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Variations in Mid-Rise Hybrid CLT Constructions: Comparative Life Cycle Assessment of CLT vs Traditional Buildings

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Team

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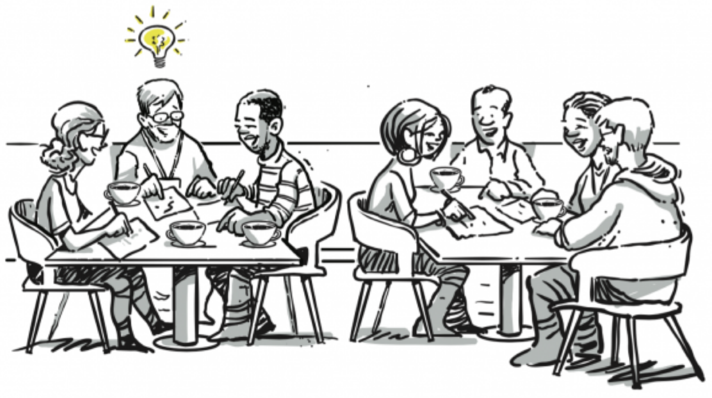


Project's goal

- Develop a comparative cradle-to-gate Life Cycle Assessments (LCA) of:
  - Hypothetical hybrid CLT building built in Washington State using wood from CLT facilities in the U.S. Pacific Northwest (**Hybrid CLT building**), and
  - Traditional reinforced concrete building (**Reinforced concrete building**)

Reinforced concrete building

Seattle, South Lake Union area

- **Reinforced concrete building**: developed starting from an **existing building** recently built in Seattle, whose geometry and construction were assessed to be **representative of the region**

Characteristics:

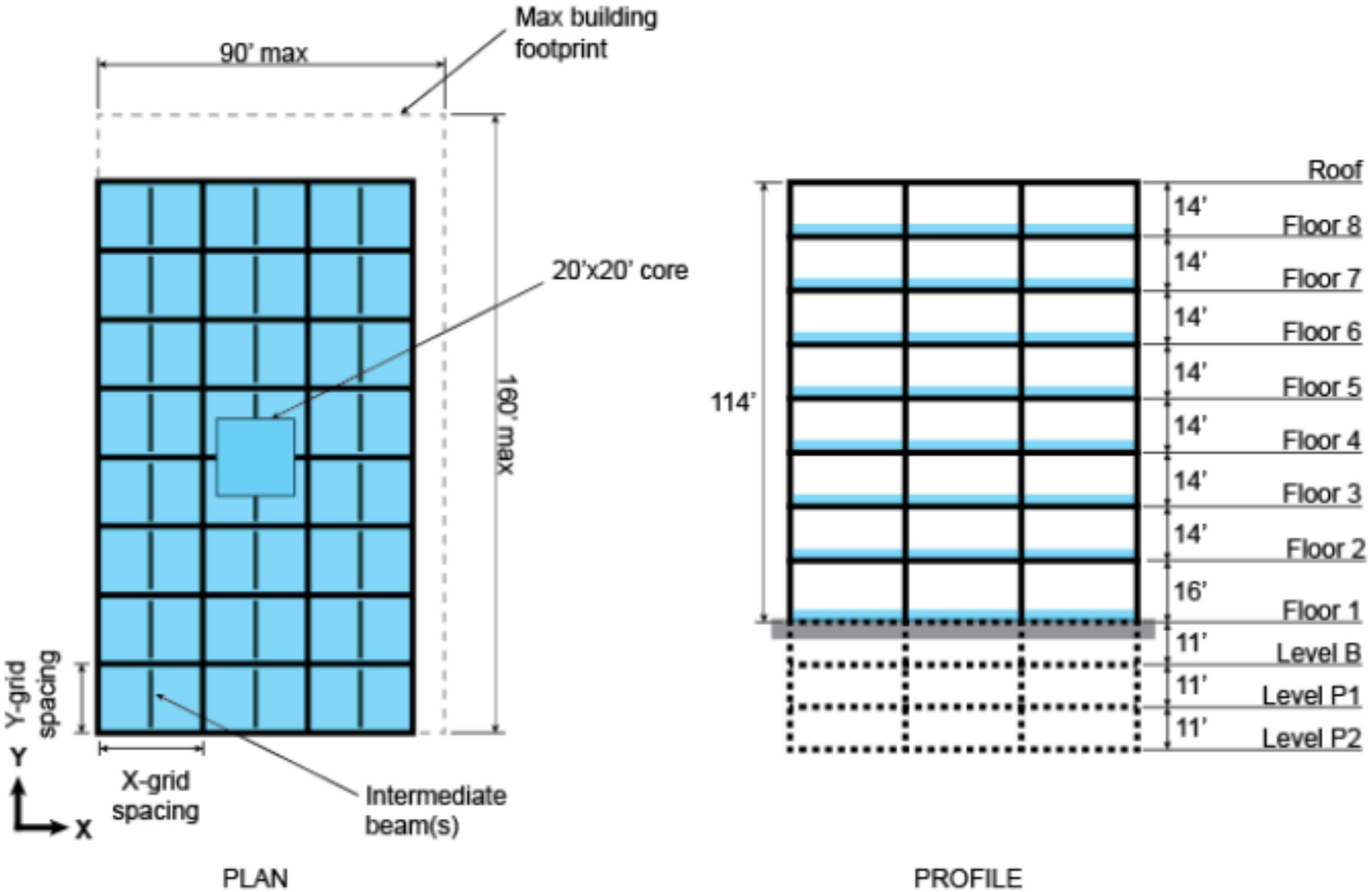
- Mid-rise (8 stories above grade)
- Commercial building
- Made of **reinforced concrete**

Hybrid CLT building

- **Hybrid CLT building:** version of the baseline building where **concrete and rebar are replaced with CLT and Glue Laminated beams** in the building structure (floors and columns)

- The hybrid CLT building is characterized by the **same functional space and geometry** as the reinforced concrete building

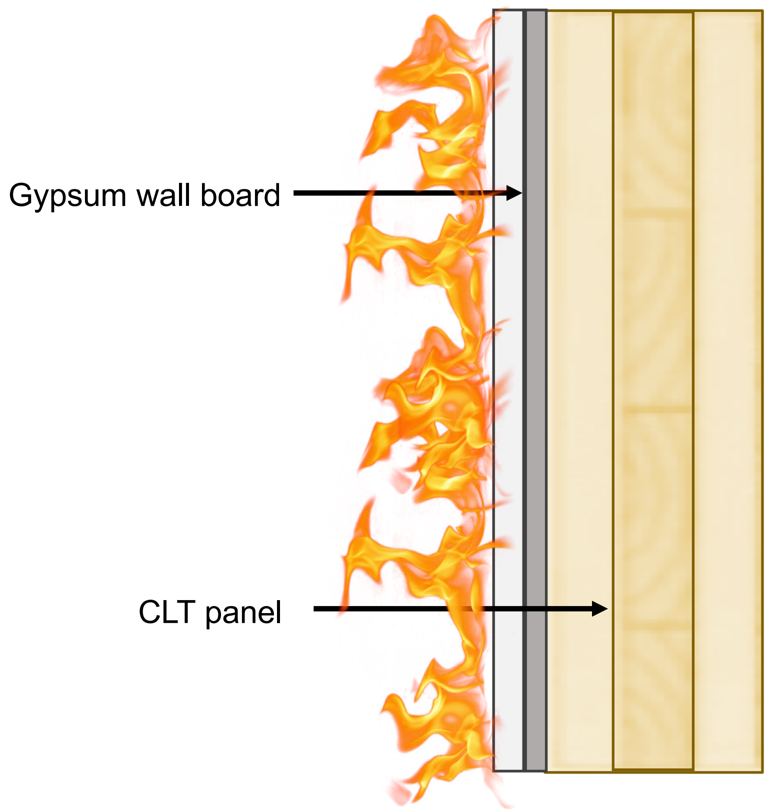
Building geometry



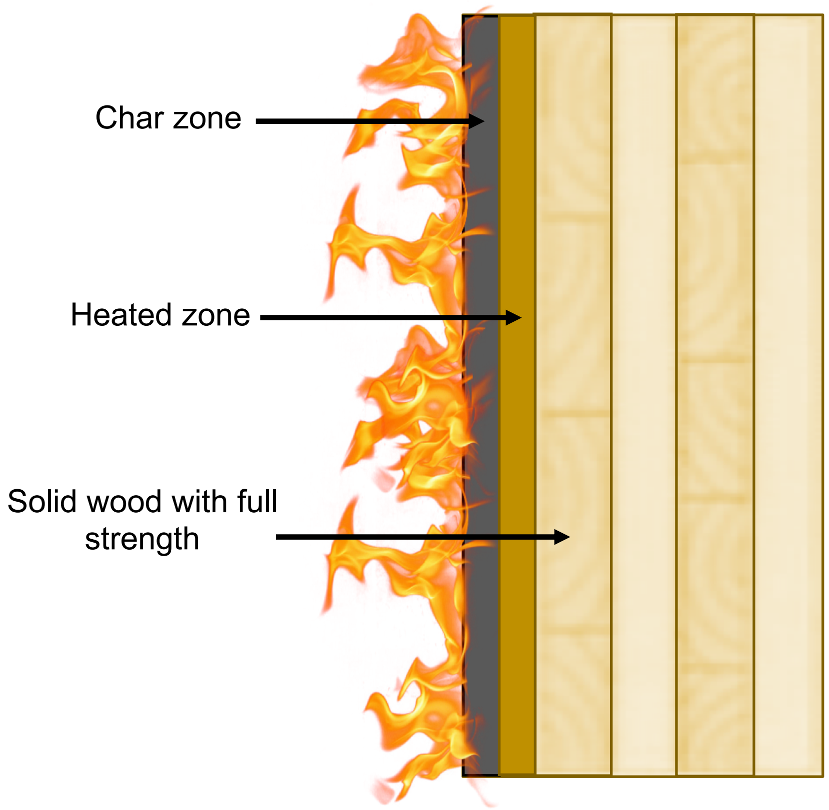
- **Geometric properties:**
- Footprint: 90'x160'
- Building height: 114'
- Floor-to-floor heights: 16' on the first floor and 14' on typical floors
- X-grid space: 30'
- Y-grid space: 20'
- Total floor area: 115,200 sf

Hybrid CLT building - Fire design scenarios

Scenario (a): Fire proofing



Scenario (b): Charring design



Methodology

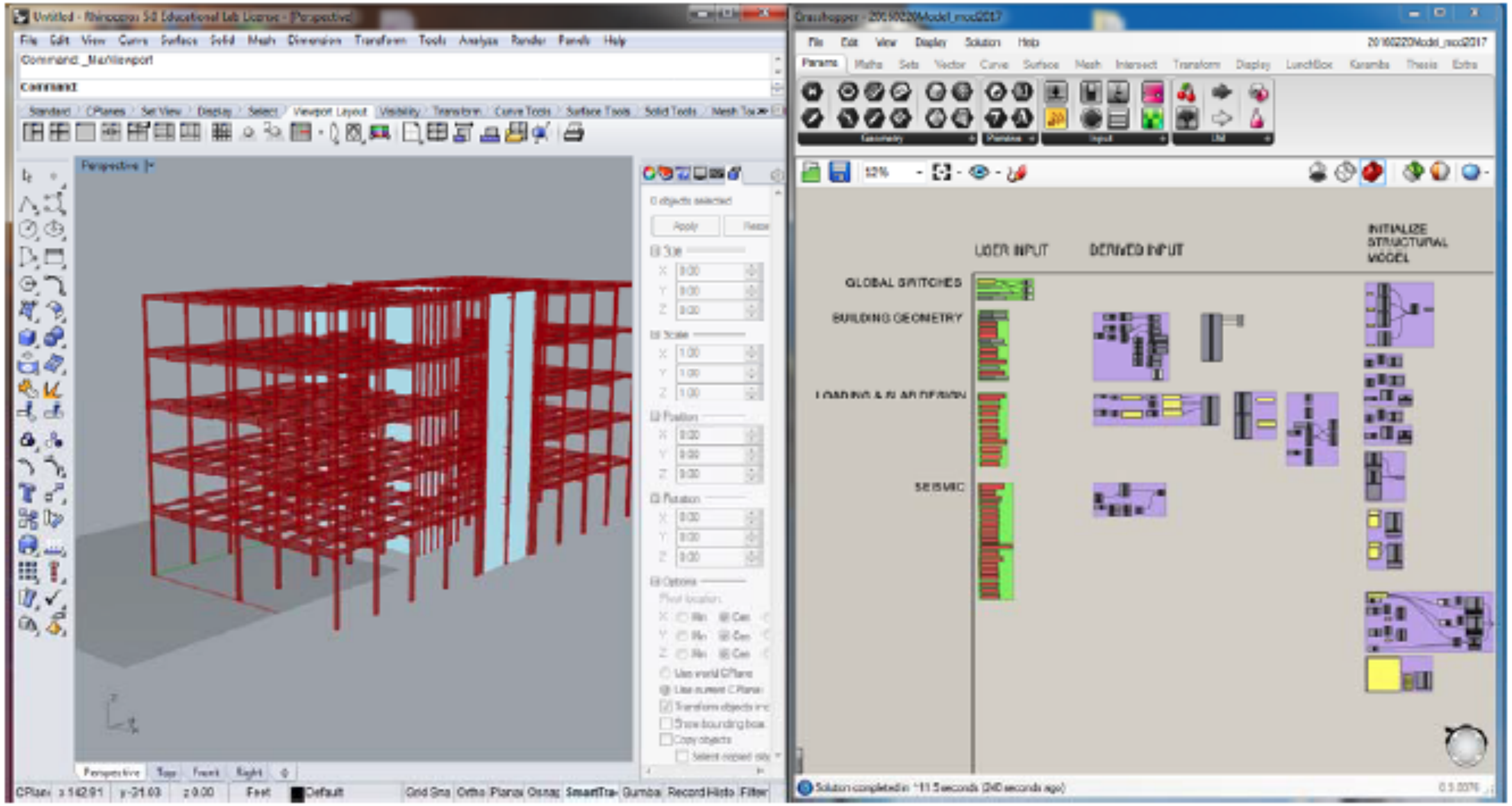
Structural design
Structural optimization of the building

Life Cycle Assessment
Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI 2.1)

Primary Energy Analysis
Cumulative Energy Demand (CED)

Biogenic carbon
Carbon storage calculation

Structural Design



Structural optimization of the building:

Parametric algorithm developed using Grasshopper, a graphical algorithm editor for Rhinoceros 5 (Rhino), a 3D geometric modeling CAD environment

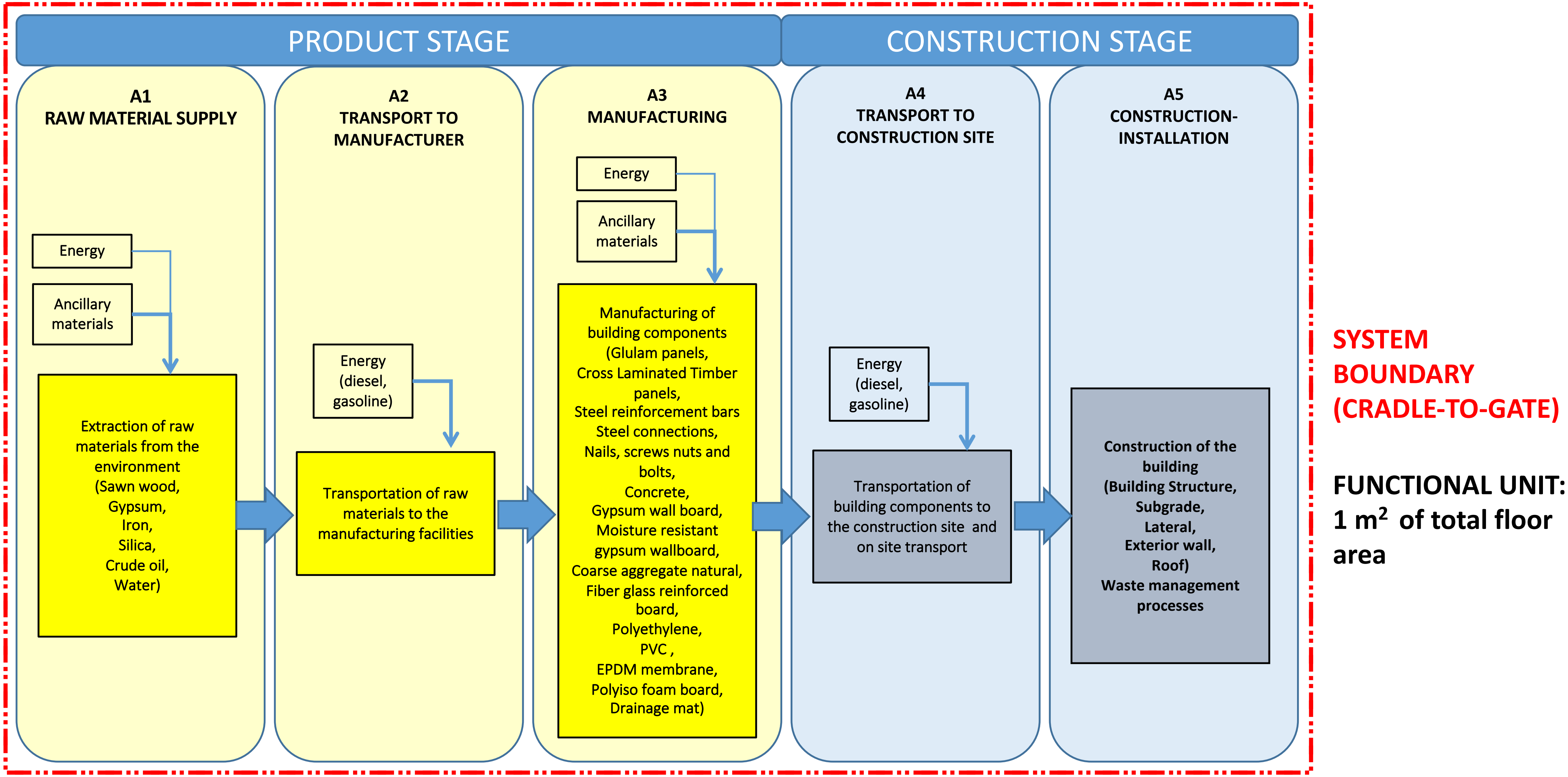
Source: USDA Mass Timber Material Quantities Report. Prototype Mass Timber Office Building Models: Material Quantities and Preliminary Life Cycle Assessment.

Material quantities – Building structure

Component	Material	Unit of Measure	Reinforced concrete building	Hybrid CLT building with fire proofing	Hybrid CLT building with charring design
Slabs + beams	Concrete, 5000 psi, PNW	cy	3,927	-	-
Slabs + beams	Steel rebar	tons	301	-	-
Concrete slabs	Concrete, 5000 psi, PNW	cy	-	889	889
Concrete slabs	Steel rebar	tons	-	51	51
CLT slabs	**Cross laminated timber**	ft^3	-	**39,600**	**66,000**
Beams	Glue laminated timber	ft^3	-	18,228	29,123
Columns	Concrete, 5000 psi, PNW	cy	747	-	-
Columns	Steel rebar	tons	205	-	-
Columns	Glue laminated timber	ft^3	-	4,733	8,099
Steel connections	Steel	tons	-	11	12
Floor underlayment	Gypsum wallboard	sf	-	115,200	115,200
Fireproofing	**Gypsum wallboard**	sf	-	**460,800**	0

Source: USDA Mass Timber Material Quantities Report. Prototype Mass Timber Office Building Models: Material Quantities and Preliminary Life Cycle Assessment.

System boundary



FUNCTIONAL UNIT: 1 m^2 of total floor area

Life Cycle Assessment

Def (ISO 14040-44): "Compilation and evaluation of the inputs, outputs and of the potential environmental impacts of a product system throughout its life cycle"

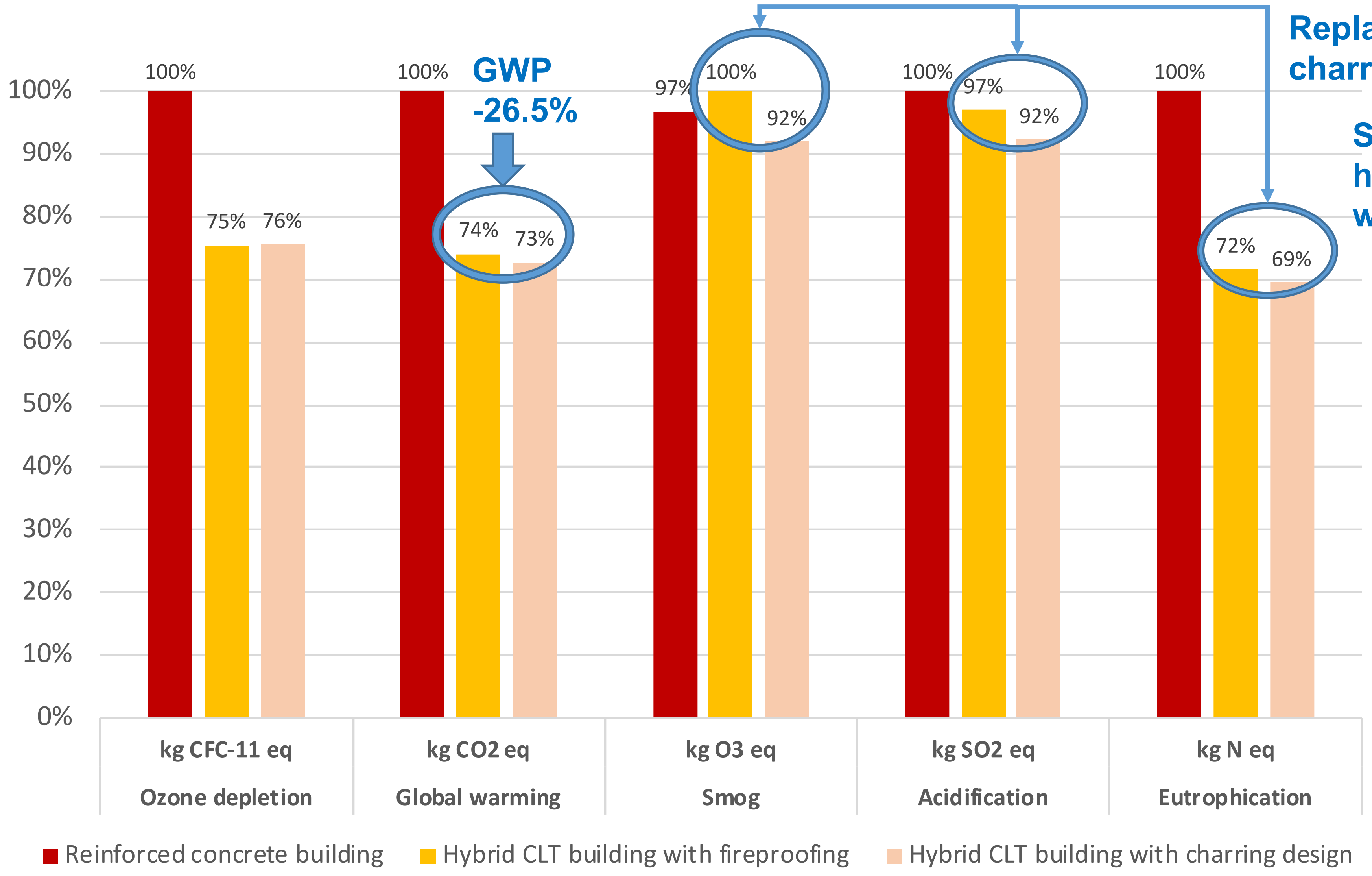
Group	Impact categories	Acr.	Media	Method
GLOBAL IMPACT CATEGORIES	Global warming	(GWP)	Air	TRACI v. 2.1
	Ozone depletion	(ODP)	Air	
LOCAL IMPACT CATEGORIES	Smog formation	(POCP)	Air	
	Acidification	(AP)	Air	
	Eutrophication	(EP)	Water	
ENERGY CONSUMPTION	Total Primary Energy	MJ	Primary energy	Cumulative Energy Demand (CED)
	Non renewable, fossil	MJ	Primary energy	
	Non renewable, nuclear	MJ	Primary energy	
	Renewable	MJ	Primary energy	

Building components

- The following **building components** (for both reference and prototype buildings) were included in the LCA:
  - **Structure**
  - **Subgrade**
  - **Lateral system**
  - **Exterior wall**
  - **Roof**

- The ***foundation was excluded*** (outside the scope of this study)

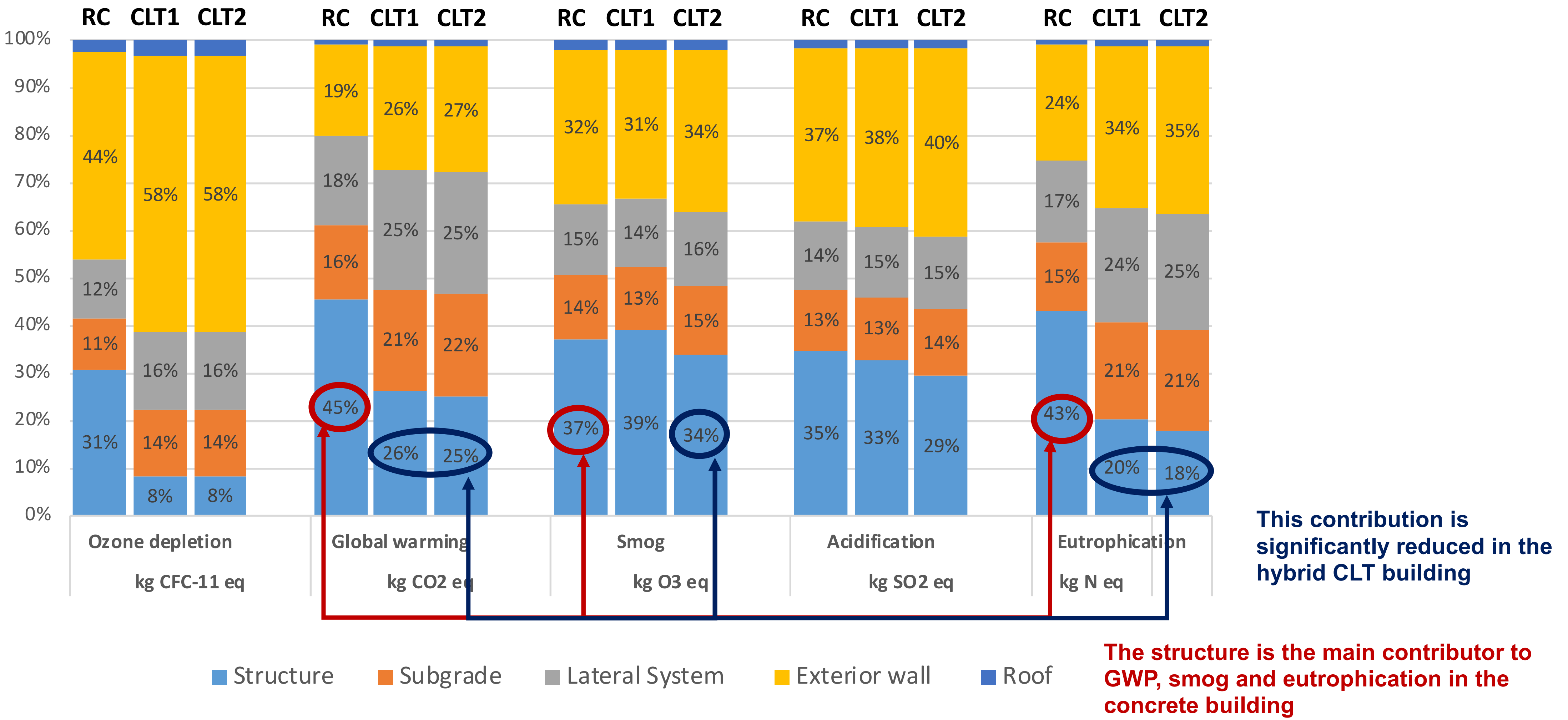
Results of the comparative analysis



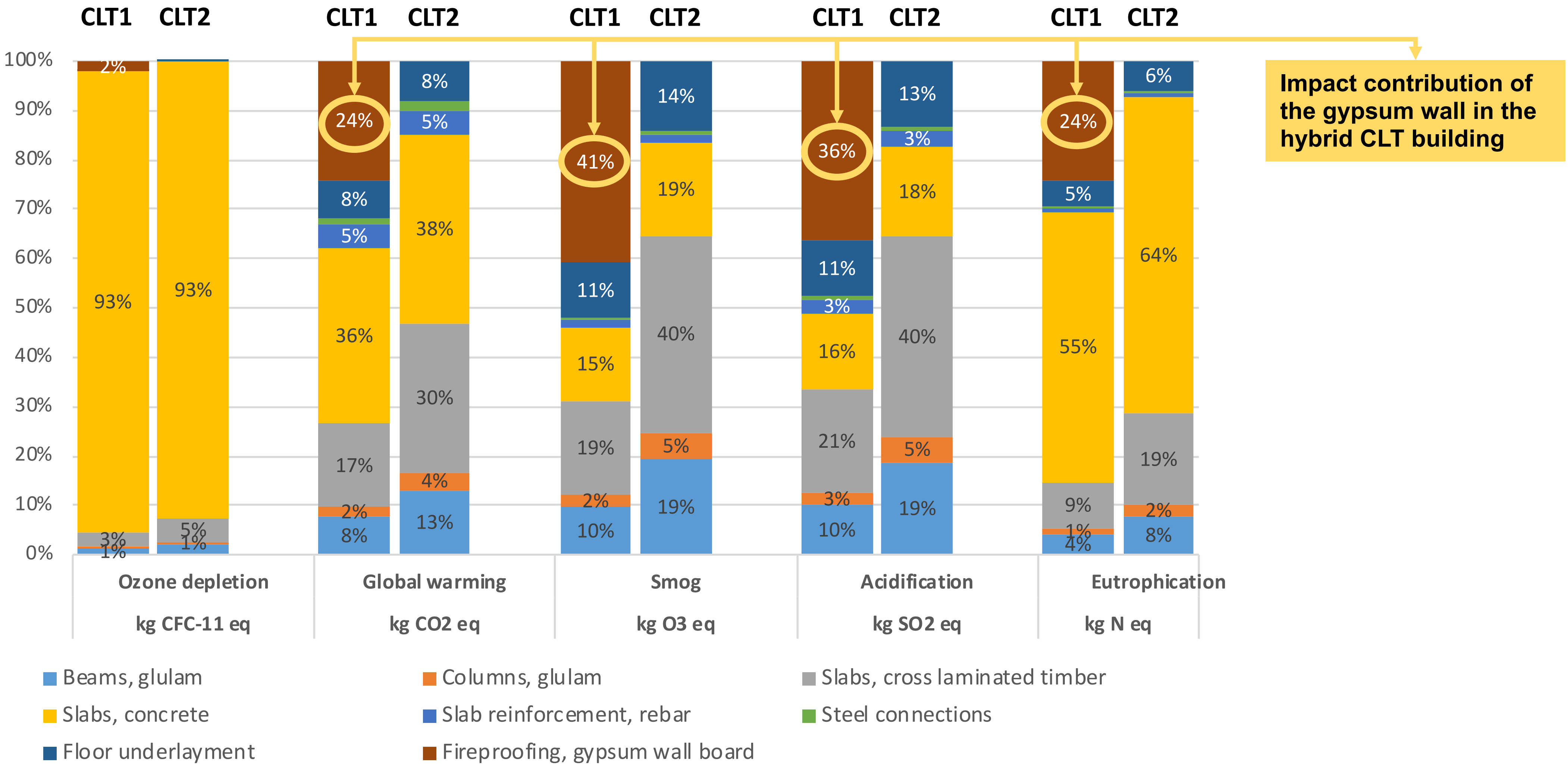
Replacing fireproofing with charring is beneficial

Smog increases in the hybrid CLT building with fire proofing

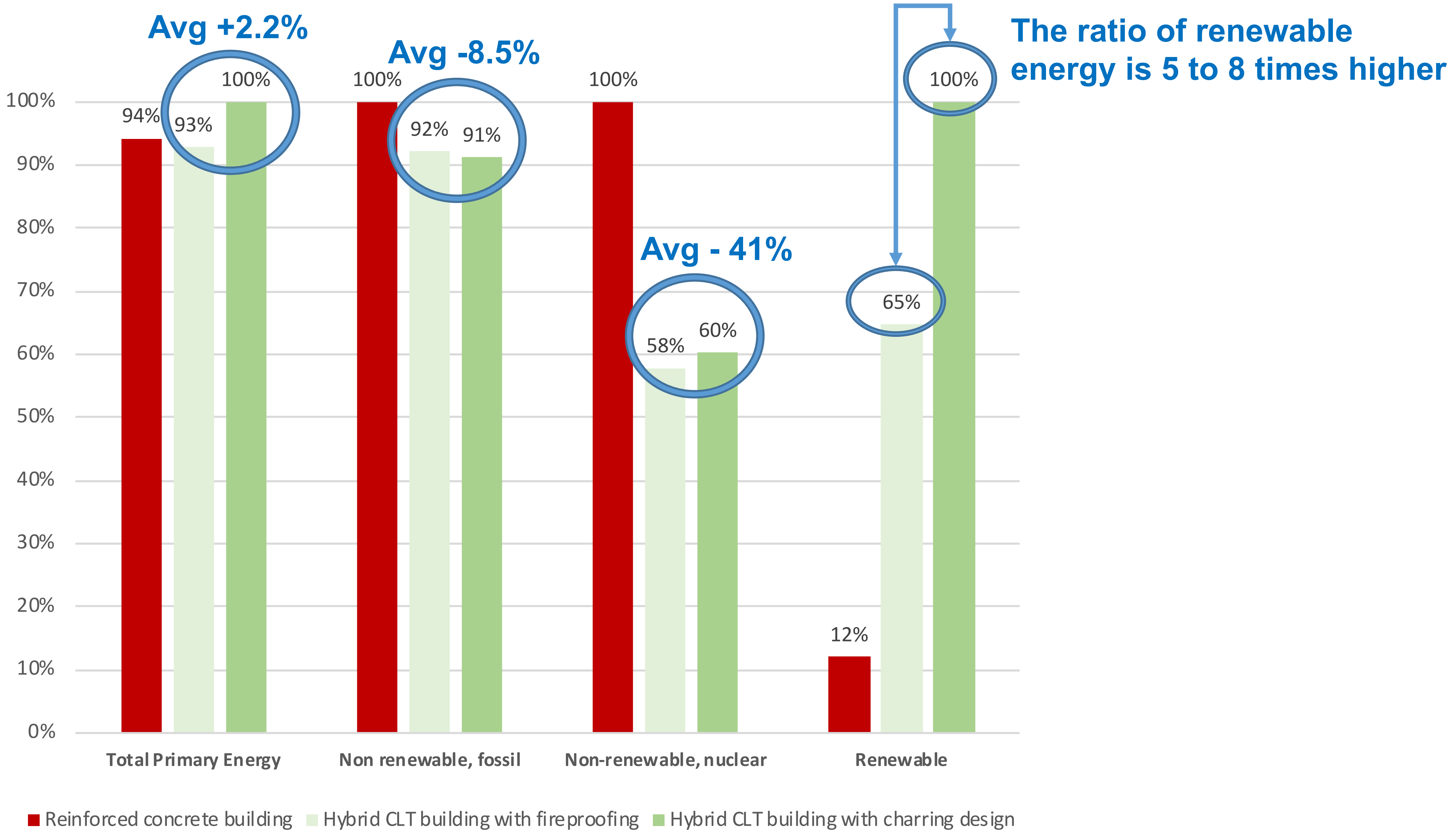
Results – Reinforced concrete building (RC), Hybrid CLT building with fire proofing (CLT1) and charring (CLT2)



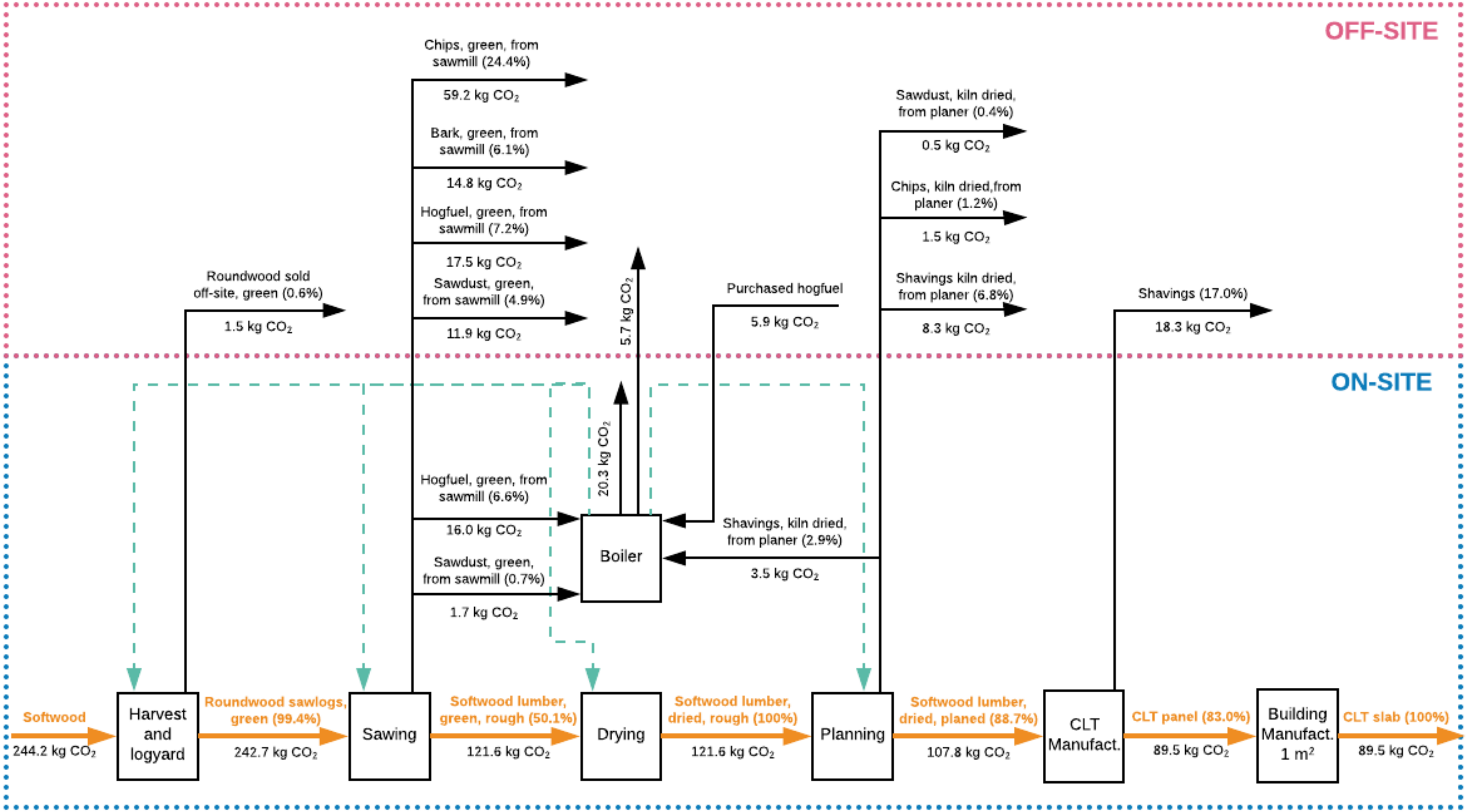
Results – Contribution analysis of individual building components (Structure)



Results – Cumulative Energy Demand



Biogenic carbon balance for the CLT components



Biogenic emissions

- Biogenic carbon was treated according to the **PCR for architectural wood products**
- The default method **does not count the biogenic CO_2 emission and sequestration contributions** in the evaluation of the global warming impact but report them separately.
- **"Carbon neutrality" assumption**, implies that the release of carbon dioxide during biomass burning for energy product (biogenic CO_2) is balanced by the carbon dioxide that is sequestered by the forest to produce a same amount of biomass
- National level inventory reporting shows **overall increasing and/or neutral forest carbon stocks** in North America in recent years
- Other emissions associated from wood combustion, e.g., **methane or nitrogen oxides, were included in the global warming impact category**

Carbon storage calculation

- The carbon storage was calculated by multiplying the oven-dry mass of wood by the quantity of carbon (C) (assumed 0.5 kg C/ kg wood) and by the quantity of CO_2 emitted per kg of wood (44/12 kgCO_2 / kg C).

- **Hybrid CLT building with fire proofing**: a total of **855 tons of biomass** (corresponding to **1,568 tons of CO_2**) are stored in the wood components of the building (CLT and glulam)
- **Hybrid CLT building with charring design:** a total of **1,409 tons of biomass** (corresponding to **2,584 tons of CO_2**) are stored in the wood components of the building, **corresponding to 65% more than in the scenario with fire proofing** (CLT and glulam)

Conclusions

- The **building structure is the main contributor** to GWP, smog and eutrophication in the reinforced concrete building
- By substituting concrete and steel with CLT in the building structure of a hybrid CLT building, an average of **26.5% reduction in global warming potential** is achieved
- With the exception of the ozone depletion, where the difference in the impact between the scenarios is <1%, **replacing fire proofing with charring design is beneficial** for all the impact categories.

Conclusions

- The hybrid CLT building consumes **an average of 2.2% more total primary energy** than the reinforced concrete building.

- However, the ratio of **renewable energy** in the hybrid CLT building is **5 to 8 times higher** in the hybrid CLT building compared to the reinforced concrete building, due to use of woody residues to produce energy.

- The hybrid CLT building helps reducing global warming by keeping CO_2 sequestered from the atmosphere for the whole life time of the building (**carbon storage**)

- **Replacing fire proofing** with **charring design** is **beneficial** also in terms of **carbon storage (+65%)**

Limitations

- This is only a cradle-to-gate analysis and not the full life cycle. **We can not make definitive comparisons without including the full life cycle of the building**.
- The study **does not include the use phase** and the potential impact of decreased thermal mass on the heating and cooling loads of the building.
- This study **does not include the end of life phase** and different option for building demolition and waste management.
- This LCA **does not include** the environmental impact of forest management on **habitat diversity.**
- This study **does not present the variability in material quantities due to design options** or uncertainty in material quantities.

Acknowledgements

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Thank you for your attention

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