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Building Design for Safety and Sustainability

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Roundtable debate:

Citizens at the Heart of the Sustainably-built Envronment

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TOPICS

1. Introduction

2. Performance Based Assessment

3. Life Cycle Assessment (LCA)

4. Conclusions

Building Design for Safety and Sustainability

- Building construction and operation cause huge impacts on the environment.
- EU policies aim at addressing sustainability in the building sector.
- Many (too many?) methods exist to measure the impact of buildings on the environment.
- LCA is applied as a (final) check at the design process.

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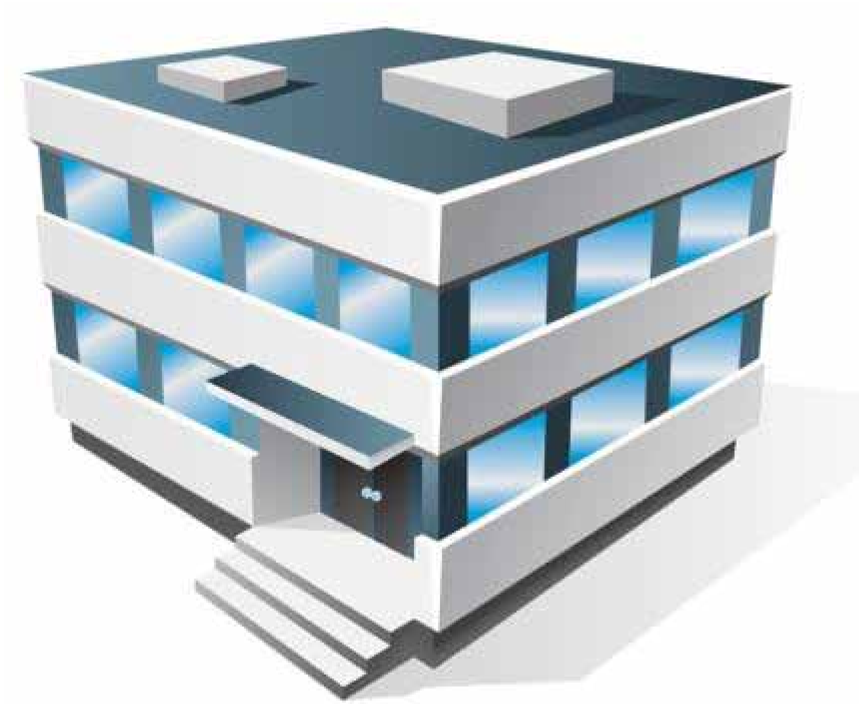

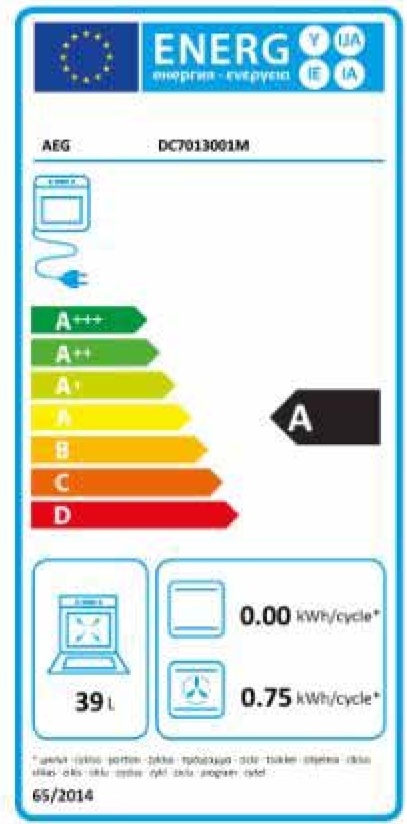

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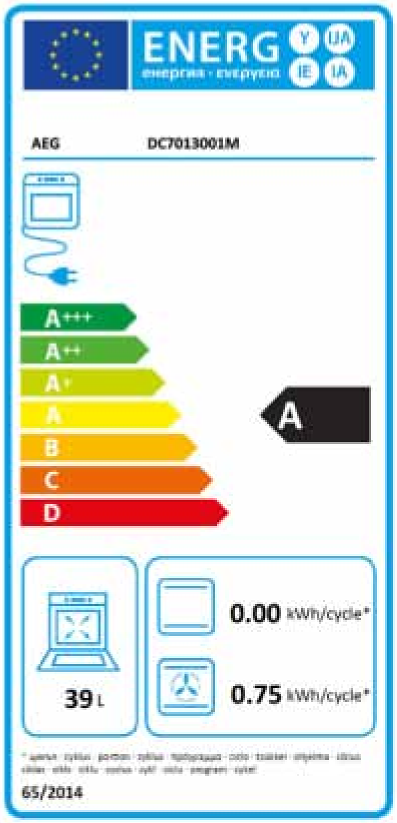
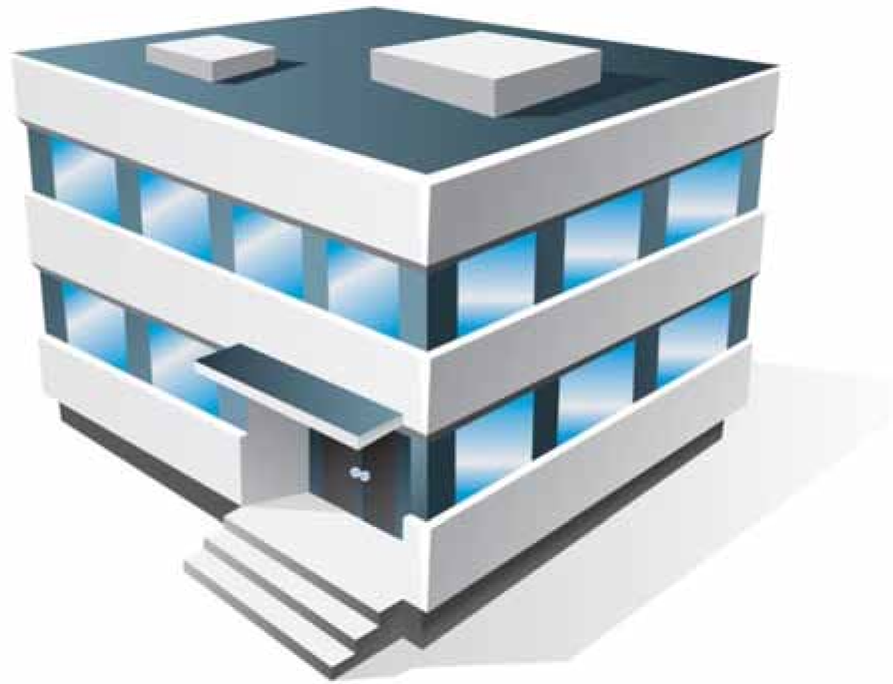




Product or Process?

2. Performance Based Design

- The most advanced (comprehensive) approach in building design.
- Originated within the Earthquake Engineering community (PEER approach).
- Based on the definition of the lifetime of the building.
- Design is treated in a probabilistic manner, with objectives that represent the cost of construction, but also the cost of expected repair measures and downtime losses.
- The construction and operation costs are summed to the expected total loss and downtime cost. The decision is made in terms of costs.

2. Performance Based Design

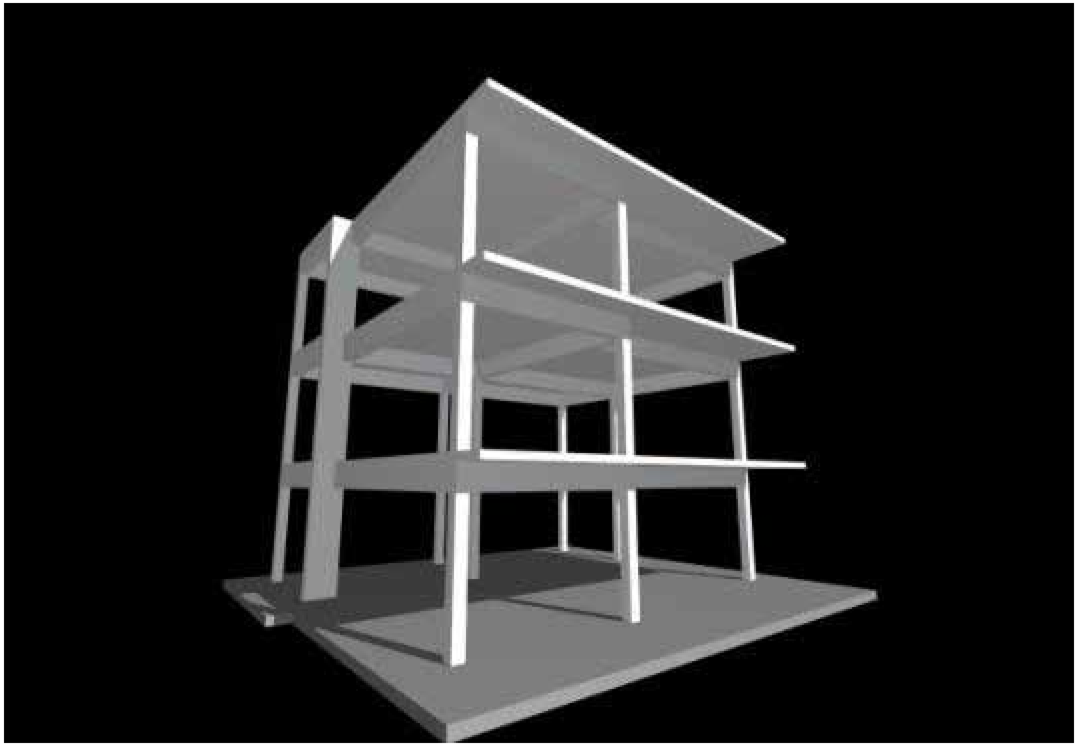
- From a fully probabilistic formulation (PEER):

$$G(DV) = \iiint_0^\infty G(DV|DM) \left|\frac{dG(DM|EDP)}{dDM}\right| \left|\frac{dG(EDP|IM)}{dEDP}\right| dIM\ d$$

$$\lambda(DV) = \iiint_0^\infty G(DV|DM)\ |dG(DM|EDP)|\ |dG(EDP|IM)|\ |d\lambda$$

- to a simplified method based on limit-states

The SPEAR Structure



- Simplification of an actual Greek 3-storey building
- Designed for gravity loads alone
- Designed using the Greek design code applied from 1954 to 1995
- Doubly non symmetric plan configuration, regular in elevation
- 2-bay frames spanning from 3 to 6 m

The SPEAR Structure

FRP retrofitted structure: lessons learnt

- The structure survived a 50% larger earthquake without visible damage
- The dynamic properties were practically not affected by the intervention (as intended)
- Global ductility was much enhanced

RC jacketed structure: lessons learnt

- The attempt to relocate the centre of strength was effective in reducing the torsional response
- The location of the centre of strength does affect the behaviour
- Even if demands were reduced, the structure failed due to lack of global ductility

Performance-based assessment exercise

Limit states and damage costs

- Low-damage, i.e., damage to the glass façade and partitions. Estimated as 36,000 EUR.
- Heavy damage, i.e. loss of the façade, associated cost was 180,000 EUR.
- Severe structural damage and collapse. Demolition-reconstruction cost, 570,000 EUR. Day-off costs was computed on the basis of a 16 months period as 90,000 EUR, summing up to 660,000 EUR.

Performance-based assessment exercise

Evaluation of costs of intervention

The costs associated to each rehabilitation measures were evaluated with reference to the real building and occupancy

- FRP-wrapping 70,000 EUR for the placement of the laminates, 6,000 EUR for dismounting, remounting and painting, 32,000 EUR for day-off costs, for a total of about 108,000 EUR
- R/C-jacketing will take place with no disruption, or with limited disruption of the office activity. The very cost of the intervention is 10,000 EUR. The day-off cost was estimated by assuming that the activity in the building would not be discontinued but affected anyway. The total day-off cost is then 30,000, summing up to a total cost of 40,000 EUR

Performance-based assessment exercise

Evaluation of total expected loss: conclusions

	Original Structure	FRP-Wrapped	RC-Jacketed
Total Loss (EUR)	40,263	9,990	34,211
Investment (EUR)	0	107,500	39,500

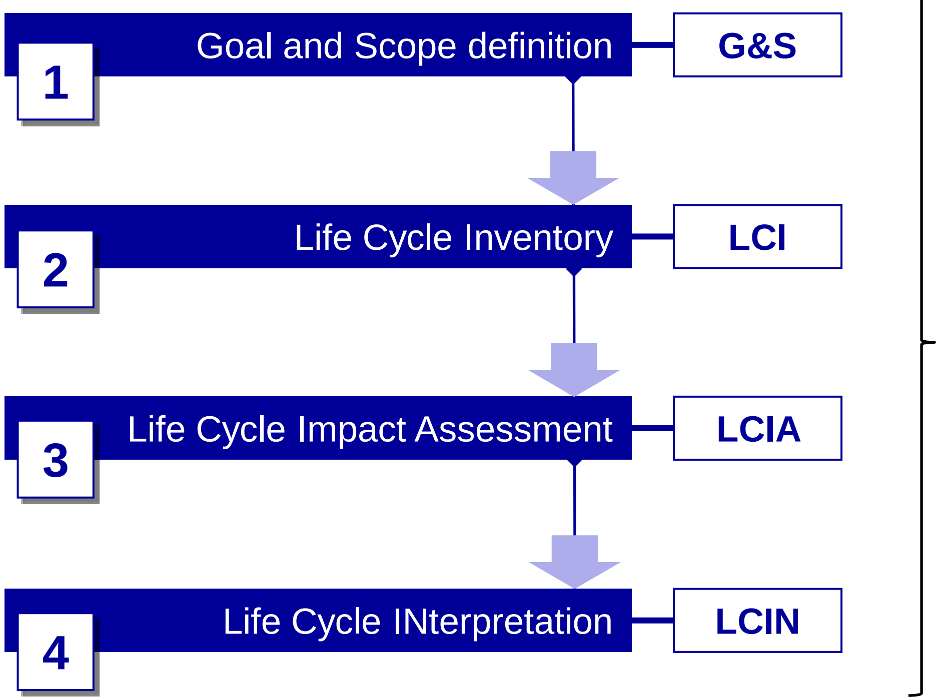
- In terms of reduction of total expected loss, the FRP-wrapped solution turns out to be by far the most effective (the total expected loss is reduced by 25%)
- The advantage in terms of reduction of the deformability due to torsional response which was offered by the RC-jacketed structure is not reflected in the corresponding total expected loss (a mere 15% reduction)

2. Performance-based assessment

- The method identifies the optimal design solution among different options.
- It is expressed in terms of costs, therefore stakeholders can define the design objectives.
- It has been developed for seismic actions, but it can be used for any other actions including fire, as well as to account for maintenance of the building, expected refurbishing, transformations and changes in use …..

3. Life Cycle Assessment (LCA)

3.1 Conceptual basis of Life Cycle Assessment (LCA)



4 major stages of the LCA (ISO 14040)

3. LIFE CYCLE ASSESSMENT (LCA)

3.2 STAGE 1: GOALS AND SCOPE DEFINITION

Evaluation of CO_2 emissions in the atmosphere, crucial to global warming relevant to two different structural prototypes :

Structure A

Structure B

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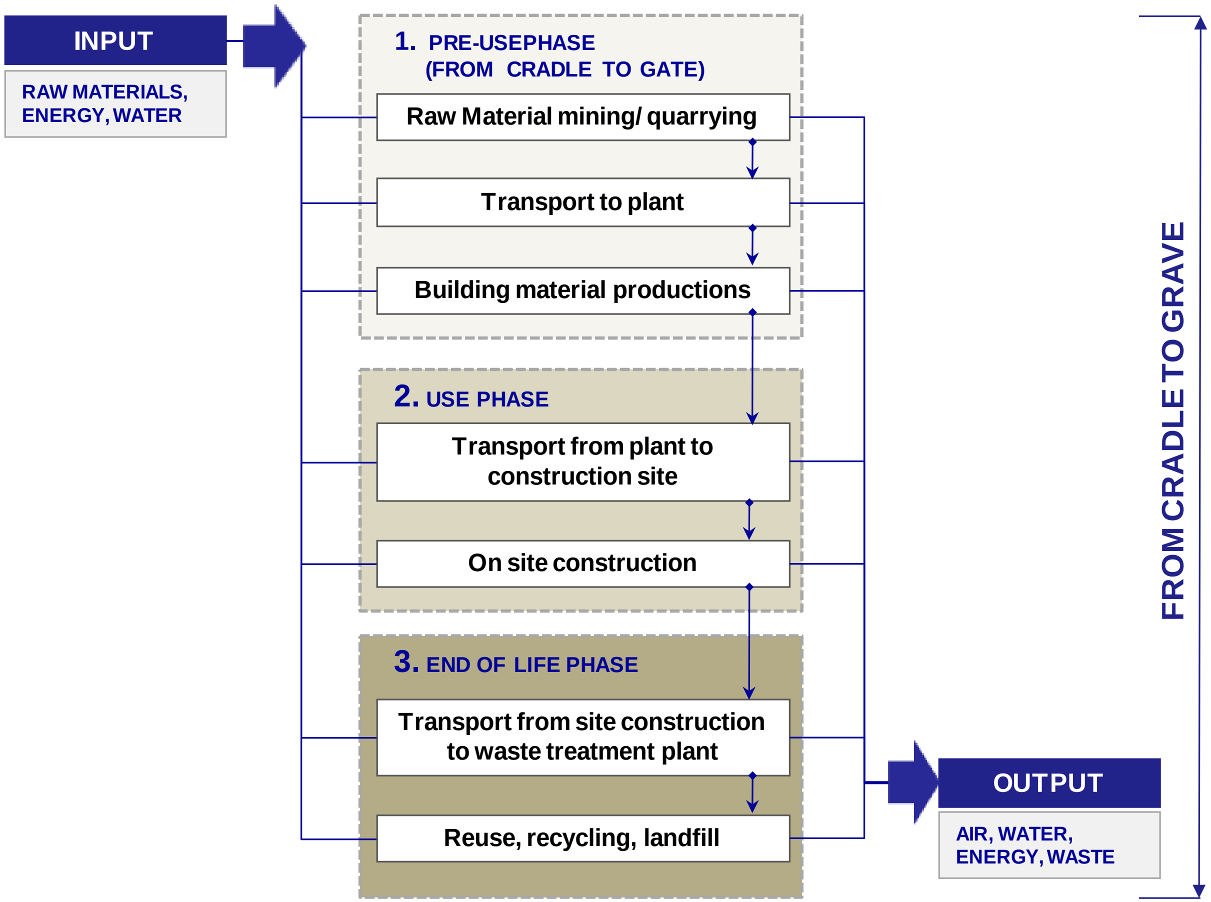
3. Life Cycle Assessment (LCA)

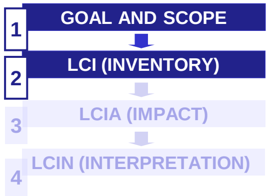
3.2 Stage 1: system boundary



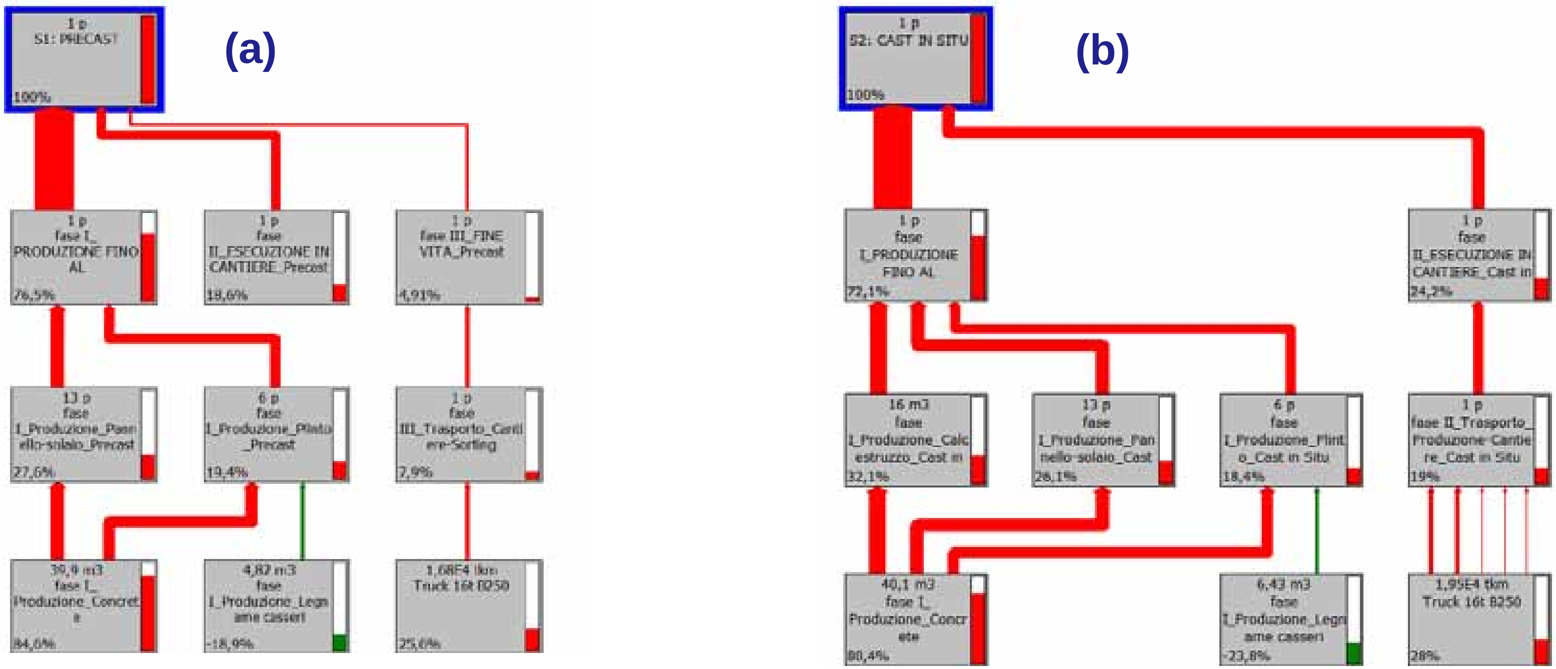
Location of the building under study

3. LIFE CYCLE ASSESSMENT (LCA)

3.3 STAGE 2: LIFE CYCLE INVENTORY (LCI)



The inventory data includes all the processes necessary to production and operational phases of the two structures



SimaPro output: processes network of **Structure A** and **Structure B**

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3. Life Cycle Assessment (LCA)

3.4 Stage 3: Life Cycle Impact Assessment (LCIA)

1 GOAL AND SCOPE
2 LCI (INVENTORY)
3 LCIA (IMPACT)
4 LCIN (INTERPRETATION)

IMPACT

CAUSE
Antrhopic activities:
emission or resource consuption

EFFECT
Environment:
complex system of natural and human resources

IPCC 2007 GWP 500a method

- Developed by the Intergovernmental Panel on Climate Change (IPCC)
- System of equivalence factors to weigh the various substances as a function of their efficiency as greenhouse gases

Chemical compound	Formula	Conversion factor	
		100 years	500 years
Fossil carbon dioxide	CO_2	1	1
Carbon monoxide	CO	2	2
Nitrous Oxide	N_2O	320	180
Methane	CH_4	25	8
Non-methane volatile organic	NM-COV	25	8

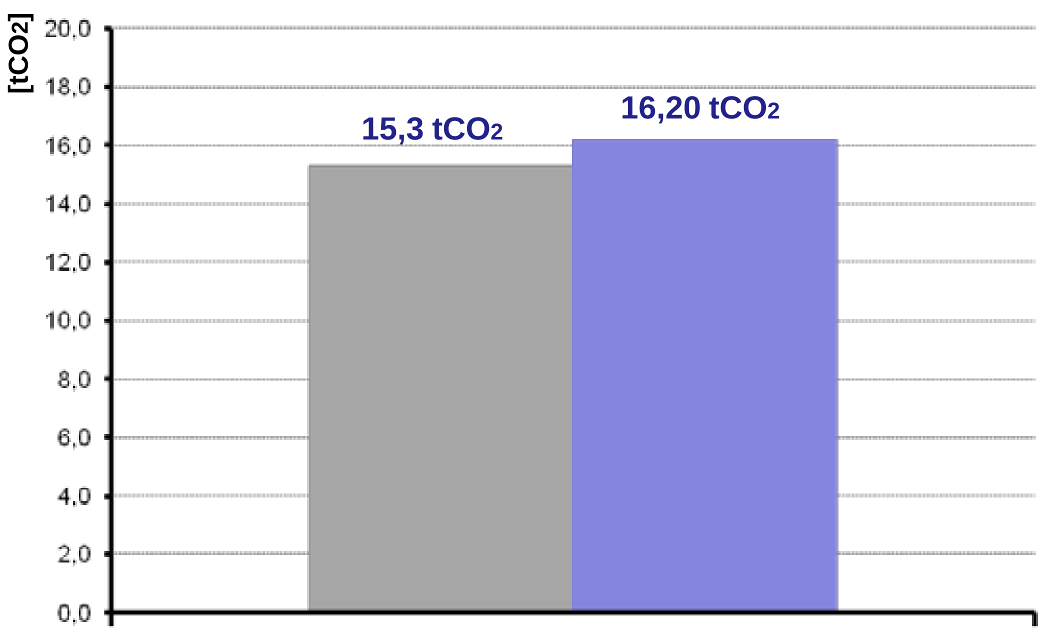
Characterization factors for greenhouse gases. GWP Potential

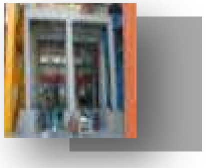
3. Life Cycle Assessment (LCA)

3.4 Stage 3: Life Cycle Impact Assessment (LCIA)

1 GOAL AND SCOPE
2 LCI (INVENTORY)
3 LCIA (IMPACT)
4 LCIN (INTERPRETATION)

Impact assessment using the IPCC 2007 GWP 500a method: Total equivalent CO_2 emissions




Structure A


Structure B

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3. Life Cycle Assessment (LCA)

3.5 Stage 4: Life Cycle Interpretation (LCIN)

- Environmental results are not compatible with cost analysis (expressed in Euro) for the two configurations

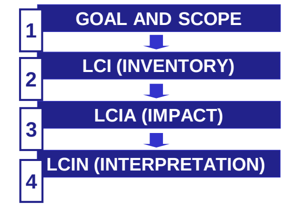
- EU ETS scheme allows a regulated operator to use (and to negotiate) carbon credits in the form of European Emission Allowances (EUA) to comply with its obligations

- Starting from LCA results and considering the cost of one ton CO_2, we can combine both values in terms of Euro

1 ton CO_2 @9 €	CO_2 emission [tons]	CO_2 cost [€]
Structure A	15,30	137,70
Structure B	16,20	145,80

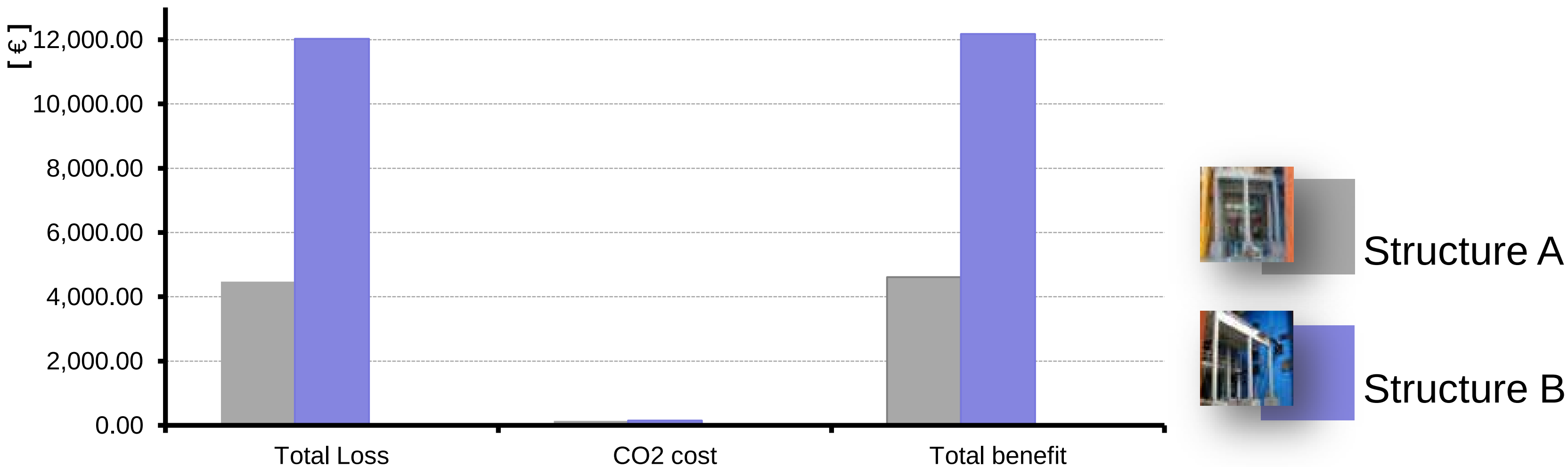
3. Life Cycle Assessment (LCA)

3.5 Stage 4: Life Cycle Interpretation (LCIN)



- The global result was carried out summing the economic costs (Total loss) and ecological results (CO_2 costs)

	Structure A [€]	Structure B [€]	Cost benefit [%]
Total Loss	4.469,74	12.032,41	62,85
CO_2 cost	137,70	145,80	5,56
Total benefit	**4.607,44**	**12.178,21**	**62,17**



4. CONCLUSIONS

- A combined approach, able to include both monetary terms (costs and associated expected losses) and environmental effects was presented

- The method is simple enough to be used in design

- The method is based on the conversion of equivalent CO_2 emissions into costs.

- The unit cost of equivalent CO_2 was derived from European Emission Allowances. To adequately account for environmental effects, the actual cost should be fixed as a result of policy measures.

4. CONCLUSIONS, CONT'D

- Applications have been shown for seismic design. The method can cover other actions, fire, maintenance and transformations.
- Being based on costs, the method could be easily extended to include other components (use of energy from different sources, scarcity of resources).
- The other dimensions of LCA (Environmental, Social) could in principle be also included, if the corresponding effects are converted into costs by targeted policy measures.

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THANK YOU FOR YOUR ATTENTION

- **Building Design for Safety and Sustainability**
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