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American Concrete Institute

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Spring Convention 2023

EXPLORING THE EFFECTIVENESS OF HYBRID TIMBER CONCRETE STRUCTURES

San Francisco, 2023, April 2

Giovanni Muciaccia, Laura Corti

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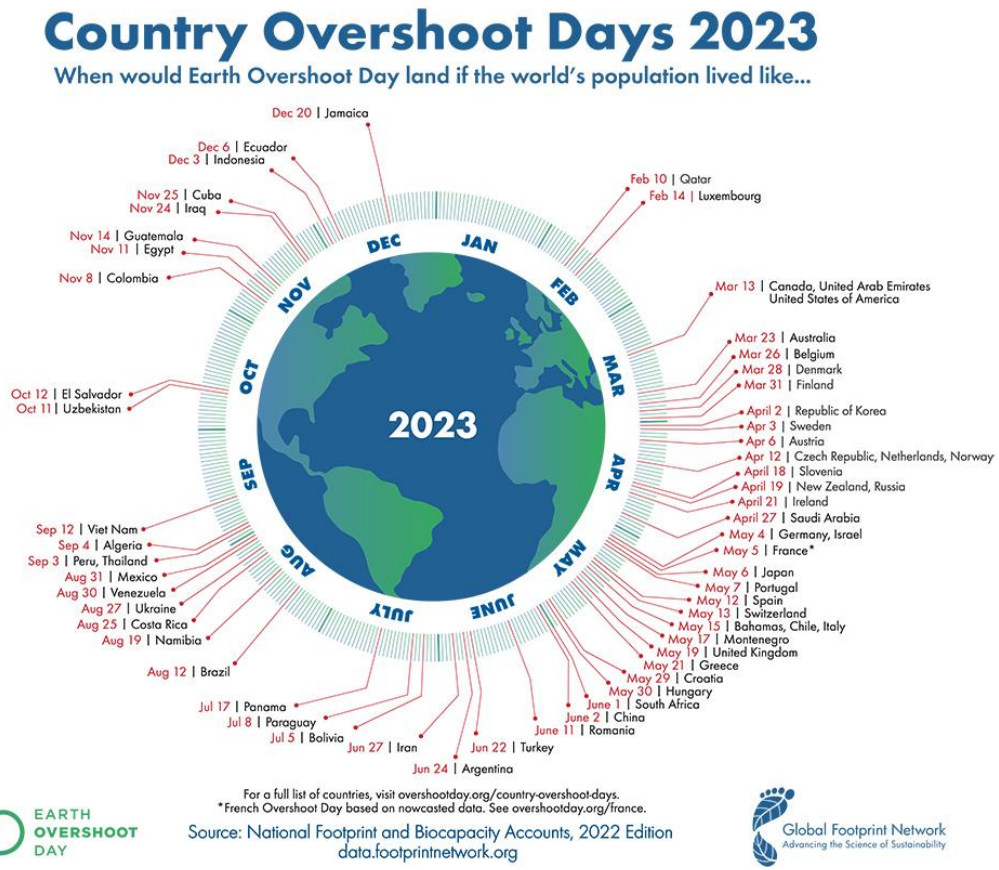


https://www.overshootday.org/

Humanity's ecological footprint > Earth's biocapacity

Year	Country	Biocapacity per person (gha)	Ecological footprint per person (gha)	Biocapacity deficit (gha)
2018	Italy	0.8	4.3	-3.5
	UK	1.0	4.2	-3.2
	US	3.4	8.1	-4.7
	China	0.9	3.8	-2.9
	India	0.4	1.2	-0.8

https://data.footprintnetwork.org/#/

Building sector is responsible for:

- 45% of global energy consumption
- 30% of global generated waste
- 40% of global GHG (greenhouse gases) emissions

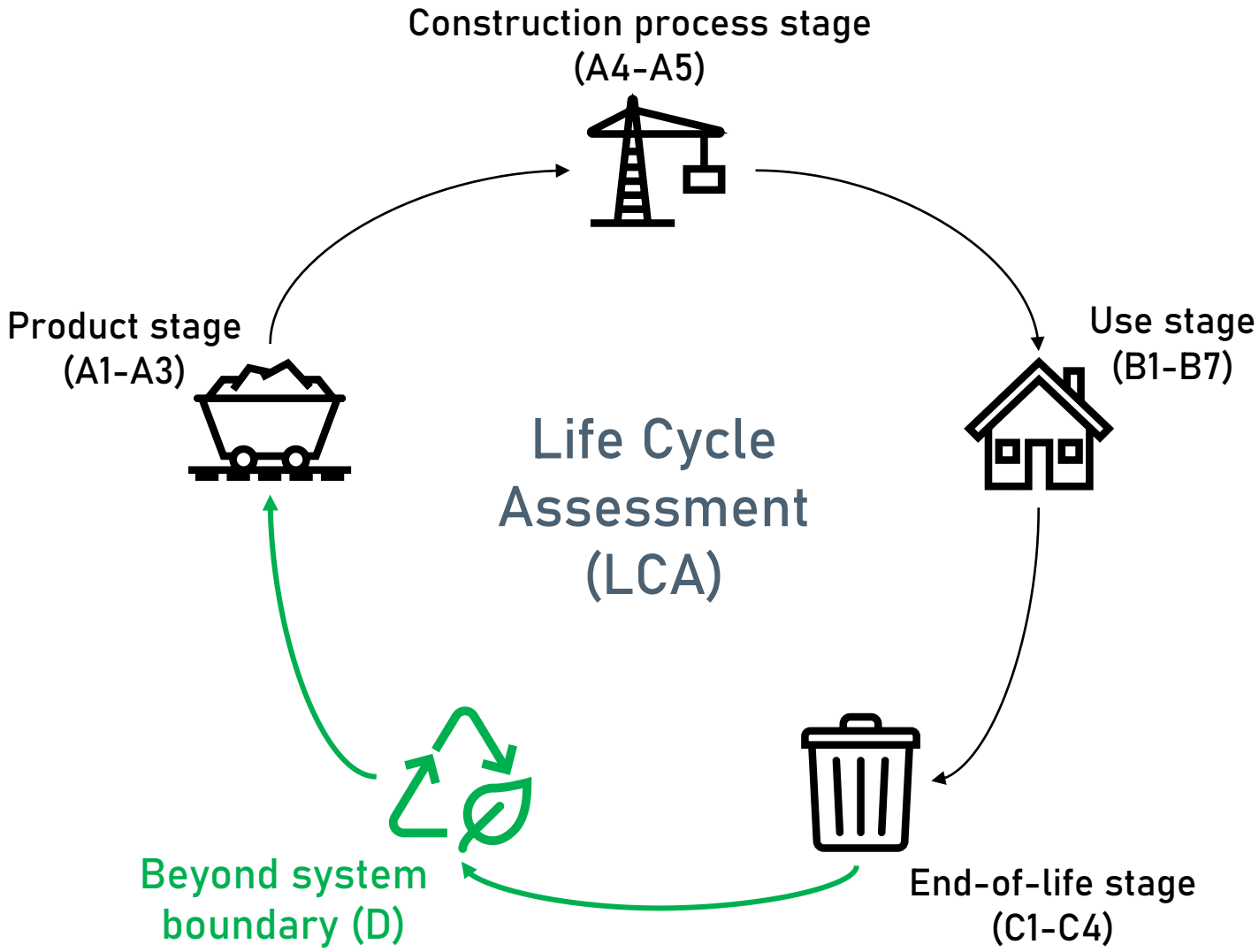
Implementation of strategies to reduce buildings environmental impact

↓

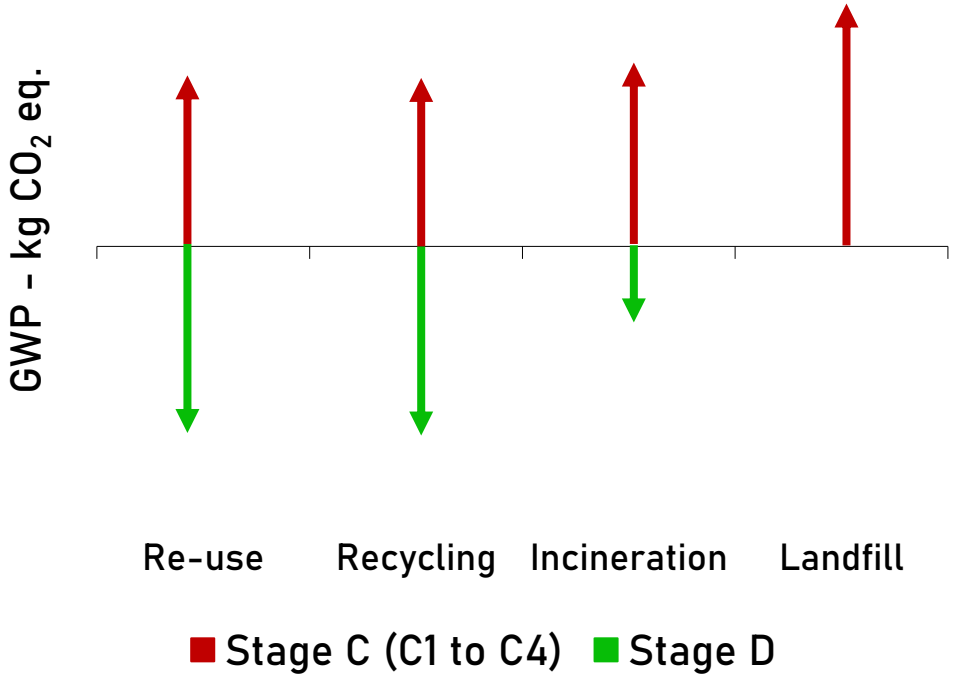
Timber hybridization with concrete

Need for in-depth studies concerning:

- Hybridization techniques
- Collection of real case studies
- Comparison with traditional solutions



Scenarios for the End-of-Life stage for a CLT wood product



Mjøstårnet, 2019
Brumunddal, Norway
11(+7) storey
Low seismicity

Social Housing via Cenni, 2019
Milan, Italy
9 storey
Medium-low seismicity

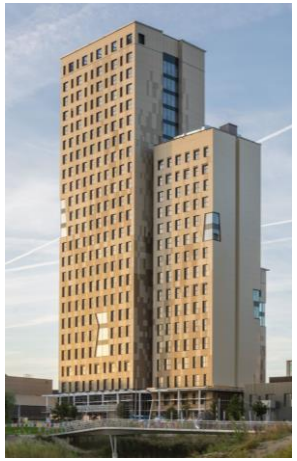
Alexander Residence, 2019
Roccaraso (L'Aquila), Italy
8 storey
Very high seismicity

TSS

RC Core

Hoas Tuuliniitty, 2021
Espoo, Finland
(1+)12 storey
Low seismicity

HoHo, 2020
Wien, Austria
24 storey
High seismicity

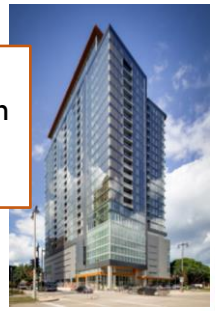


Medium-rise timber buildings built in recent years in European areas with different levels of seismic hazard (European Seismic Hazard map with 10% exceedance probability in 50 years from the SHARE web site http://www.share-eu.org). The authors superimposed the locations of some medium and high-rise timber buildings.

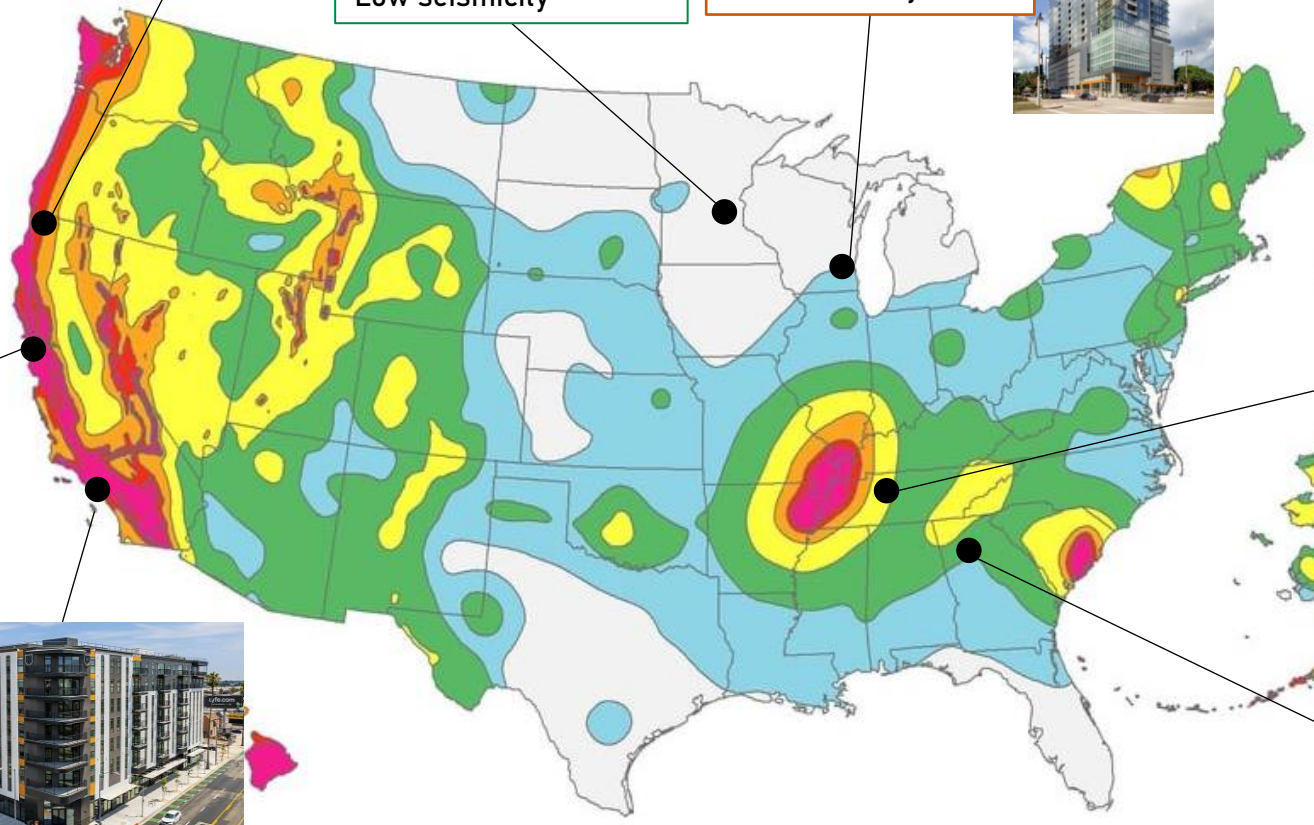
Framework, 2015
Portland, Oregon
(1+)4 storey
High seismicity

Butler Square, 1908
Minneapolis, Minnesota
9 storey
Low seismicity

Ascent MKE, 2022
Milwaukee, Wisconsin
(6+)19 storey
Low seismicity



1 De Haro, 2021
San Francisco, California
(1+)4 storey
High seismicity



1003 Music Row, 2021
Nashville, Tennessee
5 storey
Medium seismicity

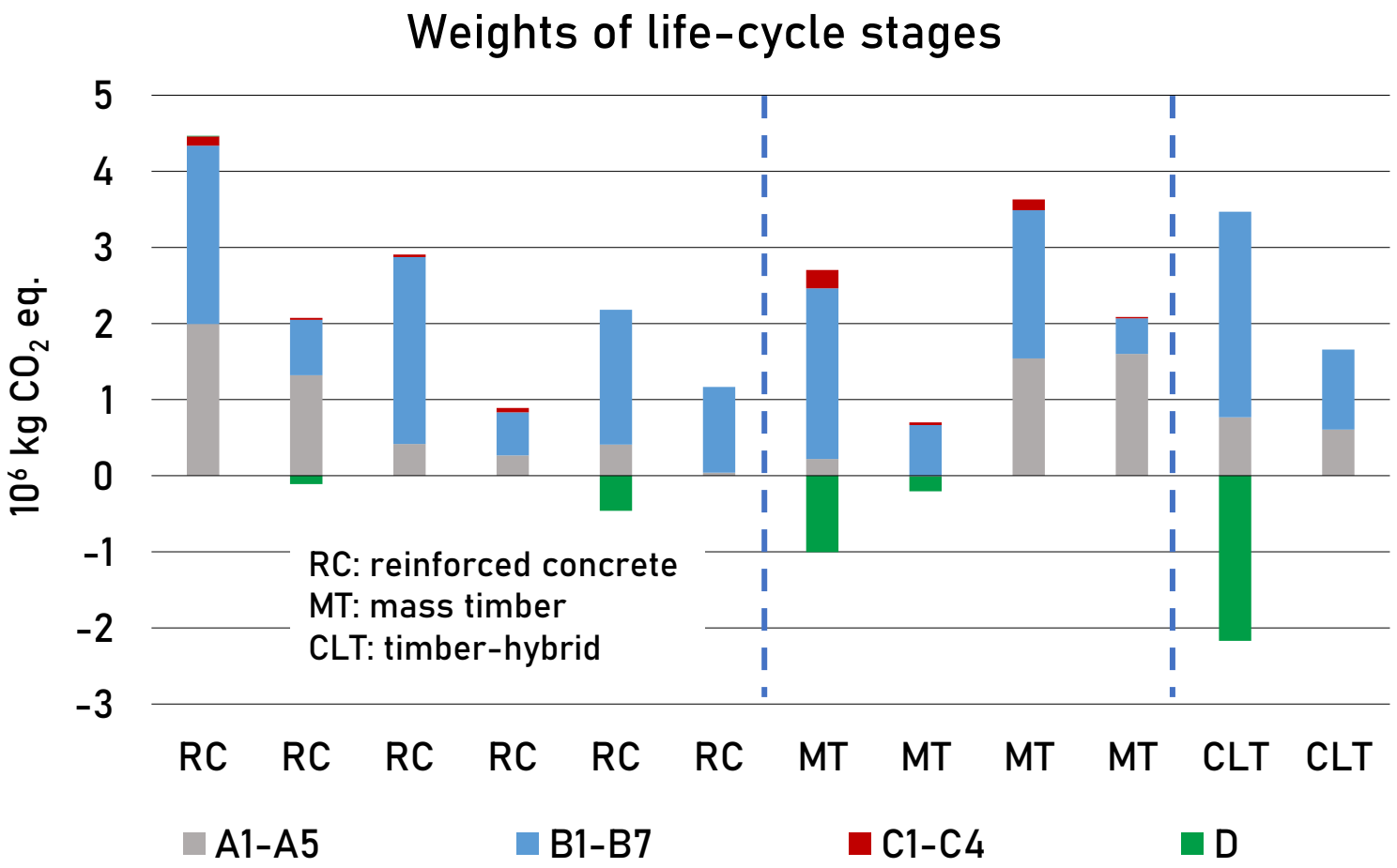
The HUB Student Housing Project, 2022
Los Angeles, California
8 storey
High seismicity

T3 Atlanta West Midtown, 2019
Atlanta, Georgia
7 storey
Medium-low seismicity

TSS

RC Core

Seismic Hazard map in the US with a 2% exceedance probability in 50 years - https://www.usgs.gov/programs/earthquake-hazards/science/national-seismic-hazard-model (*authors superimposed the locations of some medium and high-rise timber buildings*)



- Phase B is impactful, and it establishes the most substantial component of the whole LCA analysis
- Considering a cradle-to-grave (A-to-C) LCA analysis some benefits are acknowledged, but the actual advantage arises from consideration and exploitment of phase D

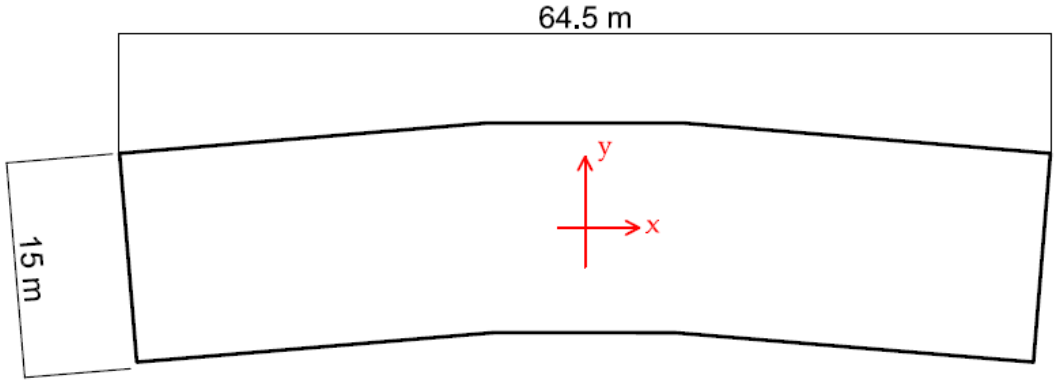
Corti, L., Di Nunzio, G., Muciaccia, G. (2022) Comparative life cycle assessment (LCA) analysis of timber and reinforced concrete multistorey buildings. State-of-the-art review. *CSCE 2022 Annual Conference*

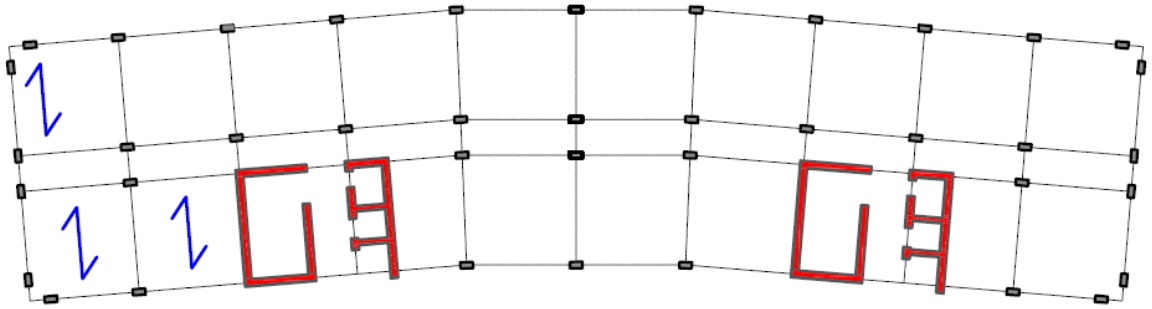
Location: Milan, Italy

Low-moderate seismicity region

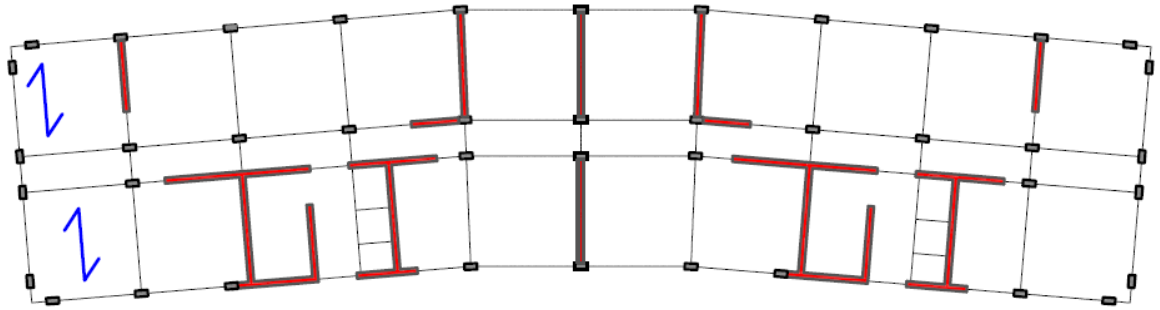
Residential building with 8 storeys (total height=26.8 m)

In-plan geometry 64.5 x 15 m

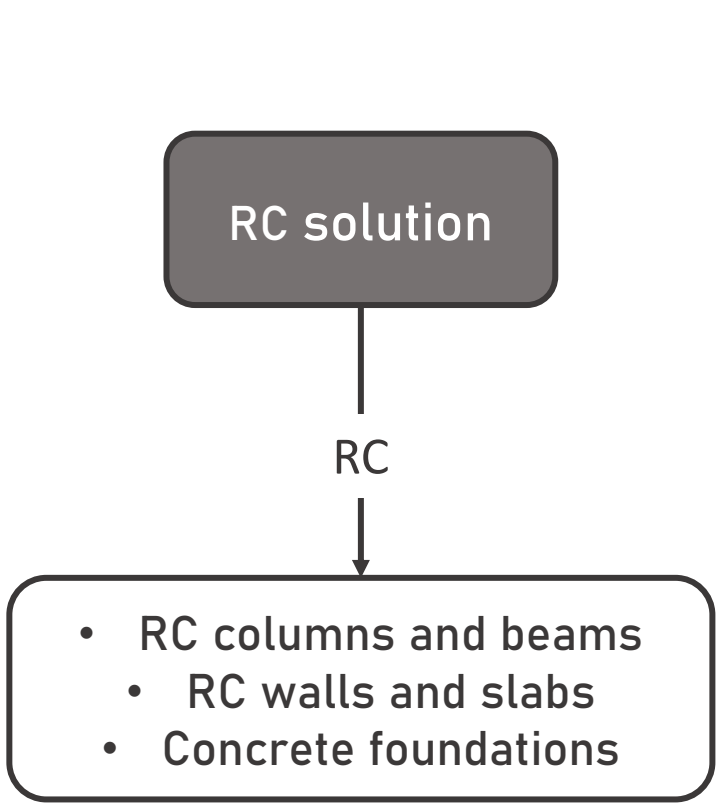


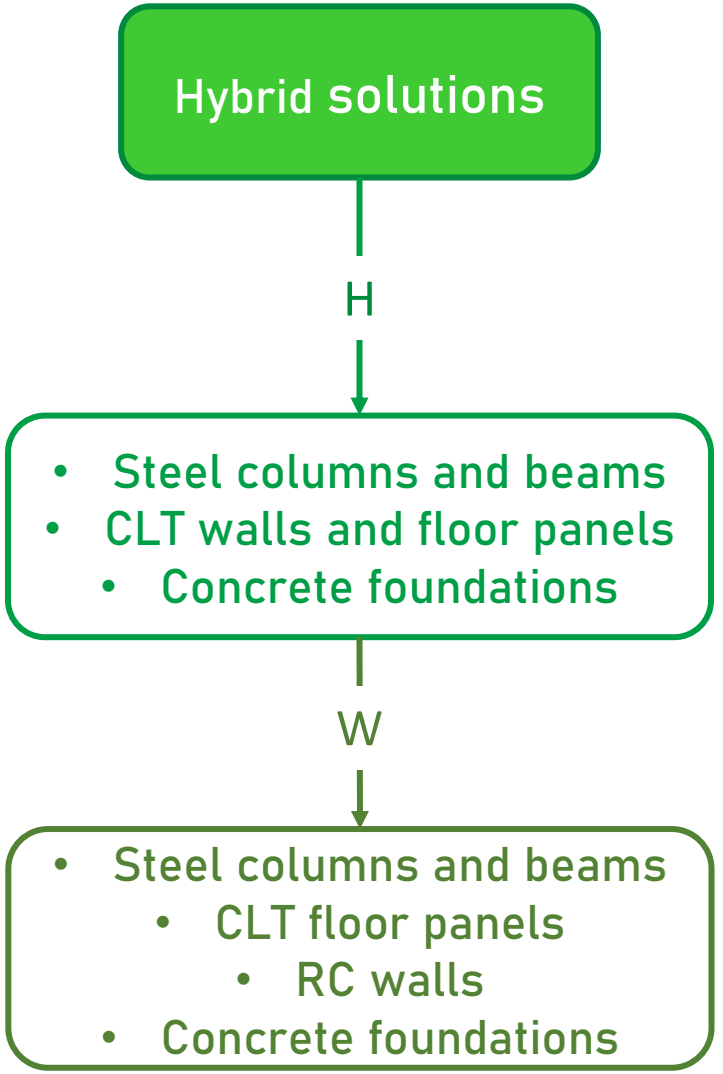


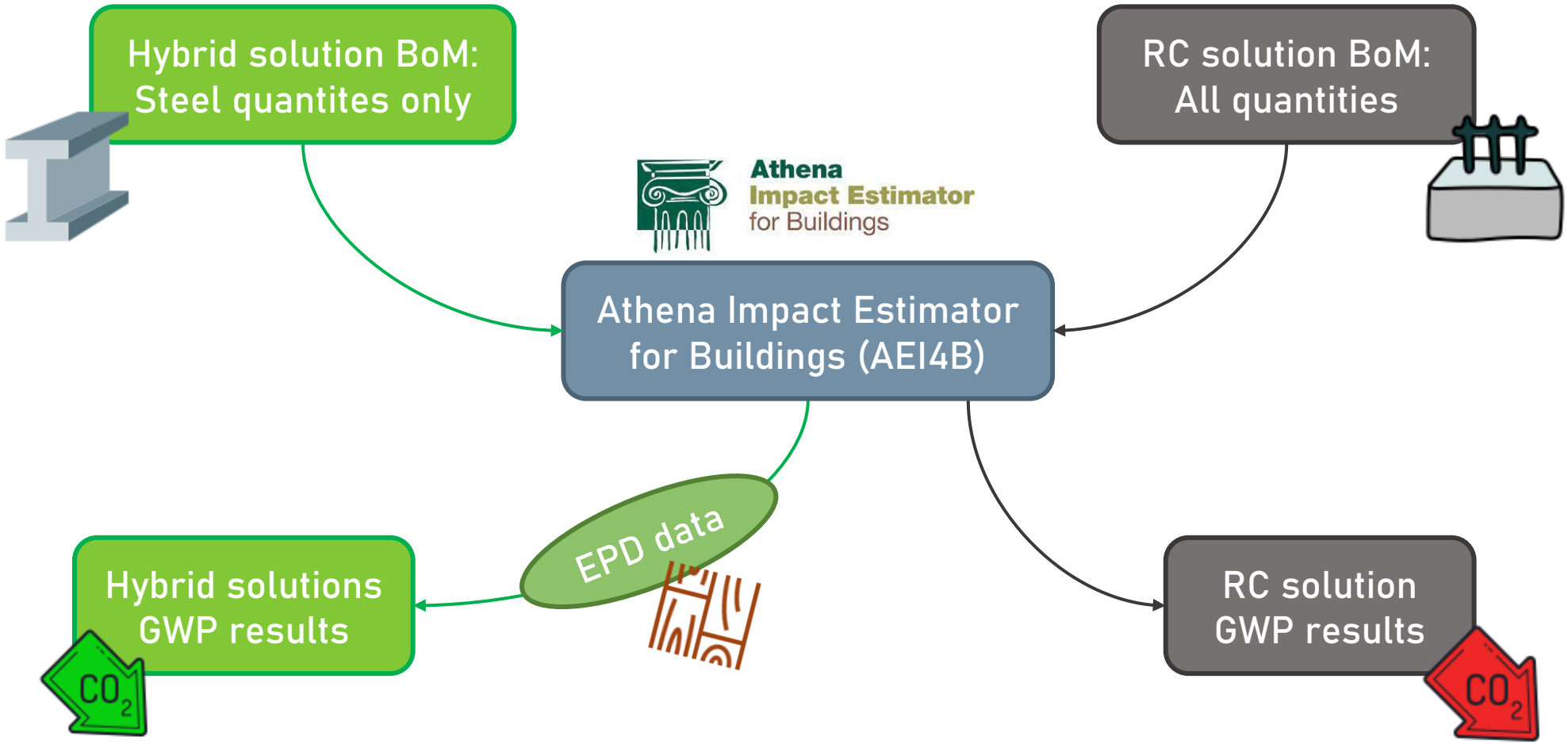
Original in-plan structural layout of columns and core positions



Proposed in-plan structural layout of columns and CLT shear walls position


RC solution
RC
• RC columns and beams
• RC walls and slabs
• Concrete foundations


Hybrid solutions
H
• Steel columns and beams
• CLT walls and floor panels
• Concrete foundations
W
• Steel columns and beams
• CLT floor panels
• RC walls
• Concrete foundations


Hybrid solution BoM:
Steel quantites only
RC solution BoM:
All quantities
Athena
Impact Estimator
for Buildings
Athena Impact Estimator
for Buildings (AEI4B)
EPD data
Hybrid solutions
GWP results
RC solution
GWP results
CO2
CO2

Solution #	End of Life Scenario	ID
Traditional solution	-	RC
Hybrid solutions - 1	Re-use	H1
Hybrid solutions – 2	Recycling	H2
Hybrid solutions – 3	Landfill	H3
Hybrid solutions - 4	70% Re-use, 30% Incineration	H4
Hybrid solutions – 5	70% Re-use, 30% Incineration (with no replanting hypothesis)	H5

STAGE D SCENARIOS

- Re-use: reuse of product, substituting virgin material
- Recycling: recovery of wood chips, substituting virgin material
- Landfill: methane uptake from landfill partly substitutes natural gas in heat production
- Incineration: incineration of wood chips obtained by disposed timber elements, as an alternative to natural gas in heat production

No replanting hypothesis: biogenic carbon storage in stage A (-762 kg CO_2 eq.) is not accounted for. Scenario H4 for stage D is considered.

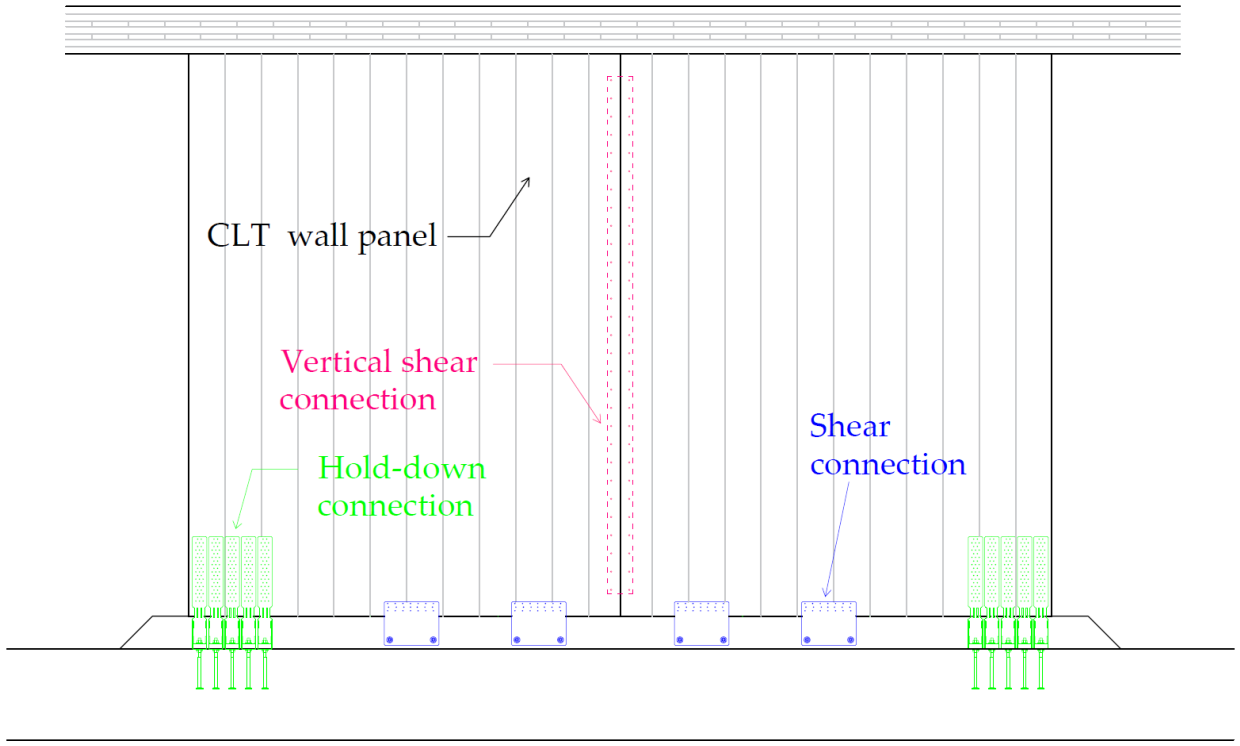
Sensitivity analysis and hypotheses

- Stage B is firstly disregarded , in order to focus on the effects of different scenarios concerning stage D and due to the cumbersome involved calculations and greater levels of uncertainties. Above all, stage B cannot be disregarded at all, so according to common values collected from literature, it is evaluated as a percentage of the GWP impact (emissions in terms of kg CO_2 eq.) of the cradle-to-grave LCA analysis.

Stage B hypothesis	% stage B/cradle-to-grave LCA
Low energy efficiency	80 %
High energy efficiency	60 %

Sensitivity analysis and hypotheses

- Hold-down, vertical and shear connections – in terms of steel quantities for CLT vertical panels – have not been considered in the LCA considering their negligible quantitative impact on the overall results



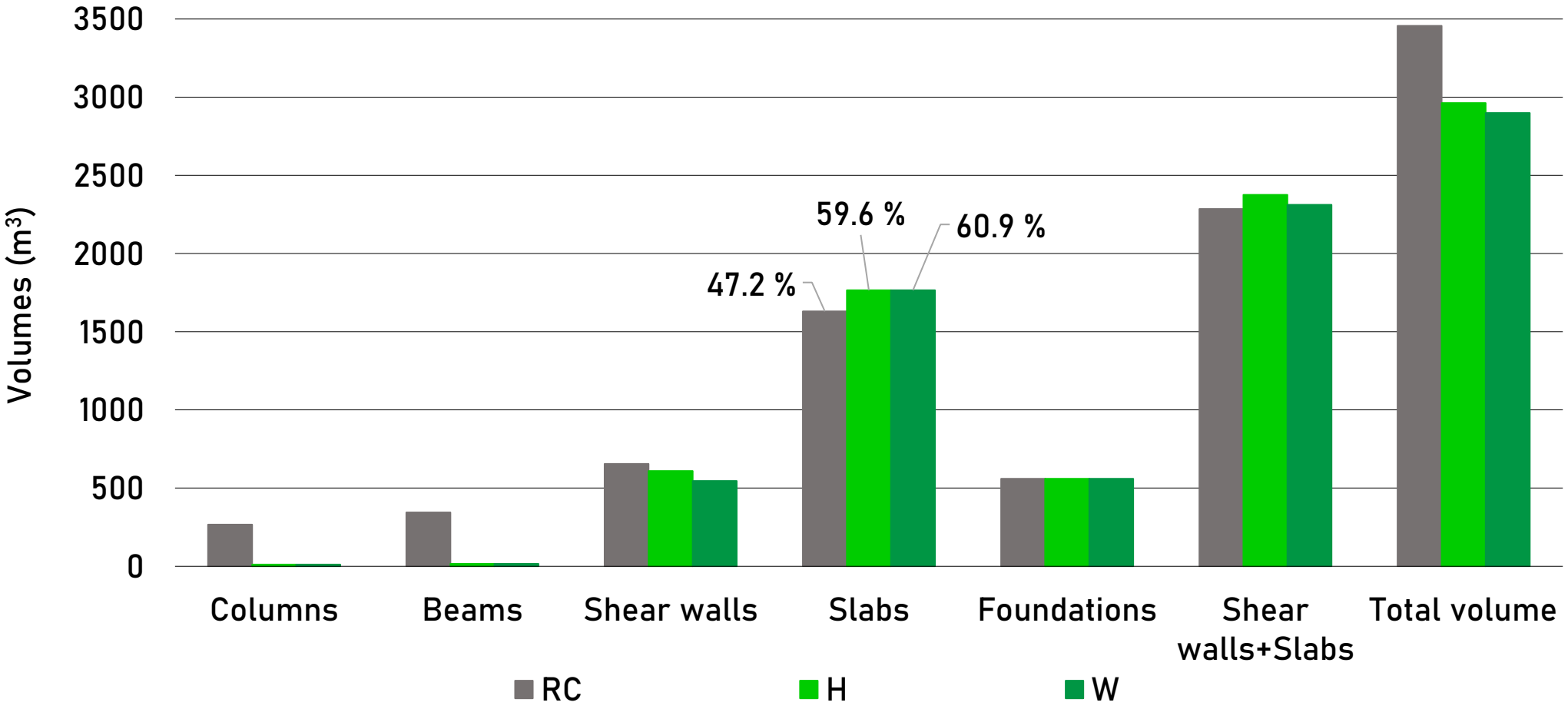
Total connection volumes (ground floor) = 0.189 m^3

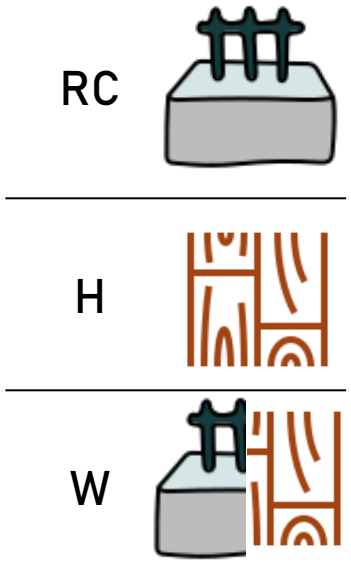
Contribution to total volume < 0,1 %

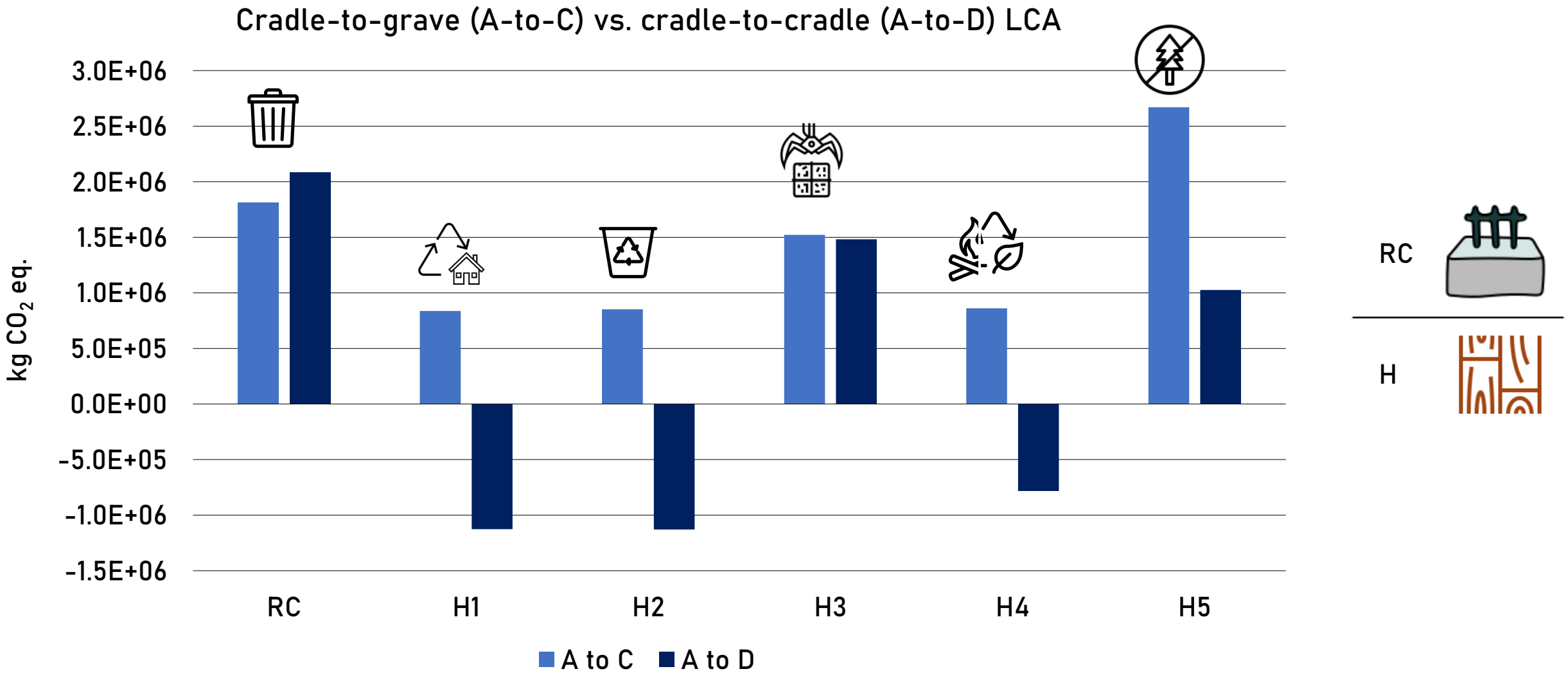
Total connection weight (ground floor) = 1.48 tonn

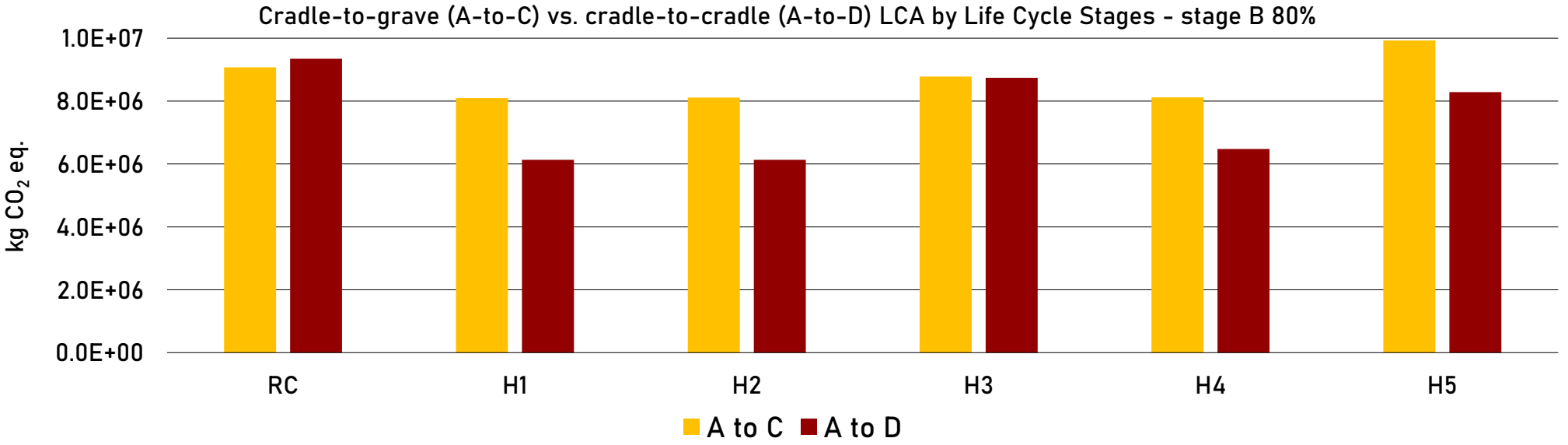
Contribution to total weight < 0,1 %

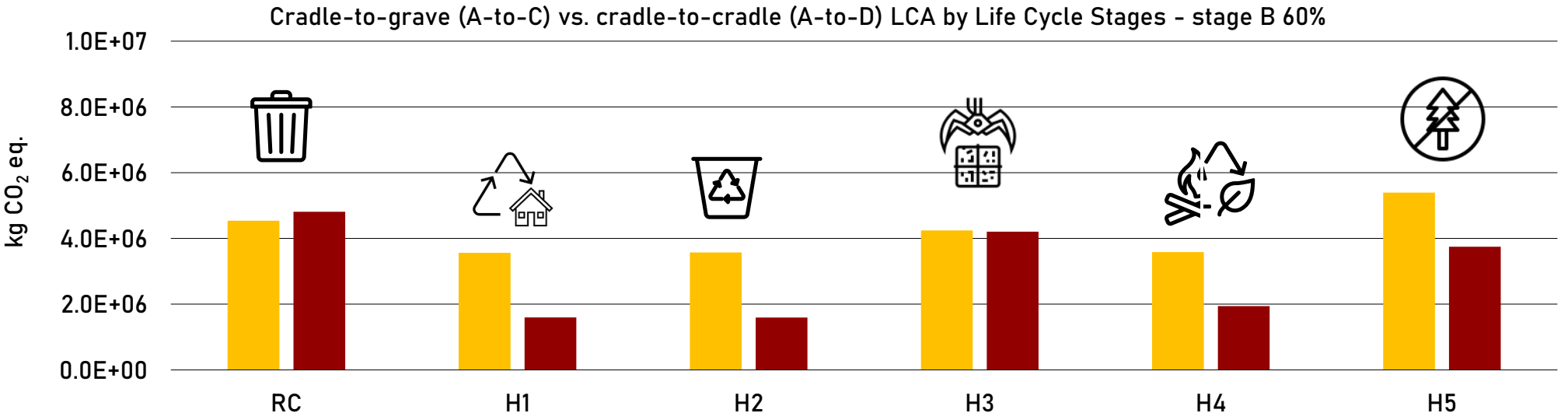
Comparison in terms of material volumes






Cradle-to-grave (A-to-C) vs. cradle-to-cradle (A-to-D) LCA
kg CO_2 eq.
3.0E+06
2.5E+06
2.0E+06
1.5E+06
1.0E+06
5.0E+05
0.0E+00
-5.0E+05
-1.0E+06
-1.5E+06
RC
H1
H2
H3
H4
H5
A to C
A to D
RC
H


Cradle-to-grave (A-to-C) vs. cradle-to-cradle (A-to-D) LCA by Life Cycle Stages - stage B 80%
kg CO_2 eq.
1.0E+07
8.0E+06
6.0E+06
4.0E+06
2.0E+06
0.0E+00
RC
H1
H2
H3
H4
H5
A to C
A to D

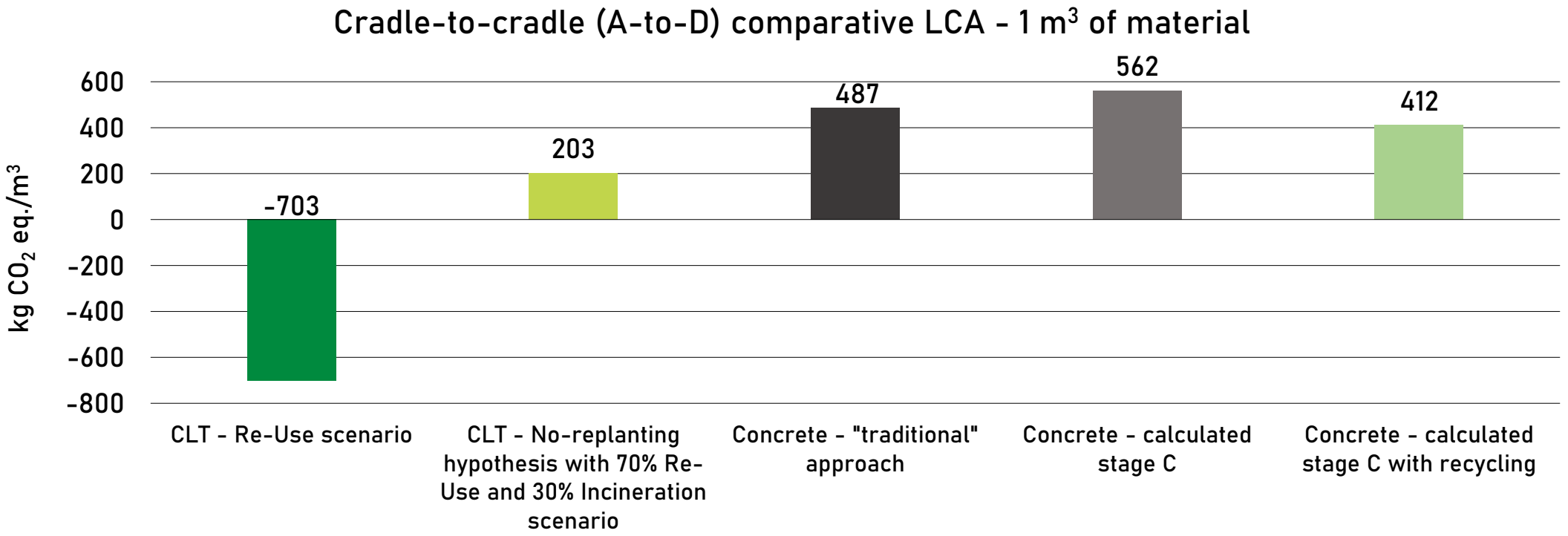

Cradle-to-grave (A-to-C) vs. cradle-to-cradle (A-to-D) LCA by Life Cycle Stages - stage B 60%
kg CO_2 eq.
1.0E+07
8.0E+06
6.0E+06
4.0E+06
2.0E+06
0.0E+00
RC
H1
H2
H3
H4
H5

RC

H

- Accurate design of building energy efficiency is crucial, given the great influence of phase B: if the burden of this step decreases, a strong effect on the whole LCA is acknowledged.
- Timber capability to bring down the building CO_2 emissions lies in a well-thought management of phase D (apart from a correct wood management), where the building is considered in a cradle-to-cradle perspective. Sustainability is achieved only if the building is thought as a microscopic part of a macroscopic system.
- Considering future developments, a life cycle cost (LCC) assessment is foreseen, in order to properly identify cost discrepancies and understand in which phases costs can be cut. From a double perspective of costs and sustainability, the hybrid proposed solution with RC walls is a viable alternative.

- Without respecting rules concerning wood management, it is not possible to take advantage of the negative CO_2 emissions. In case CLT panels are not reused or recycled, the choice of a hybrid frame may result not suitable.
- On the other hand, considering a recycling perspective for concrete, RC solutions may still play a big role



Politecnico di Milano, Building 1 – Rectorate
Photo taken by Laura Corti in spring 2022

Thank you for your attention

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Andrea Arzoni *is acknowledged for his contribution to the structural design*

ARUP *is warmly thanked for providing the initial RC case*