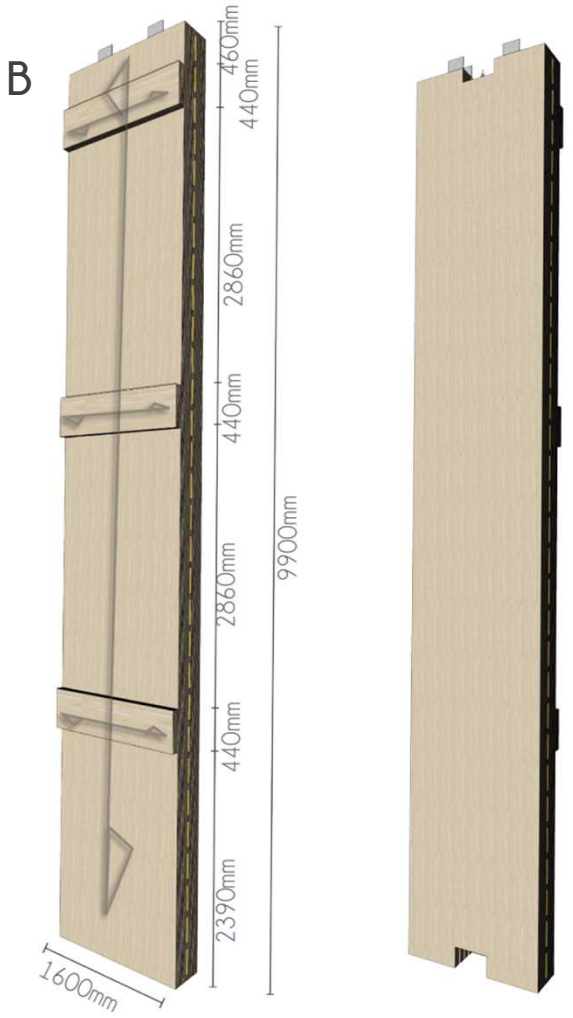


Figure:101. Exploded wall connection core element

Floor build-up (How it could be done)

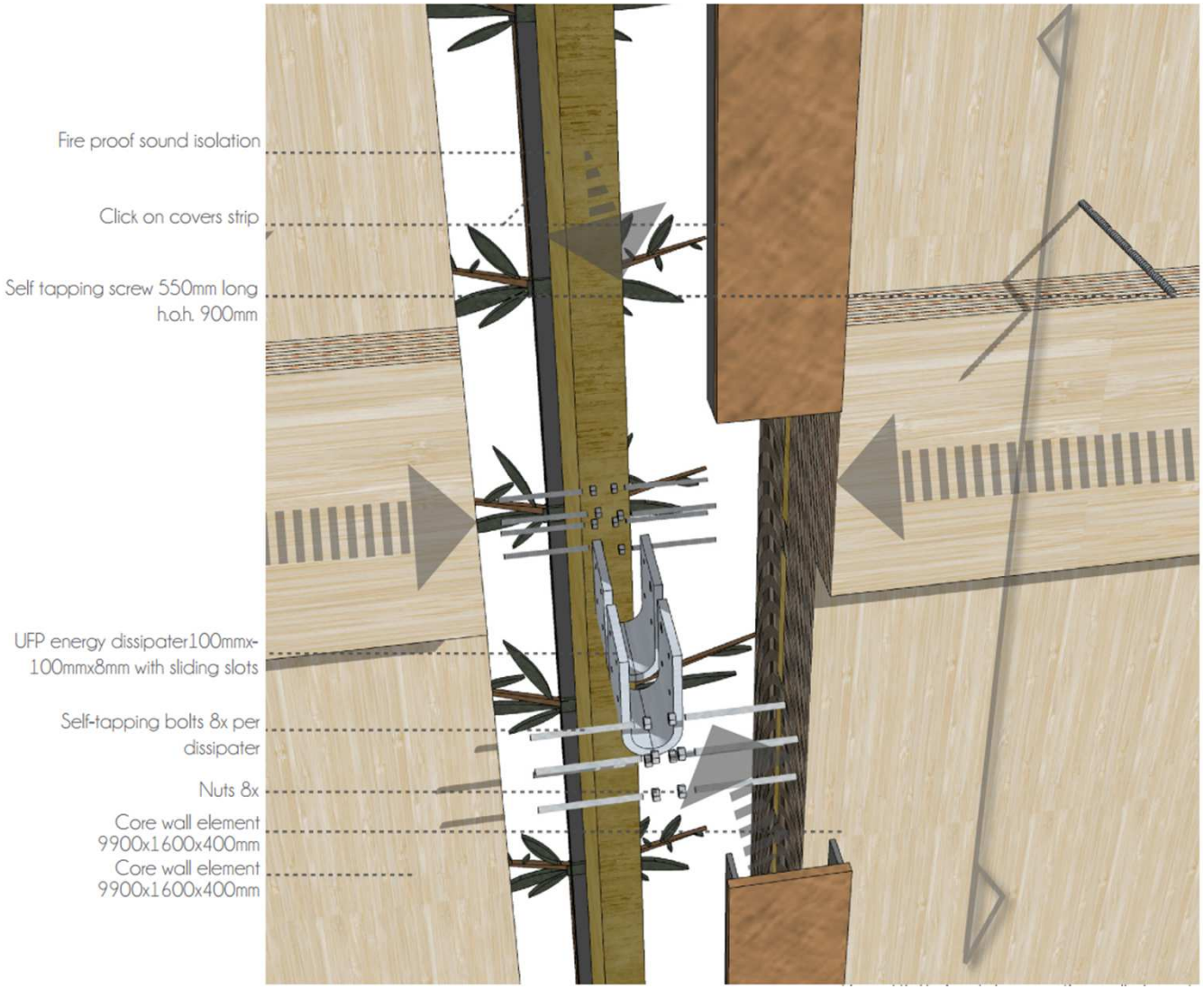
Core build-up (How it could be done)



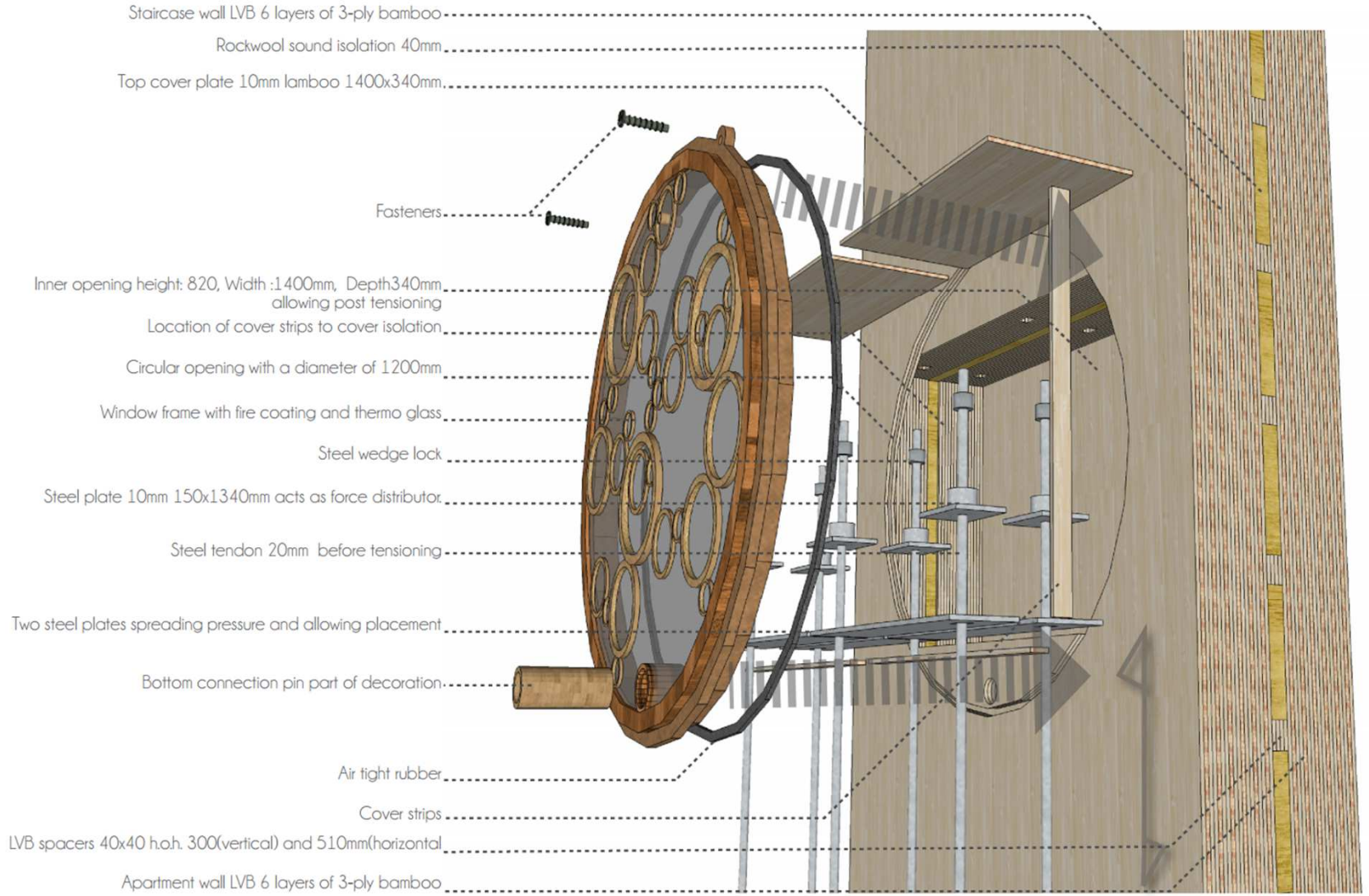


Core build-up (How it could be done)

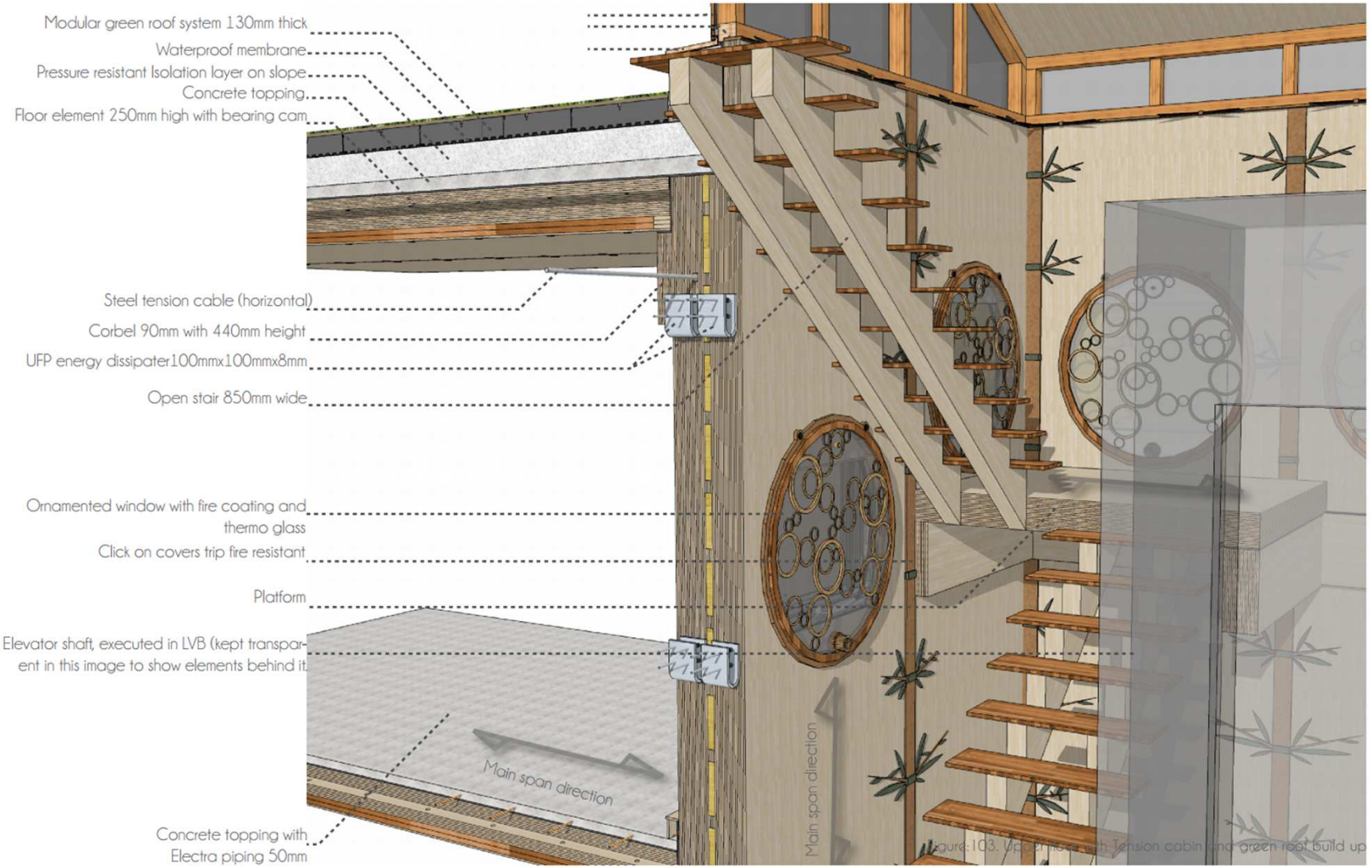
4



Core build up (How it could be done)



Core build up (How it could be done)



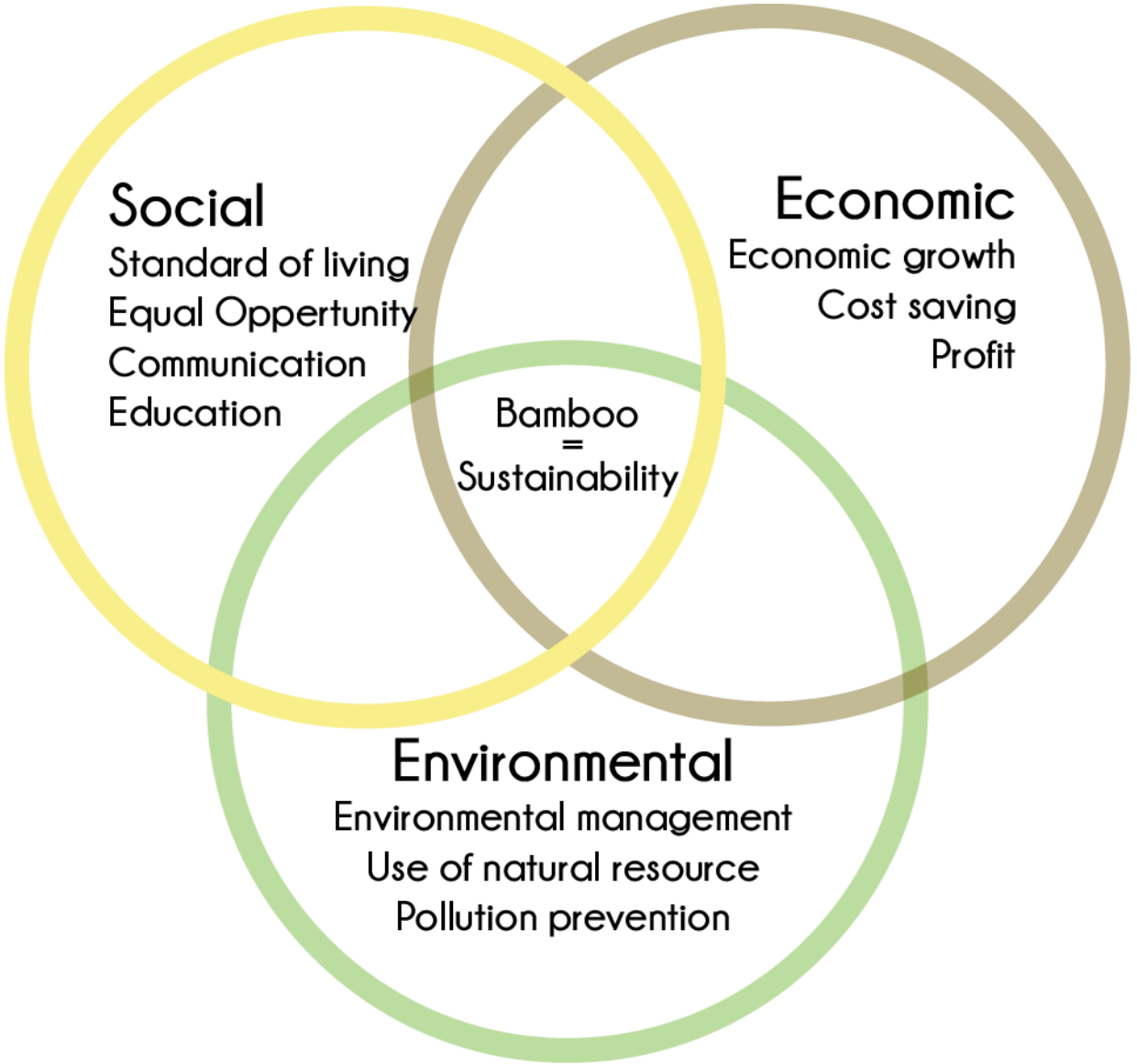
How Sustainable is it?

Sustainability

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

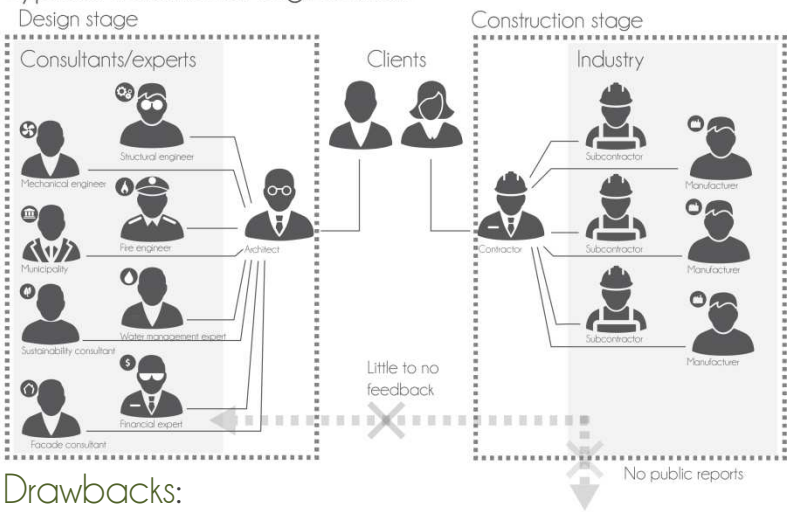
Looking at only one pillar is lying to your self.

Example: "Something can be a 100% environmental but not affordable or drastically reduce the standard of living."



Education (Social Sustainability)

Typical traditional orginisation



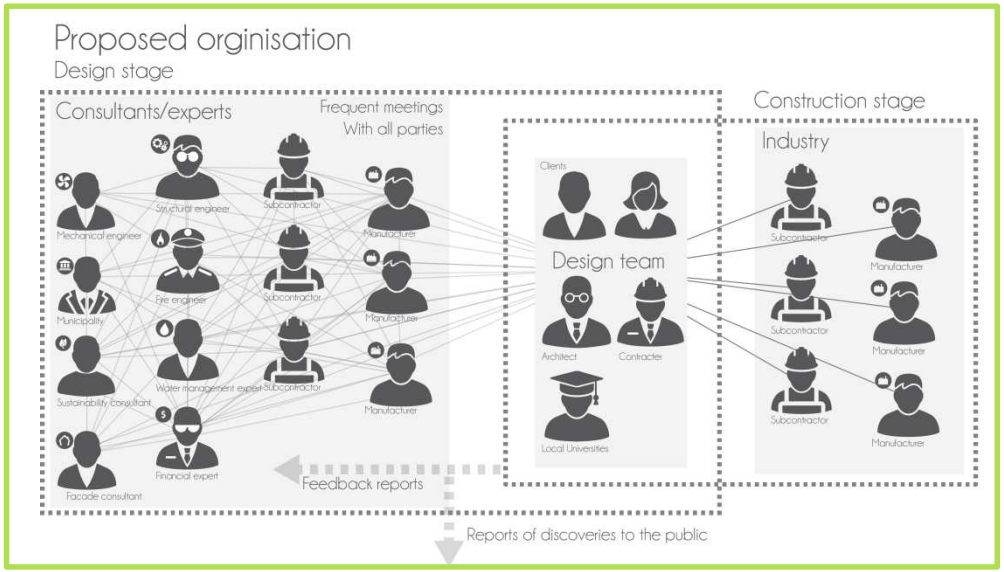
Drawbacks:

- Financial control near impossible.
- Large amount of misinforming
- Large amount of misinforming
- Large amount of misinforming
- Everyone (except the client) is only interested in their own part and dissension 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
+ For standard buildings fast and cheap
+ Invested time of different parties is minimized

Proposed orginisation



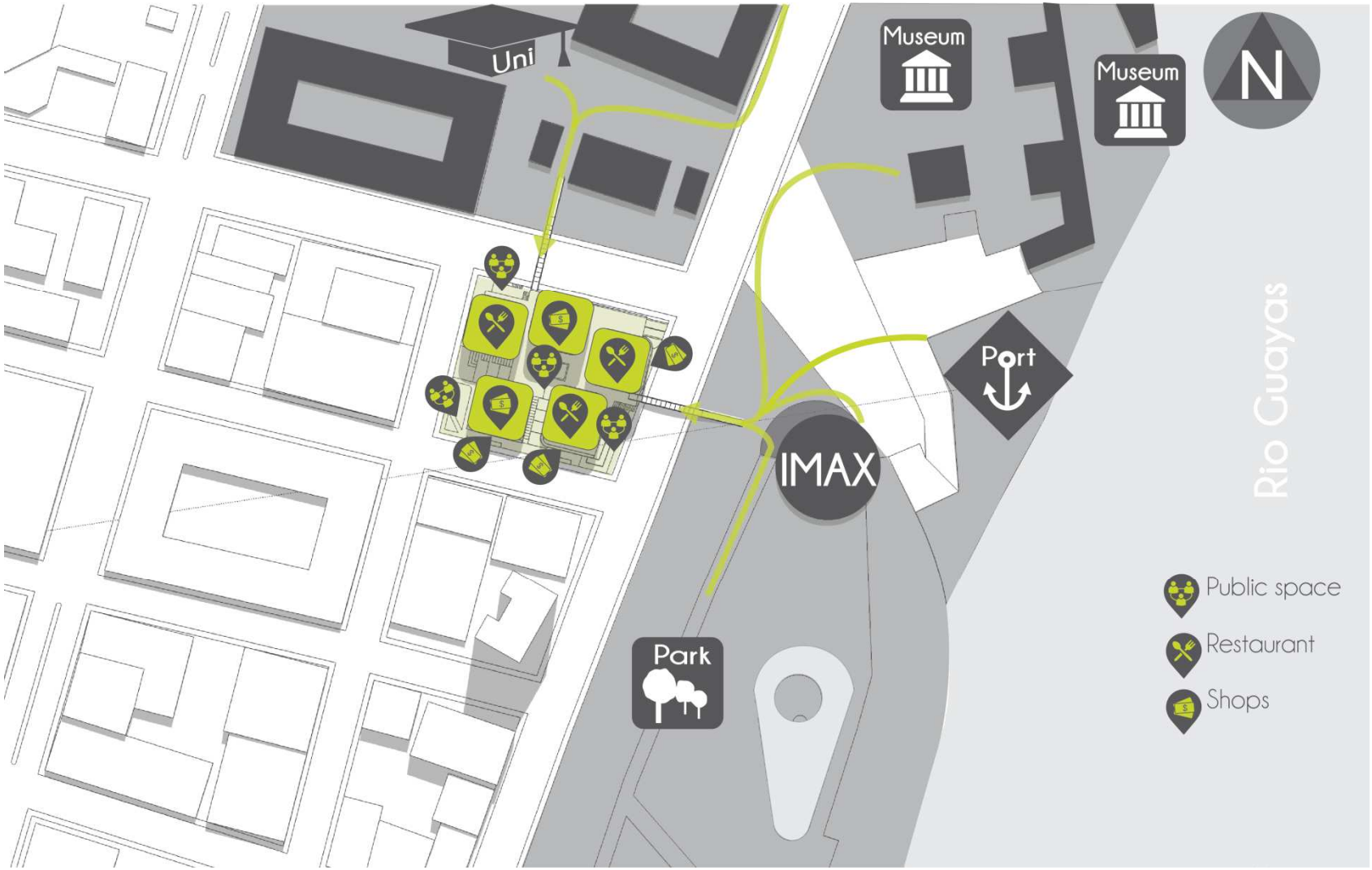
Drawbacks:

- 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 be happy to shear knowledge

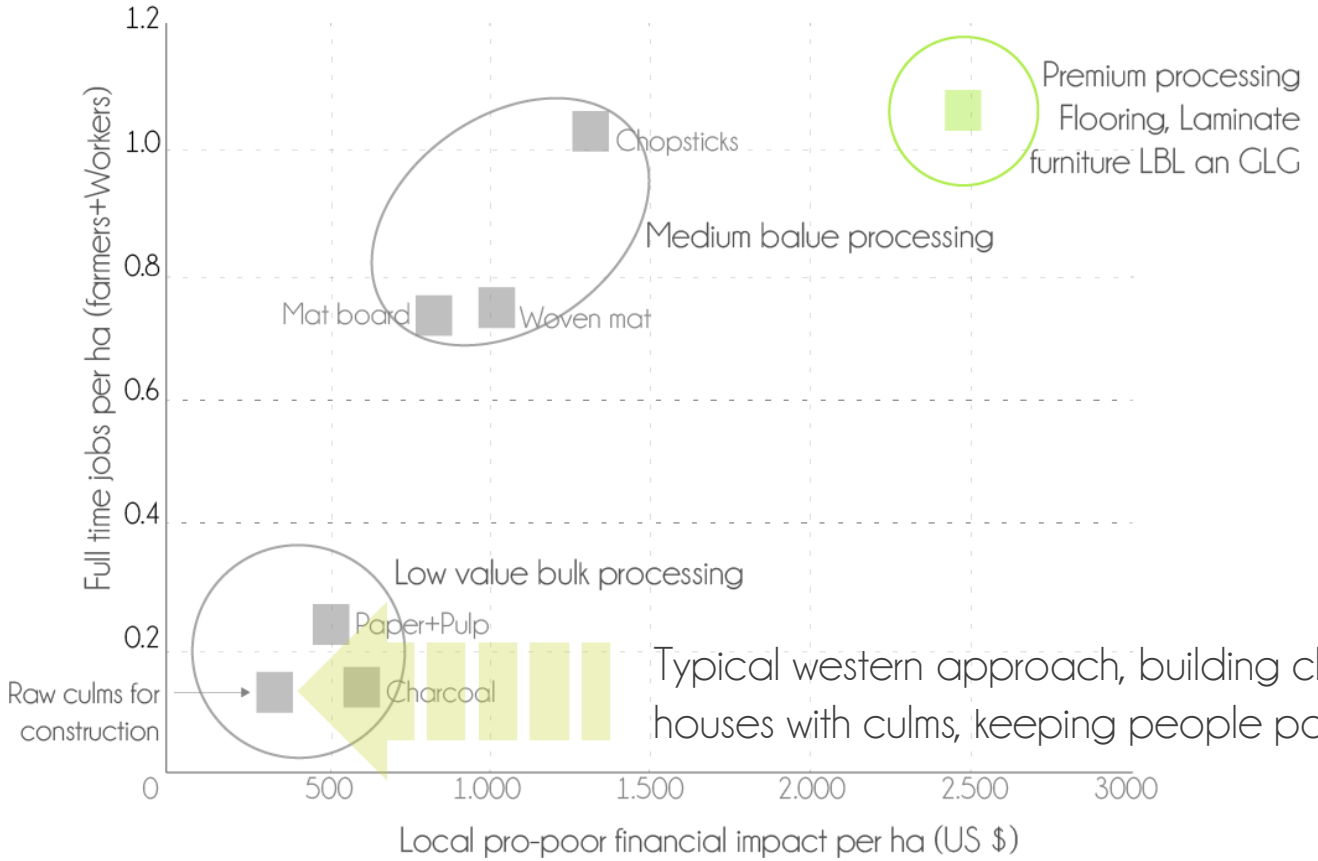
Pro's:

+ 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

Interaction (Social Sustainability)



Standard of living/Equalization (Social Sustainability)



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

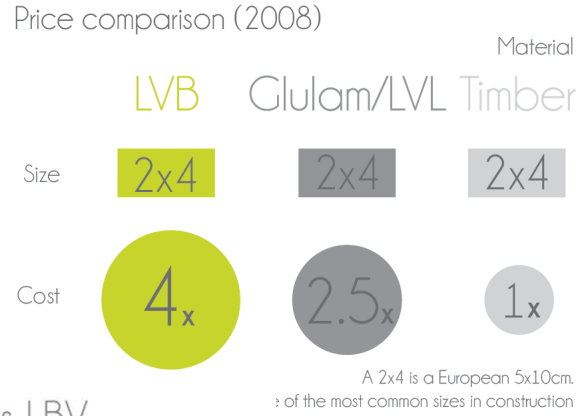
Increased jobs for woman from

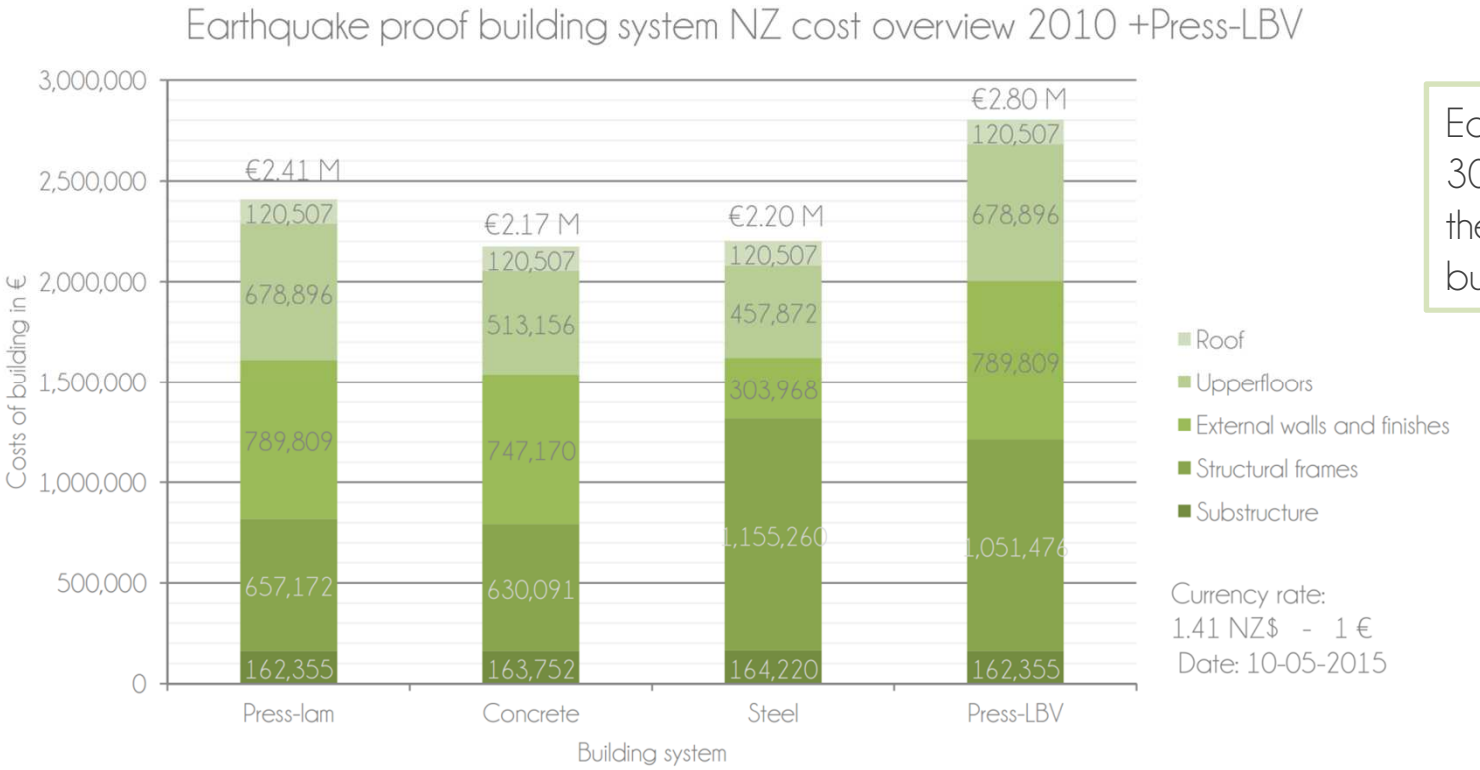
31% (raw culm industry) to

49% (premium processing)

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

Prize comparison (Economic Sustainability)





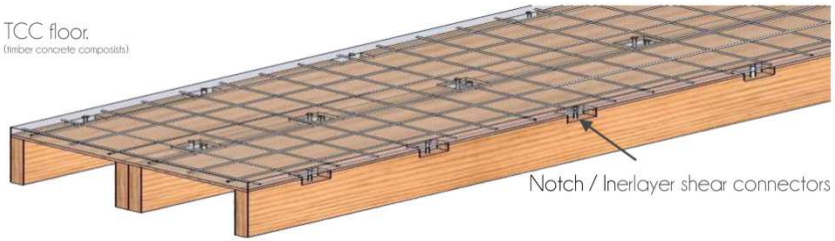
Early estimation:
30% more expensive then concrete buildings

Currency rate:
1.41 NZ$ - 1 €
Date: 10-05-2015

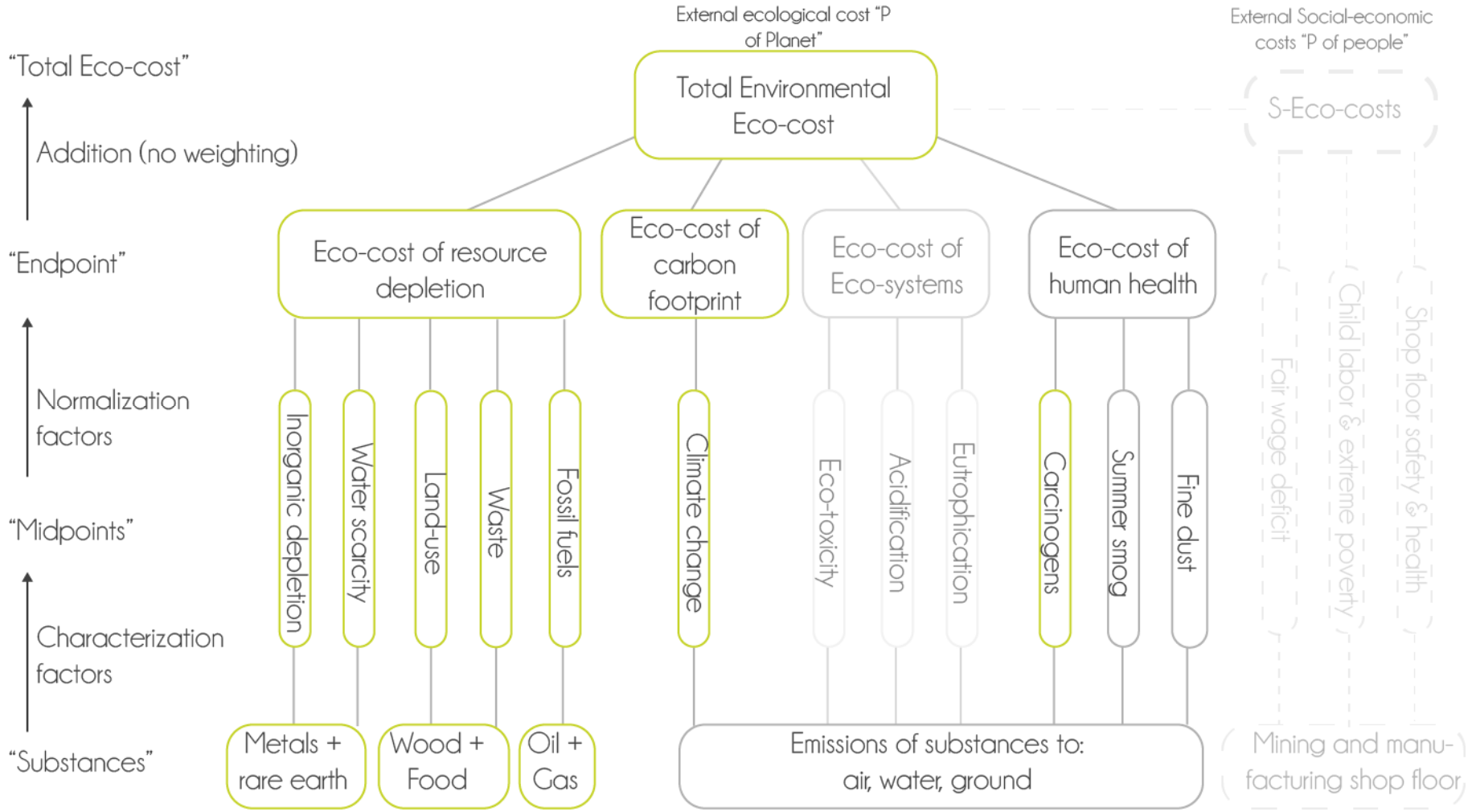
Critical notes (Economic Sustainability)

Concrete floor non structural

LBV solid floor

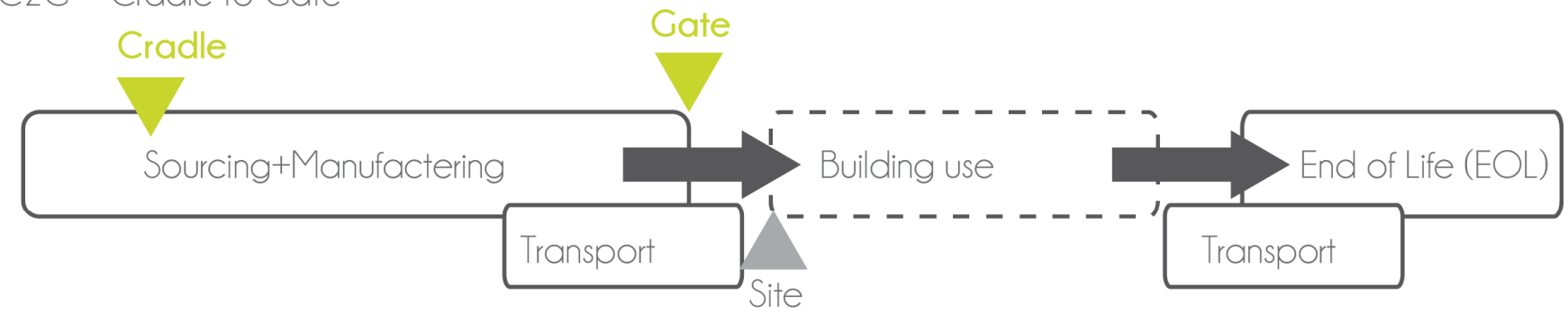


Environmental Sustainability

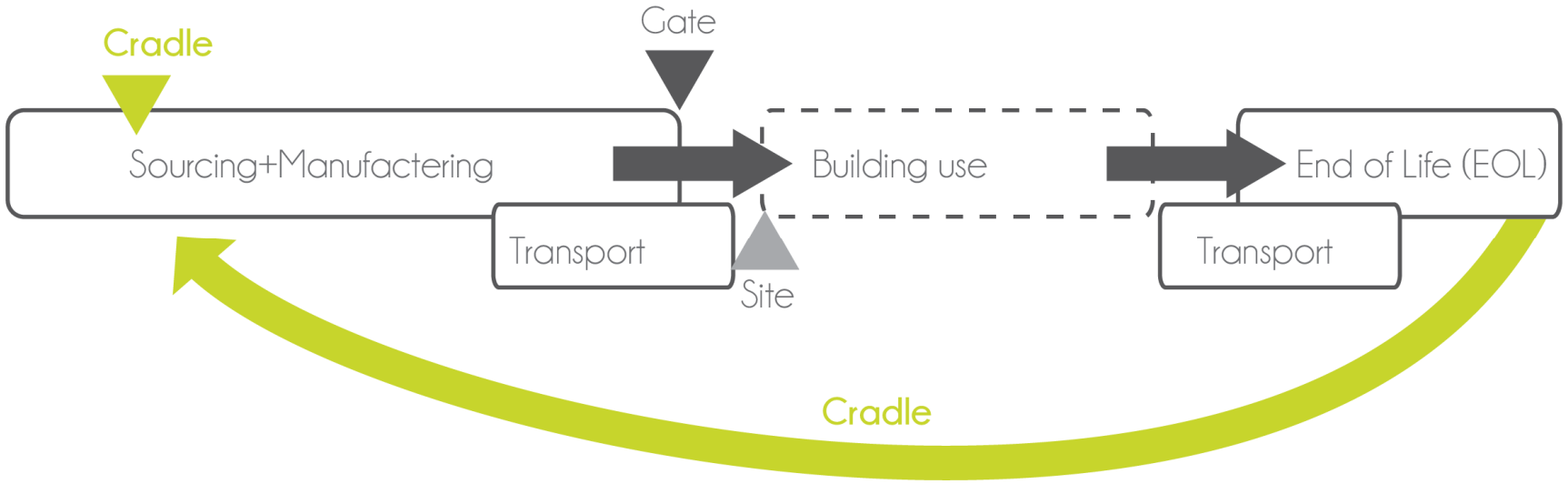


C2G vs. C2C (Environmental Sustainability)

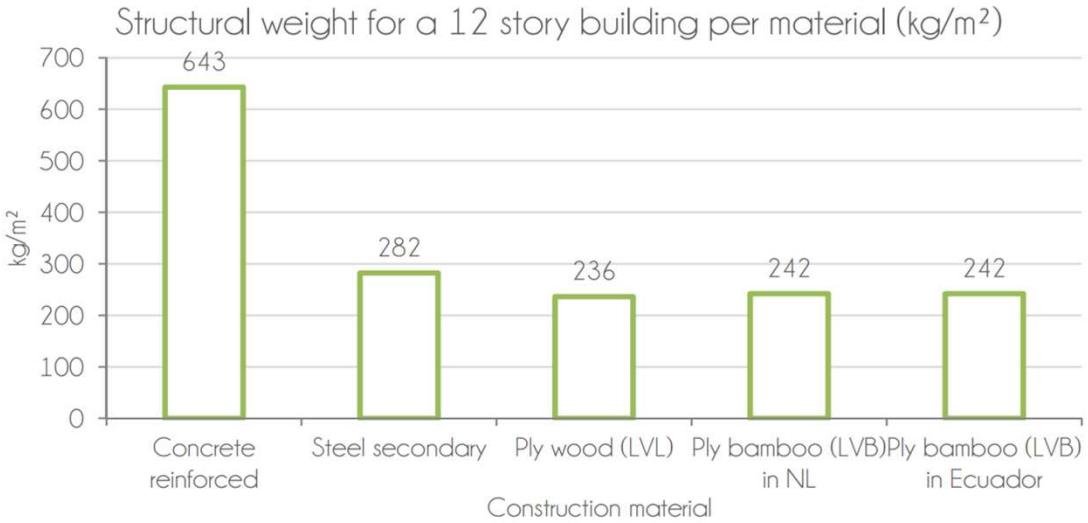
C2G = Cradle to Gate



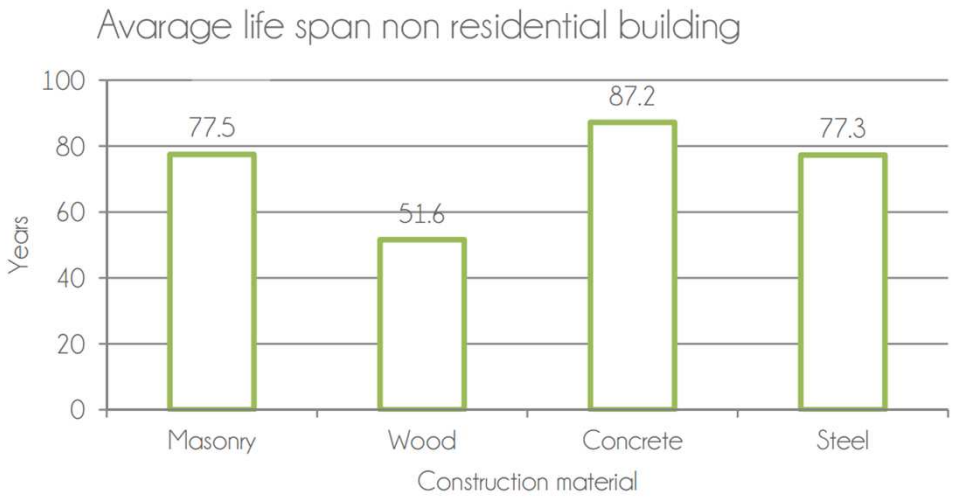
C2C = Cradle to cradle



KG/m² + Life span (Environmental Sustainability)



Concrete is a heavy building material



Life time of a single structure less than a 100 years

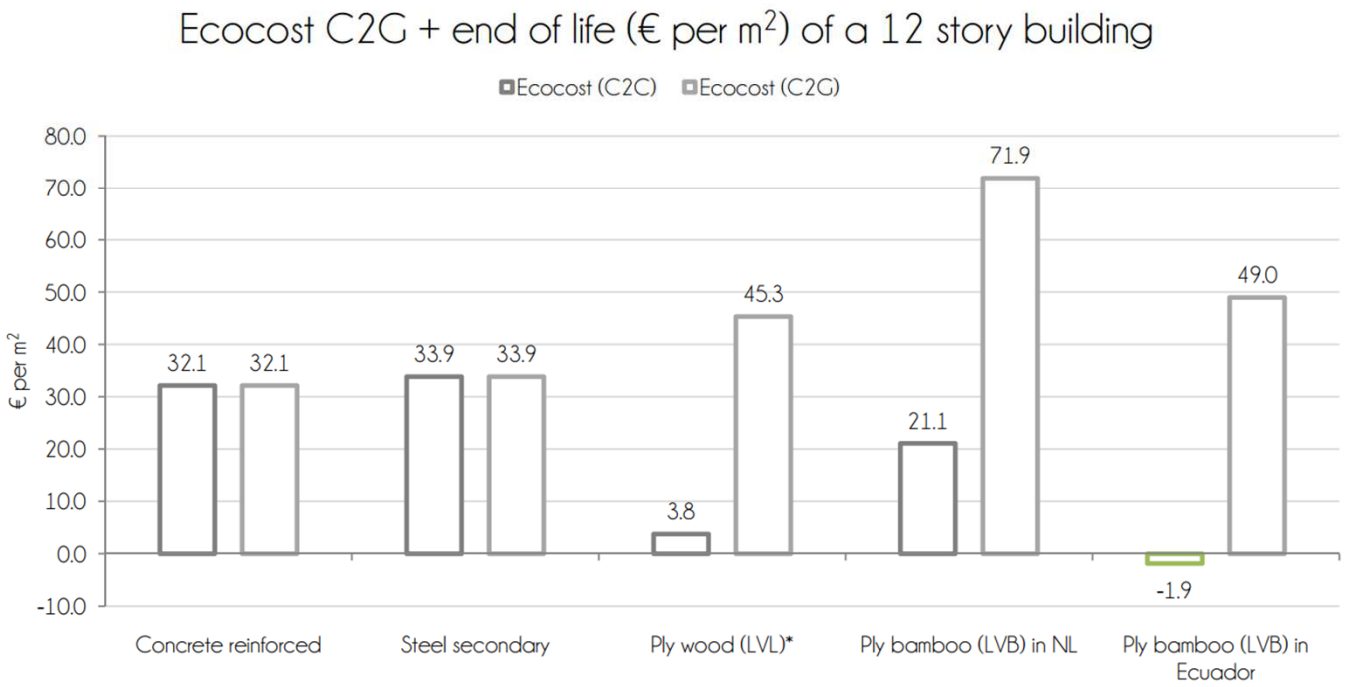
Eco-cost (Environmental Sustainability)

	Concrete reinforced	Steel secondary	Ply wood (LVL)*	Ply bamboo (LVB) in NL	Ply bamboo (LVB) in Ecuador
kg/m2	643	282	236	242	242
Eco-cost/kg (C2G)	0.05	0.12	0.19	0.35	0.20**
End of life	0	0	-0.18	-0.21	-0.21
Eco-cost (C2G)	32.1	33.9	45.3	71.9	49
Eco-cost (C2C)	32.1	33.9	3.8	21.1	-1.9

* Ply wood (LVL) Is a hybrid structure 80% wood, 20% steel

** Ply bamboo (LVB) in Ecuador No shipping, no transport to harbor, no transport to warehouse, only 300km from plantation to factory not 600km

Table: 16. Eco-cost for each structure



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 then a concrete building

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

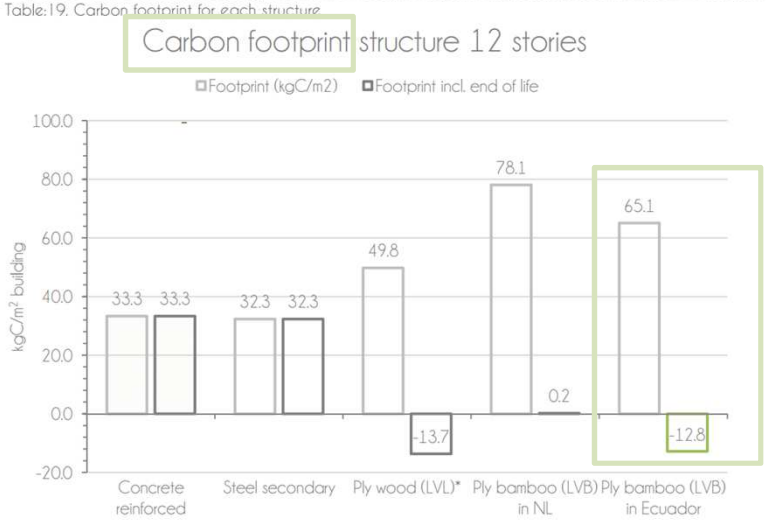
Carbon + Energy (Environmental Sustainability)

	Concrete reinforced	Steel secondary	Ply wood (LVL)*	Ply bamboo (LVB) in NL	Ply bamboo (LVB) in Ecuador
kg/m2	643	282	236	242	242
Carbon (kgCO2e/kg)	0.19	0.42	0.77	1.18	0.99**
End of life (kgCO2e/kg)	0	0	-0.98	-1.18	-1.18
Footprint (kgC/m) (C2G)	33.3	32.3	49.84	78.1	65.1
Footprint (kgC/m) (C2C)	33.3	32.3	-13.7	0.2	-12.8

* Ply wood (LVL) Is a hybrid structure 80% wood, 20% steel

** Ply bamboo (LVB) in Ecuador No shipping, no transport to harbor, no transport to warehouse, only 300km from plantation to factory not 600km

Table:19. Carbon footprint for each structure

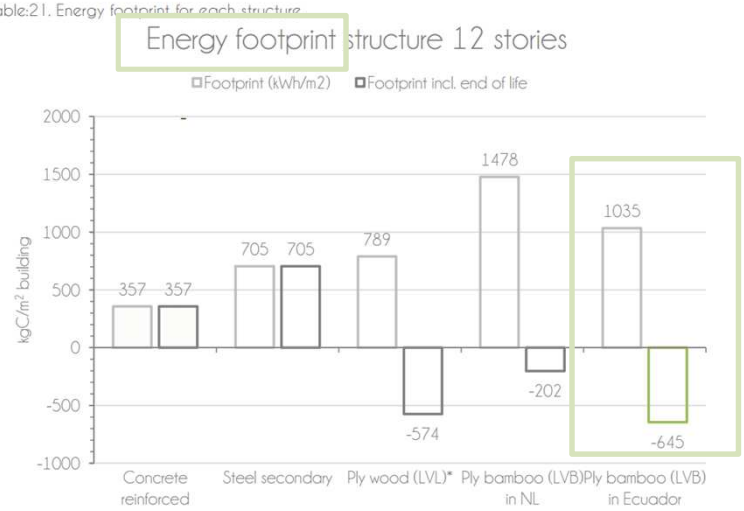


	Concrete reinforced	Steel secondary	Ply wood (LVL)*	Ply bamboo (LVB) in NL	Ply bamboo (LVB) in Ecuador
kg/m2	643	282	236	242	242
Energy (MJ/kg)	2	9	12	22	15.4**
End of life	0	0	20.8	-25	-25
Footprint (kWh/m2)(C2G)	357	705	789	1478	1035
Footprint (kWh/m2)(C2C)	357	705	-574	-202	-645

* Ply wood (LVL) Is a hybrid structure 80% wood, 20% steel

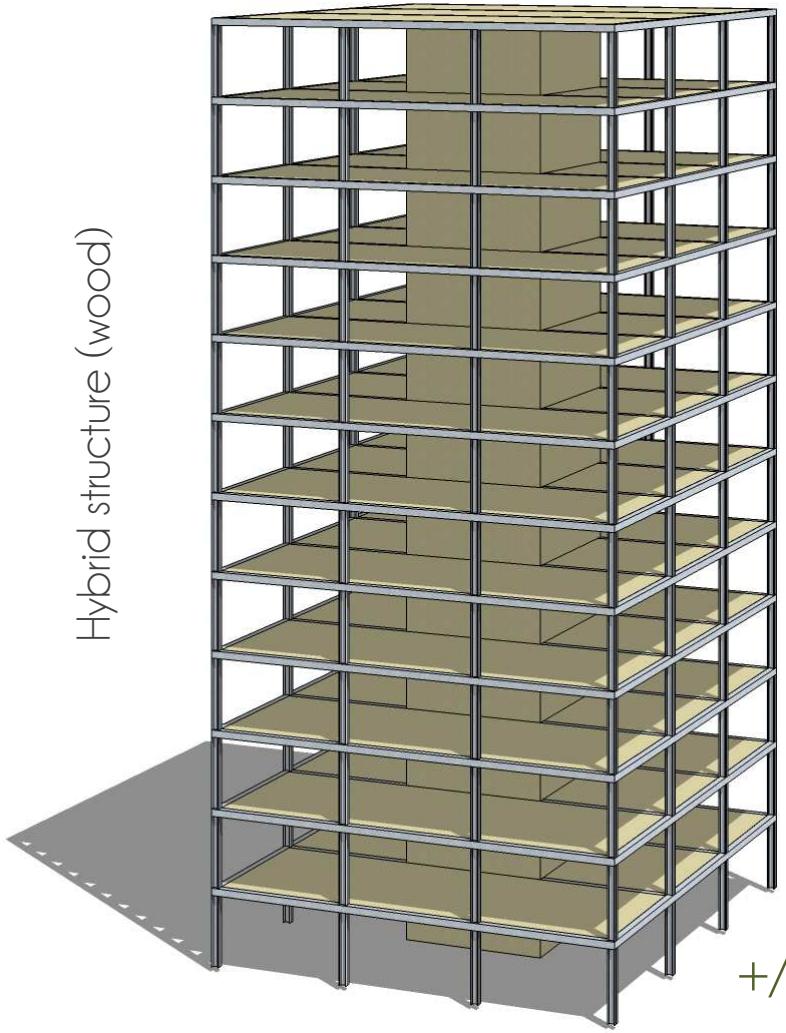
** Ply bamboo (LVB) in Ecuador No shipping, no transport to harbor, no transport to warehouse, only 300km from plantation to factory not 600km

Table:21. Energy footprint for each structure

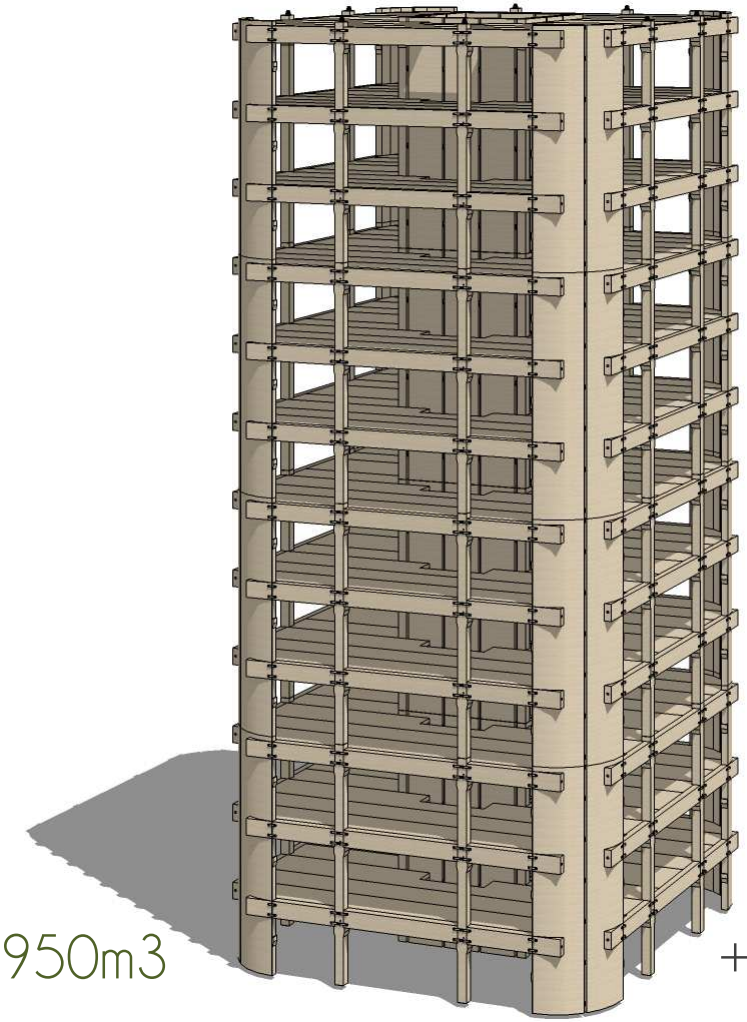


Systems compared (Land-Use)

Hybrid structure (wood)



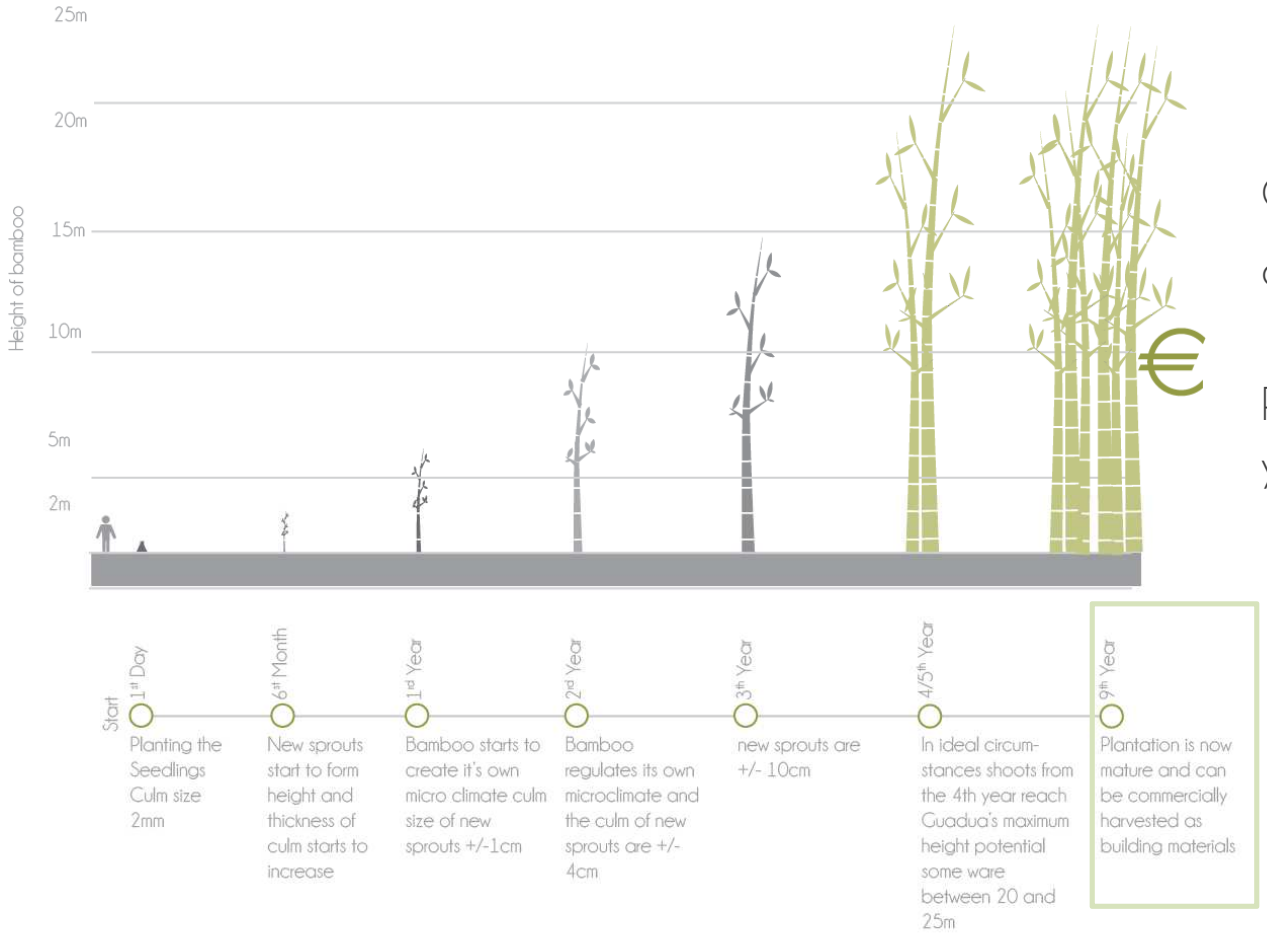
+/-1.950m3



LVB structure

+/-1.250m3

Fundamentals (Land-Use)



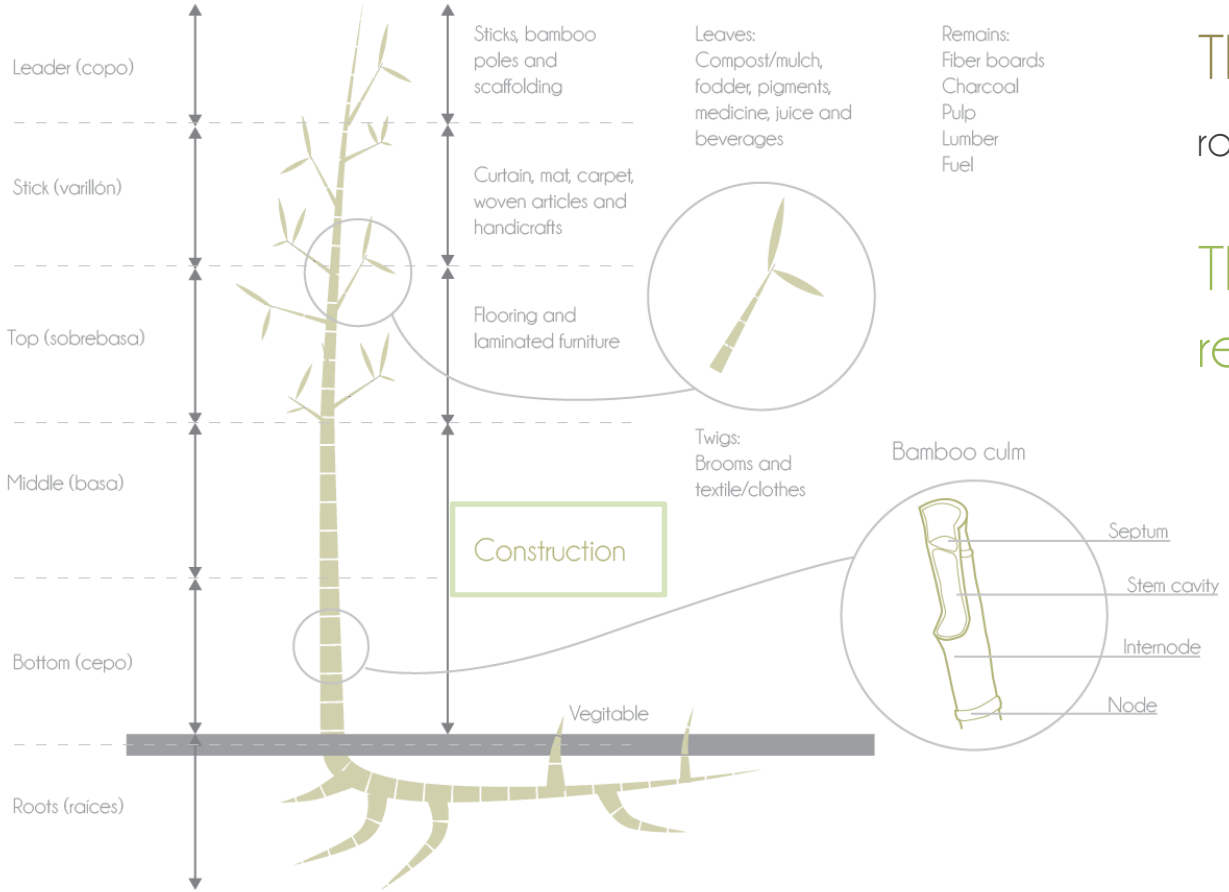
Source: http://www.guaduabamboo.com/blog/guadua-bamboo-growing-habits

Guadua matures in 4-5 years and van be harvest

Plantation is Mature after 9 years

Fundamentals (Land-Use)

Parts of a bamboo



Source : http://www.niccep.dti.gov.ph/admin/img/industry/Full-Utilization-of-Bamboo-part-1.jpg

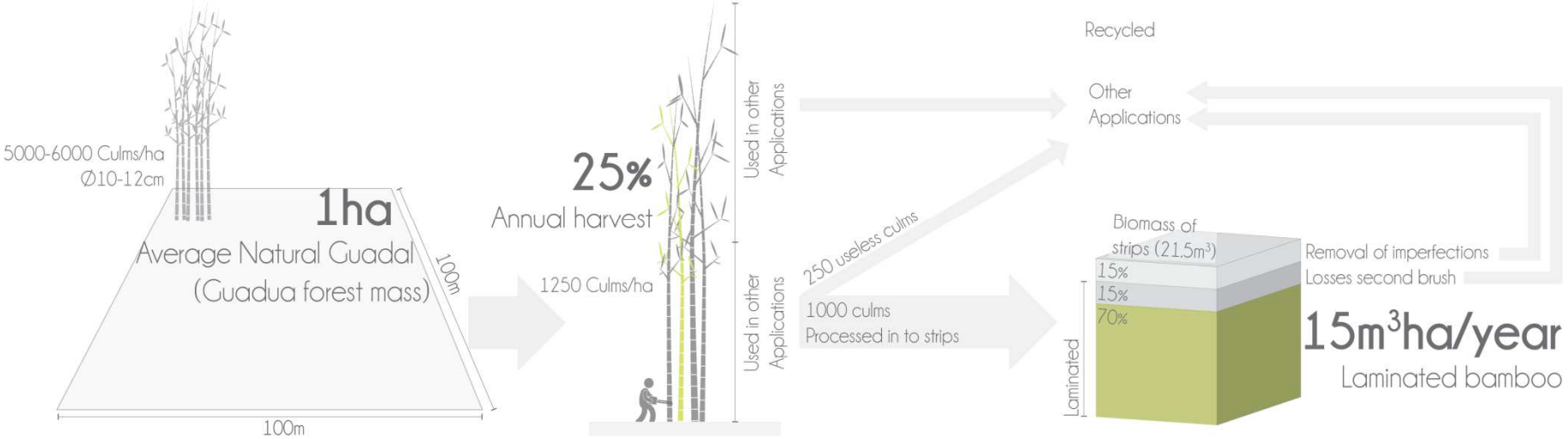
The hole plant except the roots can be used.

The roots are needed to regenerate

Yield rate (Land-Use)

CLT 15m³/ha/year

LBV 15m³/ha/year



Results (Land-Use)

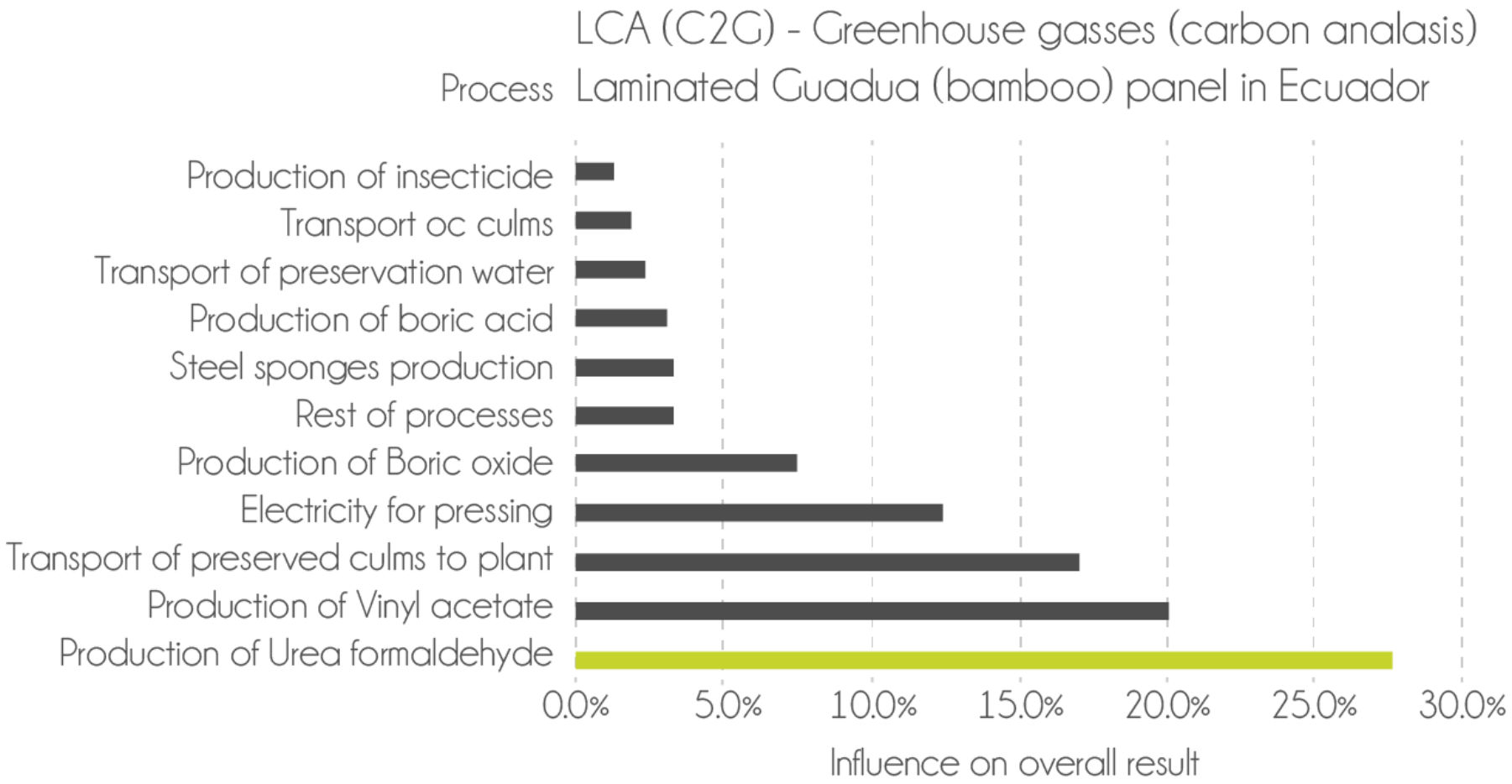
Una reunión educa-
tiva con el bambu

Regular multistory
CLT building

Adhesives (Adhesives)

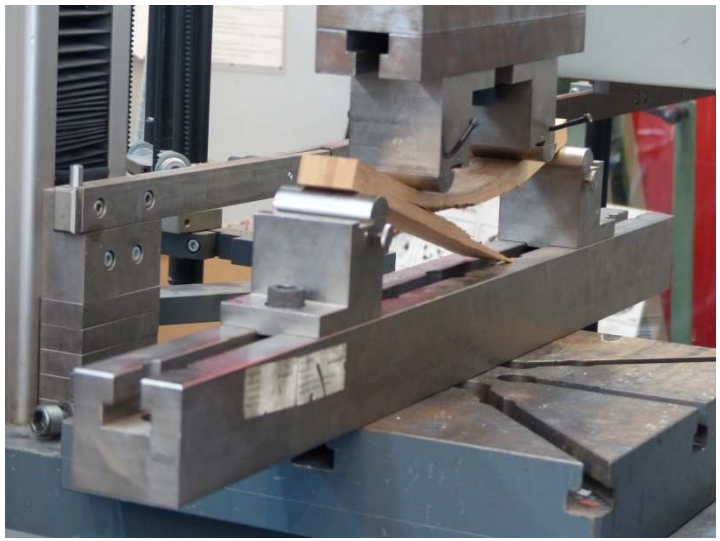
- Adhesives have to be used
- There are no sustainable structural adhesives only less bad ones
- Wood can use more 'sustainable' structural adhesives
- No good sustainable alternative at the moment but there is hope
- Structural adhesives based on soybeans and other organic material
- PF adhesives are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

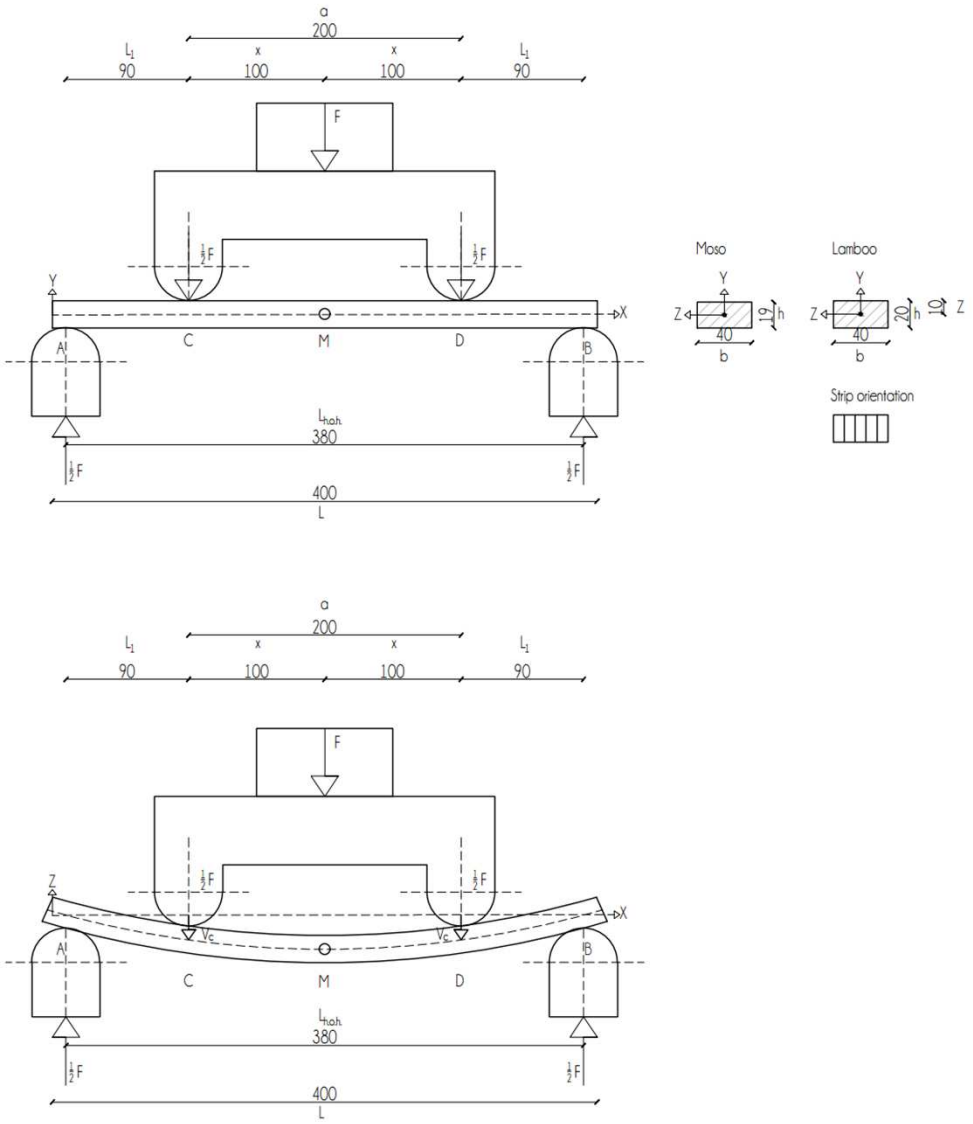
Impact (Adhesives)



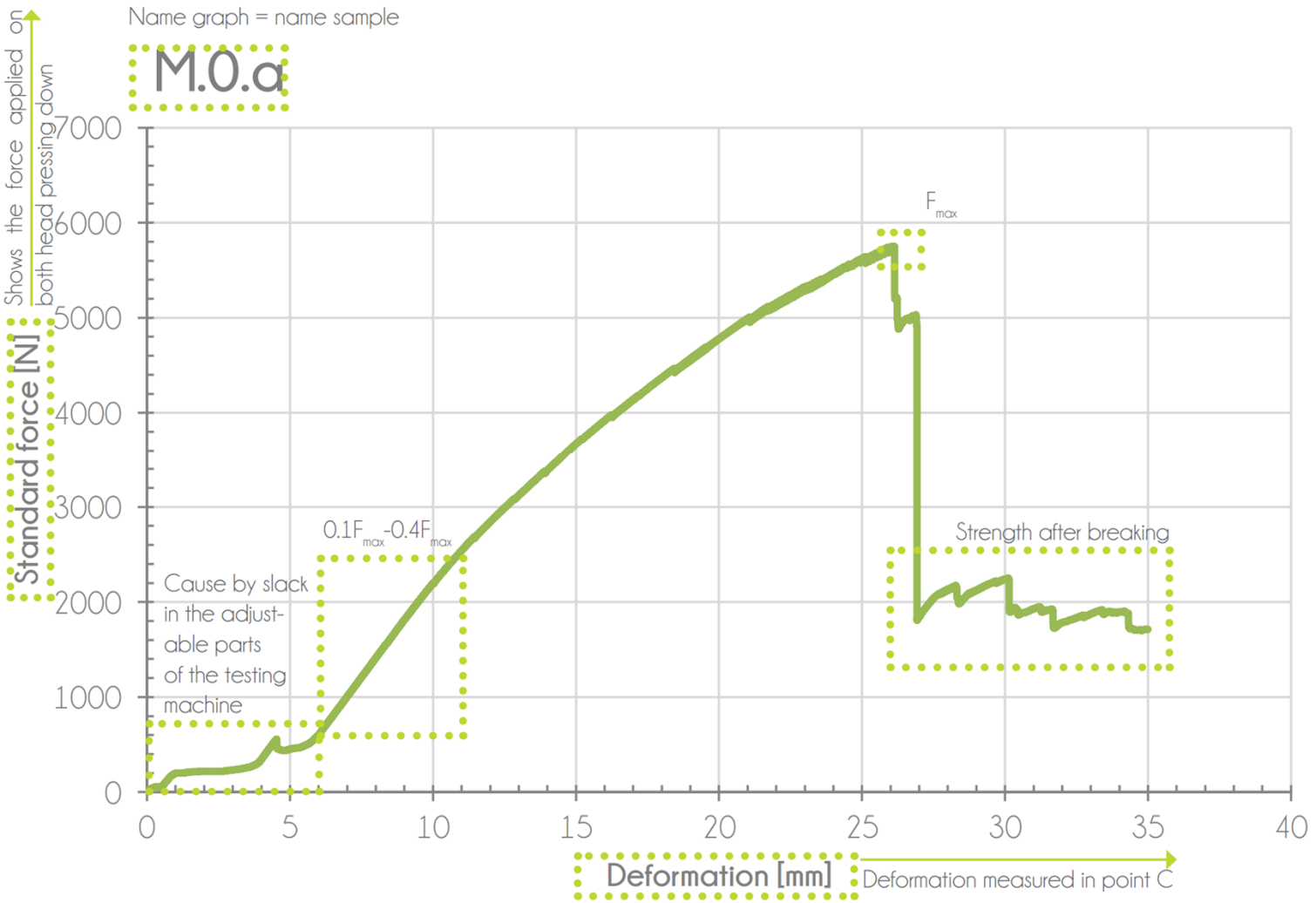
Physical tests

Physical testing





Physical testing



Physical testing

Formula's Mechanical

Modules of Elasticity

$$E(x) = -\frac{\Delta F x}{\Delta V b(h)^3}\left(3l_1 l_{h.o.h.} - 3{l_1}^2 - x^2\right)$$

Stress caused by bending (bending strength)

$$\sigma_M = \frac{3F l_1}{bh^2}$$

Formula's Statistics

Mean

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

Standard deviation

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

Standard error of the mean

$$\sigma_{\bar{x}} = \frac{\sigma_{SD}}{\sqrt{n}}$$

Physical testing

	Lamboo		Moso	
	MOE (MPa)	σ_m(MPa)	MOE (MPa)	σ_m(MPa)
Mean:	9446	48.1	9688	56.8
SD(σ):	516	5.4	650	4.4
$\sigma_{\bar{x}}$:	108	1.13	174	1.18
CV:	8569	39.2	8620	49.5

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