UNIVERSIDADE D COIMBRA
FACULDADE DE CIÊNCIAS E TECNOLOGIA

isise
Institute for Sustainability and Innovation in Structural Engineering

The role of resource efficiency towards circular economy

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BAMB BUILDING AS MATERIAL BANKS
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642384.

Introduction

- Development of a **performance based approach for sustainable design**, enabling to assess the resource efficiency of buildings, throughout the complete life cycle;
- To support **European policies related to the efficient use of resources** in construction;
- To foster the **harmonization between structural design and sustainability design** of buildings, in order to enable an easier integration of structural and sustainability criteria in the design process, thus coping with the basic requirements for construction works of the **Construction Products Regulation**.

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EU policies

- Roadmap to a **Resource Efficient Europe** (COM(2011) 571 final)
- Resource efficiency opportunities in the building sector (COM(2014) 445 final)
- Towards a circular economy: A zero **waste programme** for Europe (COM(2014) 398 final)
- Closing the loop – An EU action plan for the **Circular Economy** (COM(2015) 614 final)

Life cycle thinking

Standardized criteria and methodologies for impact assessment

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Methodology

- **Performance-based approach for sustainable design**: a structure shall be designed in such a way that it will with appropriate degrees of reliability, in an economical way and with **low environmental impacts**, attain the required performance.

✓ **Reduce use of natural resources**

✓ **Reduce consumption of energy**

✓ **Reduce production of waste**

→ **Resource efficiency**

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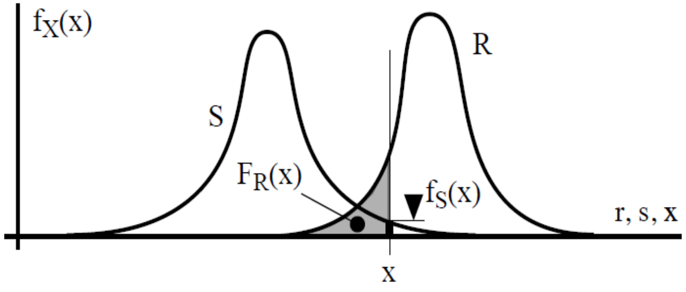
Harmonization between structural and sustainable design

Structural design

The safety condition: R ≥ S

Limit state function: G = R - S

- ✓ Ultimate Limit States (ULS)
- ✓ Serviceability Limit States (SLS)



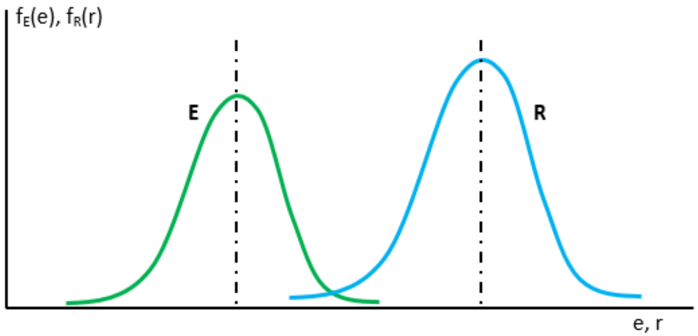
$P_f = P[G(X)] \leq 0$

Sustainable design

Condition that should be satisfied: R ≥ E

Limit state function: S = E - R

- ✓ Limit State of Sustainability



$p_{env} = P[S(X)] \leq 0$

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Methodology

1. **Adoption of a consistent model for LCA enabling comparability**

   standardized framework of CEN-TC350 for the life cycle assessment of construction works (**EN 15804** and **EN 15978**).

2. **Collection of building data**

3. **Quantification of benchmarks**

- Focus on **residential and office buildings**;
- The analysis is limited to the **structural systems of building.**

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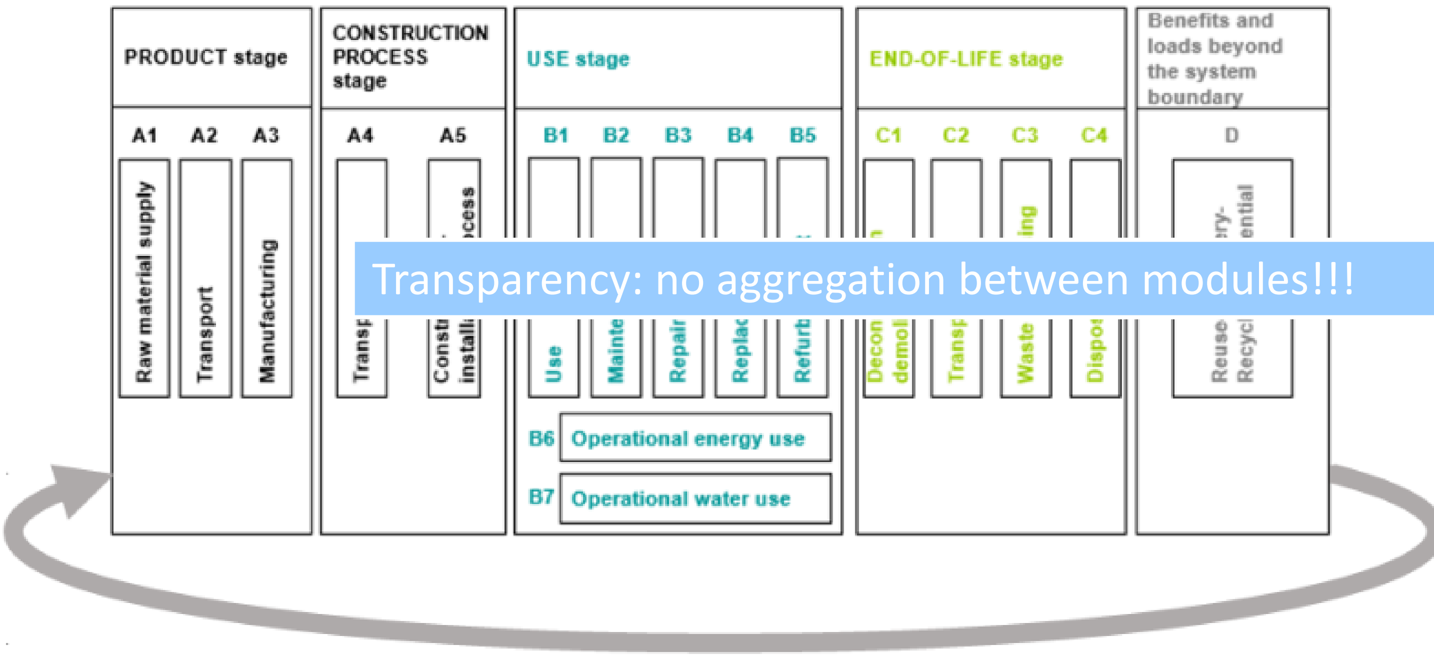
Model for LCA

CEN TC350 standards - **Sustainability of construction works**



Transparency: no aggregation between modules!!!

Product level: EN 15804:2012

Building level: EN 15978:2011

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Model for LCA

Environmental indicators

Parameters describing environmental impacts						
GWP [kg CO_2 eq.]	ODP [kg CFC eq.]	AP [kg SO_2 eq.]	EP [kg PO_4 eq.]	POCP [kg Ethen. Eq.]	APD-elements [kg Sb Eq.]	ADP-fossil fuels [MJ]

Parameters describing resource use, primary energy					
Use of renewable primary energy excluding renewable primary energy resources used as raw materials [MJ NCV]	Use of renewable energy resources used as raw materials [MJ NCV]	Total use of renewable primary energy (primary energy and primary energy resources used as raw materials) [MJ NCV]	Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials [MJ NCV]	Use of non renewable energy resources used as raw materials [MJ NCV]	Total use of non renewable primary energy (primary energy and primary energy resources used as raw materials) [MJ NCV]

Parameters describing resources use, secondary materials and fuels, and use of water			
Use of secondary material [kg]	Use of renewable secondary fuels [MJ]	Use of non renewable secondary fuels [MJ]	Use of net fresh water [m3]

Other environmental information describing waste categories			Other environmental information describing output flows			
Hazardous waste disposed [kg]	Non hazardous waste disposed [kg]	Radioactive waste disposed [kg]	Components for reuse [kg]	Materials for recycling [kg]	Materials for energy recovery [kg]	Exported energy [kg]

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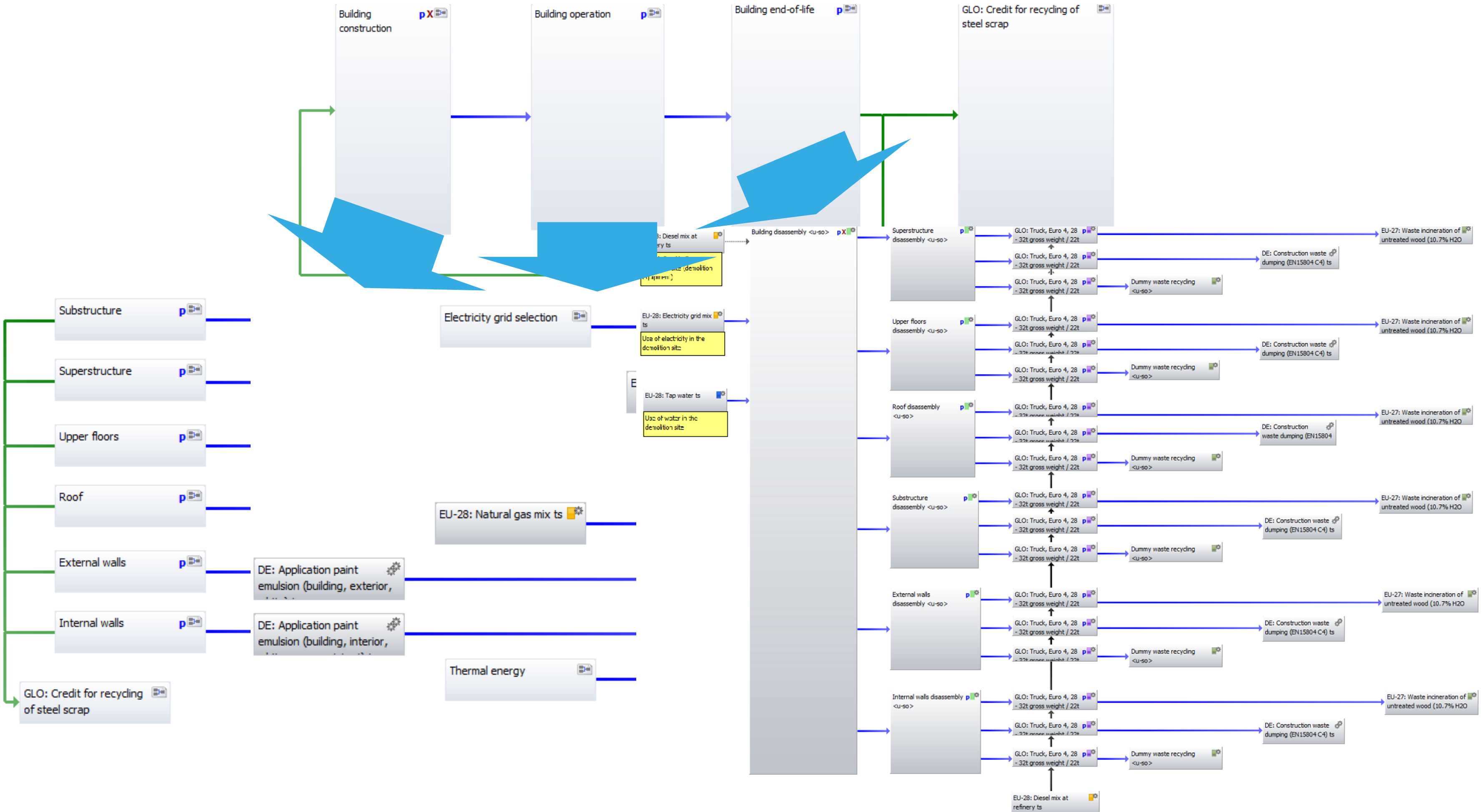
Model for LCA

Implementation in a LCA software (GaBi software)



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Model for LCA

Implementation in a LCA software (GaBi software) → Parametric model

Parameter Explorer: Building life cycle

Active scenario group: Scenario group 1 | Active scenario: Composite building

Scenarios | Parameter | Plan

DB object settings
Scenario group 1
Scenario standard
Z1_SI (IMPRO)
Z1_MF (IMPRO)
Z1_HR (IMPRO)
Z2_SI (IMPRO)
Z2_MF (IMPRO)
Z2_HR (IMPRO)
Z3_SI (IMPRO)
Z3_MF (IMPRO)
Z3_HR (IMPRO)

Basic settings (valid for all Sc...
- Z3_HR_001
- Z3_HR_001 ref
- Z3_HR_002_ex
- Z3_HR_002_ex ref
- Z3_HR_002
- Z3_HR_002 ref

< New: Scenario group >
Subset: Concrete selection in 3.1.1
Subset: Concrete selection in 3.1.2
Subset: Concrete selection in 3.1.3
Subset: Concrete selection in 4.1.1
Subset: Concrete selection in 4.1.2
Subset: Concrete selection in 4.1.3
Subset: External walls coating
Subset: External walls insulation selection
Subset: Window selection

Basic settings (valid for all Scenarios)

Alias	Object	Parameter	Value	Comment, units,
Building operat				
Area	Building oper.	Area	0	[m2] Total area
Lifespan	Building oper.	Lifespan	0	[years] Number
occupancy	Building oper.	occupancy	0	[units] Number o
Alias	*Object*			

Definition of multiple scenarios

Input parameters

Scenarios

Alias	Object	Parameter	Z3_HR_001	Z3_HR_001	Z3_HR_002	Z3_HR_002	Z3_HR_002	Z3_HR_002	Comment, units, defaults
Building materials									
1. Substructure									
1.1 Ground work									
1.1.1 Excavation to b	Substructure - 'Building life cycle'	SB11	0	0	0	0	0	0	[m3] Excavation of soil for basement
1.1.2 Gravel base	Substructure - 'Building life cycle'	SB12	0	0	0	0	0	0	[kg] Gravel bed
1.2 Piling									
1.2.1 Concrete in pilir	Substructure - 'Building life cycle'	SB21	0	0	0	0	0	0	[kg] Concrete in piling
1.2.2 Steel Reinforce	Substructure - 'Building life cycle'	SB22	0	0	0	0	0	0	[kg] Reinforcement in piling
1.3 Concrete									
1.3.1 Concrete in foo	Substructure - 'Building life cycle'	SB31	0	0	0	0	0	0	[kg] Concrete in footing beams
1.3.2 Concrete in gro	Substructure - 'Building life cycle'	SB32	0	0	0	0	0	0	[kg] Concrete in ground slab
1.3.3 Concrete in fou	Substructure - 'Building life cycle'	SB33	0	0	0	0	0	0	[kg] Concrete in foundation caps
1.3.4 Bitumen membr	Substructure - 'Building life cycle'	SB34	**1,08E003**	**540**	**1,08E003**	**540**	**1,08E003**	**1,08E003**	[kg] Bitumen membrane
1.4 Formwork									
1.4.1 Formwork to co	Substructure - 'Building life cycle'	SB41	0	0	0	0	0	0	[kg] Formwork
1.5 Steel reinforcen									
1.5.1 Bar reinforceme	Substructure - 'Building life cycle'	SB51	0	0	0	0	0	0	[kg] Reinforcement in footing beams
1.5.2 Bar reinforceme	Substructure - 'Building life cycle'	SB52	0	0	0	0	0	0	[kg] Reinforcement in ground slab
1.5.3 Bar reinforceme	Substructure - 'Building life cycle'	SB53	0	0	0	0	0	0	[kg] Reinforcement in foundation caps
2. Superstructure									
2.1 Concrete									
2.1.1 Concrete infill t	Superstructure - 'Building life cy	SS11	0	0	0	0	0	0	[kg] Concrete in tubular sections
2.1.2 Concrete in colu	Superstructure - 'Building life cy	SS12	0	0	0	0	0	0	[kg] Concrete in columns
2.2 Steel reinforcen									
2.2.1 Bar reinforceme	Superstructure - 'Building life cy	SS21	0	0	0	0	0	0	[kg] Reinforcement in tubular sections
2.2.2 Bar reinforceme	Superstructure - 'Building life cy	SS22	0	0	0	0	0	0	[kg] Reinforcement in columns
2.3 Structural steel									
2.3.1 Steel sections	Superstructure - 'Building life cy	SS31	0	0	0	0	0	0	[kg] Steel sections
2.3.2 Steel plate	Superstructure - 'Building life cy	SS32	0	0	0	0	0	0	[kg] Steel plate
2.4 Formwork									
2.4.1 Formwork to co	Superstructure - 'Building life cy	SS41	0	0	0	0	0	0	[kg] Formwork columns
2.5 Partitions									
2.5.1 Fire protection	Superstructure - 'Building life cy	SS51	0	0	0	0	0	0	[kg] Fire cladding
3. Upper foors									

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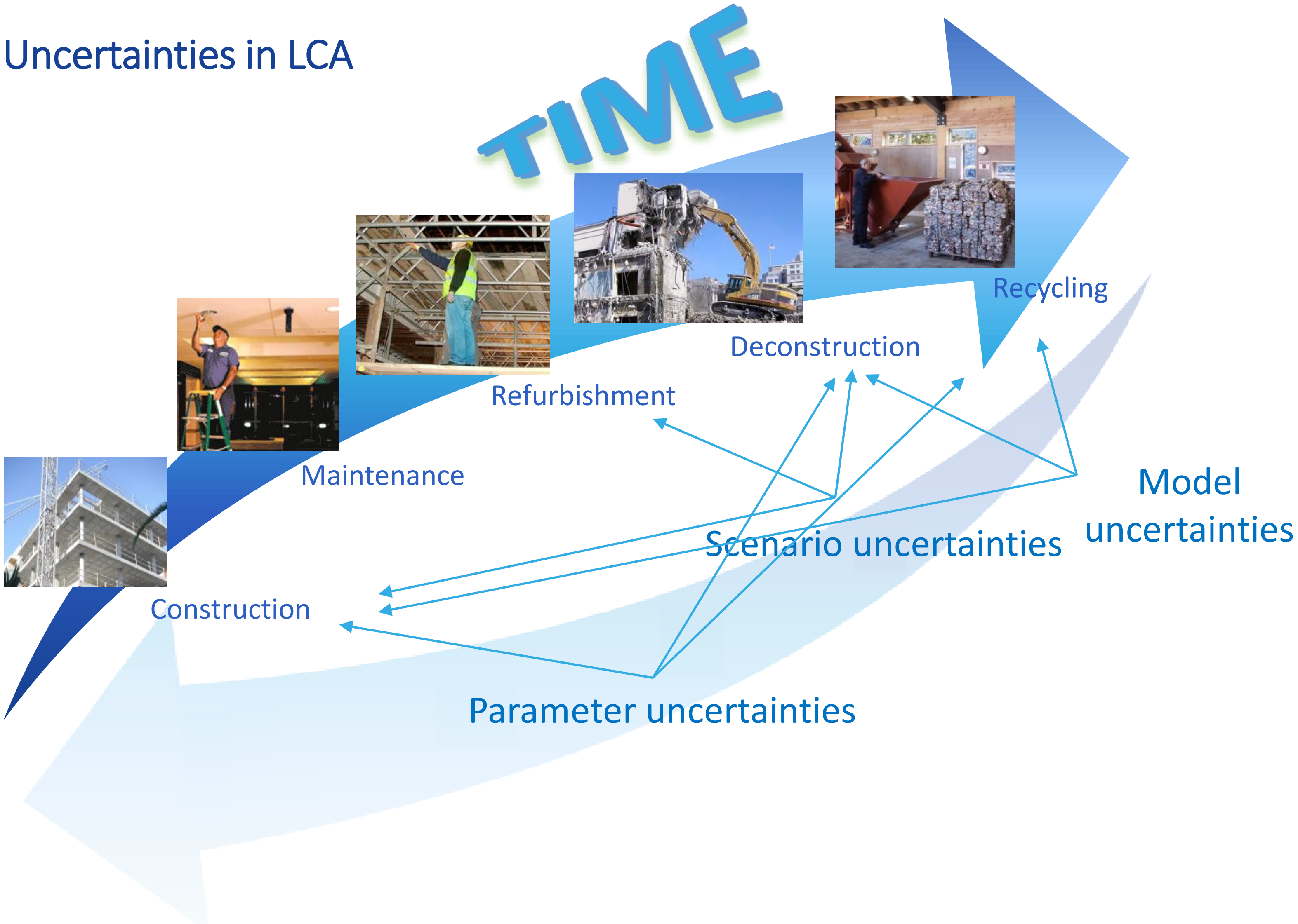
Uncertainties in LCA



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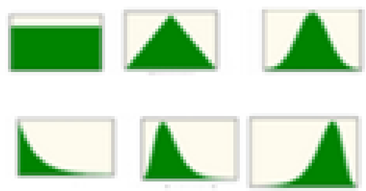
Uncertainties in LCA

Model for the LCA of buildings

Identification of probability distributions for the uncertain parameters



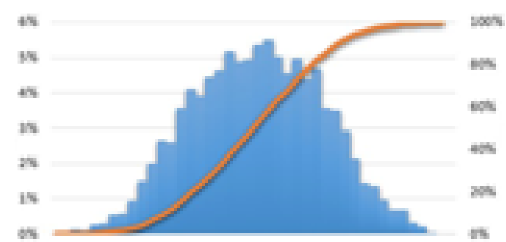
Uncertainty contribution analysis

Global sensitivity analysis

Uncertainty analysis

Generation of Monte Carlo samples for each input parameter

Generation of Monte Carlo sample of the output



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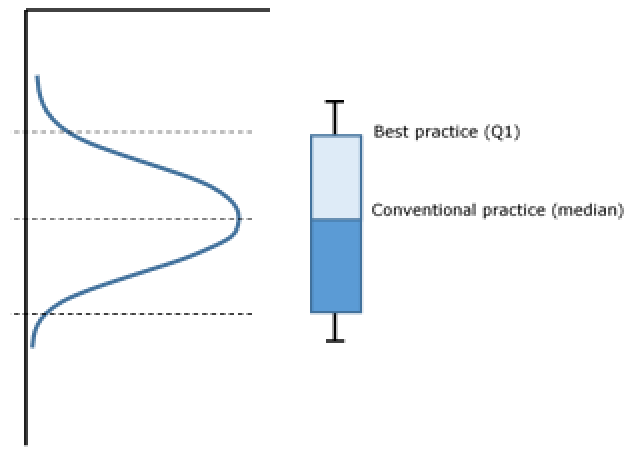
Quantification of benchmarks

Collection of building data

Statistical approach



Types of buildings

Tier 1	Tier 2	Tier 3		Tier 4
Buildings	Residential buildings	SF	Single-family houses (SF)	Reinforced concrete structure
		MF	Multi-family houses (≤ 5 stories)	Steel structure
		MR	Medium rise buildings (5 – 15 stories)	Composite structure
		HR	High rise buildings (> 15 stories)	Wood structure
	Office buildings	LR	Low rise buildings (≤ 5 stories)	Masonry structure
		MR	Medium rise buildings (5 – 15 stories)	Hybrid structure
		HR	High rise buildings (> 15 stories)	Others
		TB	Tall buildings (> 60 stories)	

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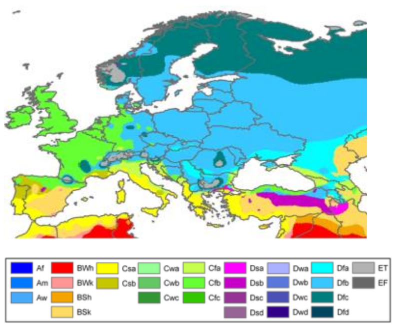
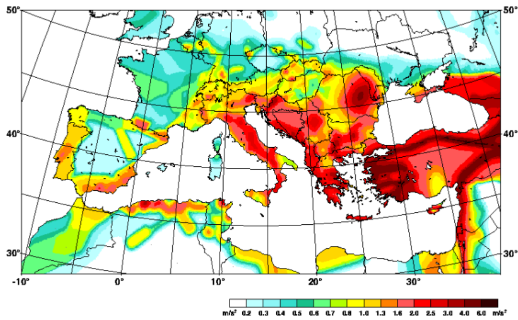
Quantification of benchmarks

Differentiation factors

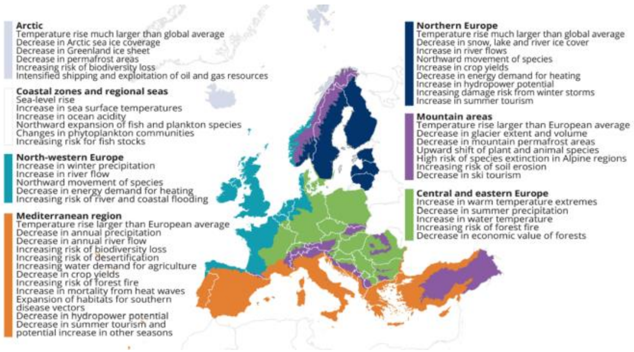
Climatic regions



Seismic regions



Other vulnerable regions (climate change effects)



National Annexes

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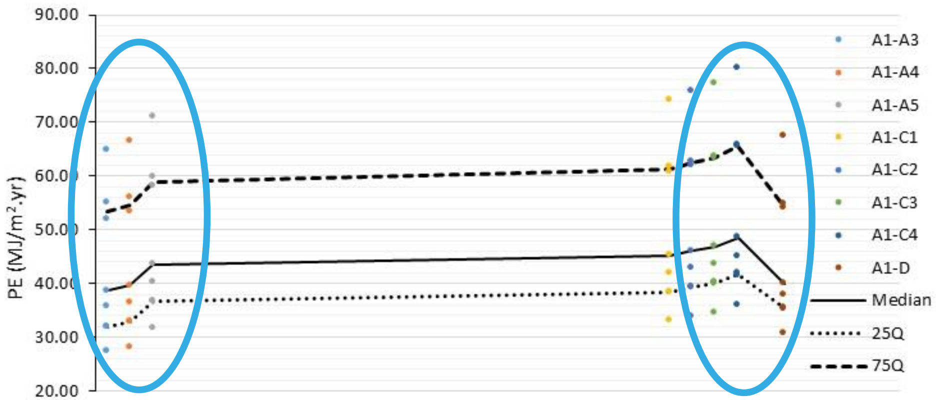
Benchmarks for residential buildings

Range of values for GWP in each module

Range of values for PE in each module



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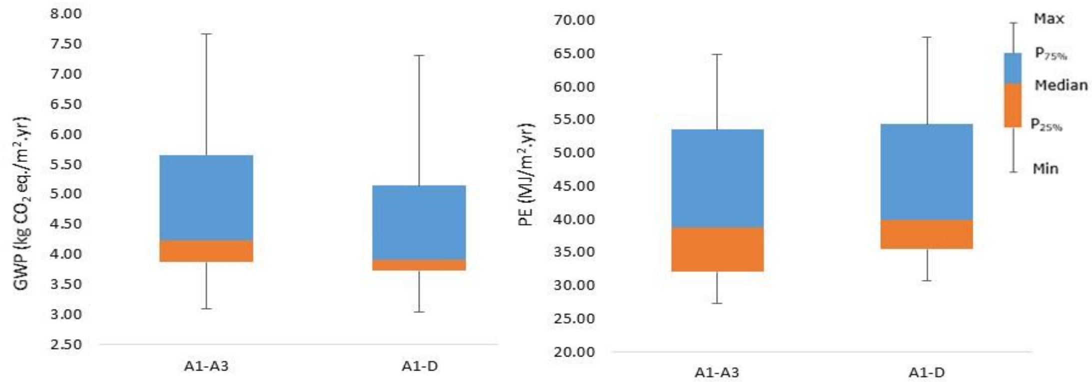
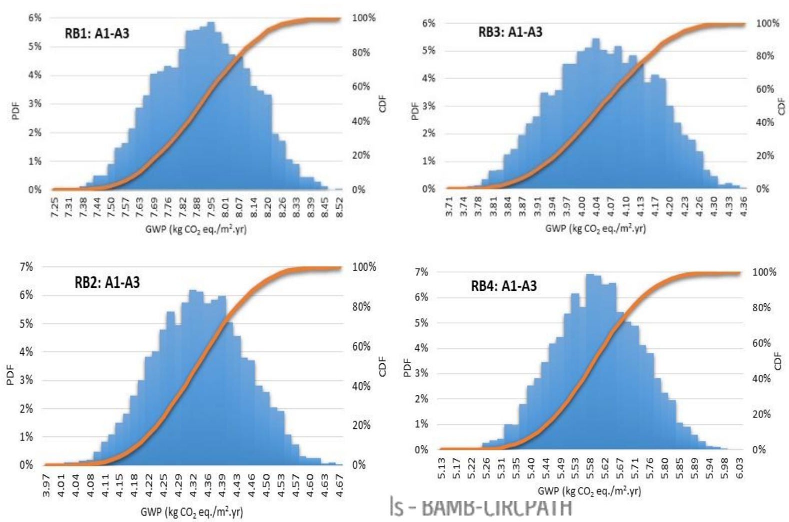
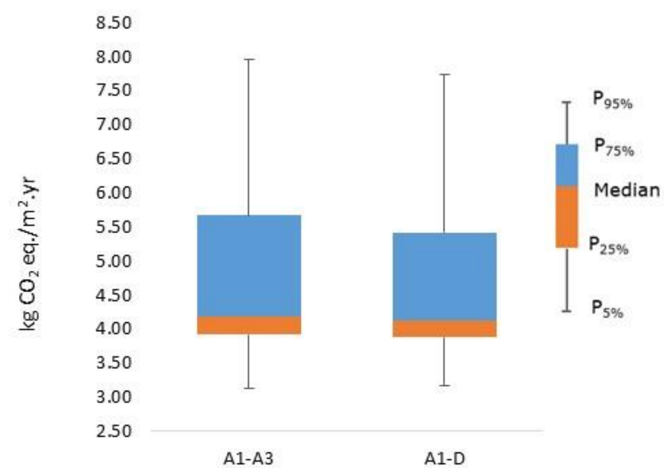
Benchmarks for residential buildings

Range of values for GWP and PE in A1-A3 & A1-D



Uncertainty propagation and distribution of GWP values





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Benchmarks for residential buildings

Preliminary set of benchmarks for residential buildings

	Single-family house		Multi-family house		High-rise building	
						
Climatic zones	existing	new	existing	new	existing	new
Zone 1: South European countries	8	3	8	3	2	1
Zone 2: Central European countries	8	3	8	3	2	1
Zone 3: North European countries	7	2	8	2	2	1
TOTAL	31		32		9	

		Median	σ	$P_{25\%}$	$P_{75\%}$
SI	GWP1	**7.22**	3.80	2.53	8.71
	GWP2	**8.94**	4.20	5.01	11.27
	PE	**139.25**	54.17	124.19	186.18

		Median	σ	$P_{25\%}$	$P_{75\%}$
MF	GWP1	**6.30**	3.76	4.88	9.94
	GWP2	**7.32**	3.89	5.37	10.75
	PE	**105.60**	48.80	84.50	159.77

		Median	σ	$P_{25\%}$	$P_{75\%}$
HR	GWP1	**5.53**	2.05	4.34	6.91
	GWP2	**6.57**	1.81	5.03	6.94
	PE	**88.89**	24.78	68.51	94.93

Source: IMPRO-Building: Environmental Improvement Potentials of Residential Buildings (IMPRO-Building), EUR 23493 EN

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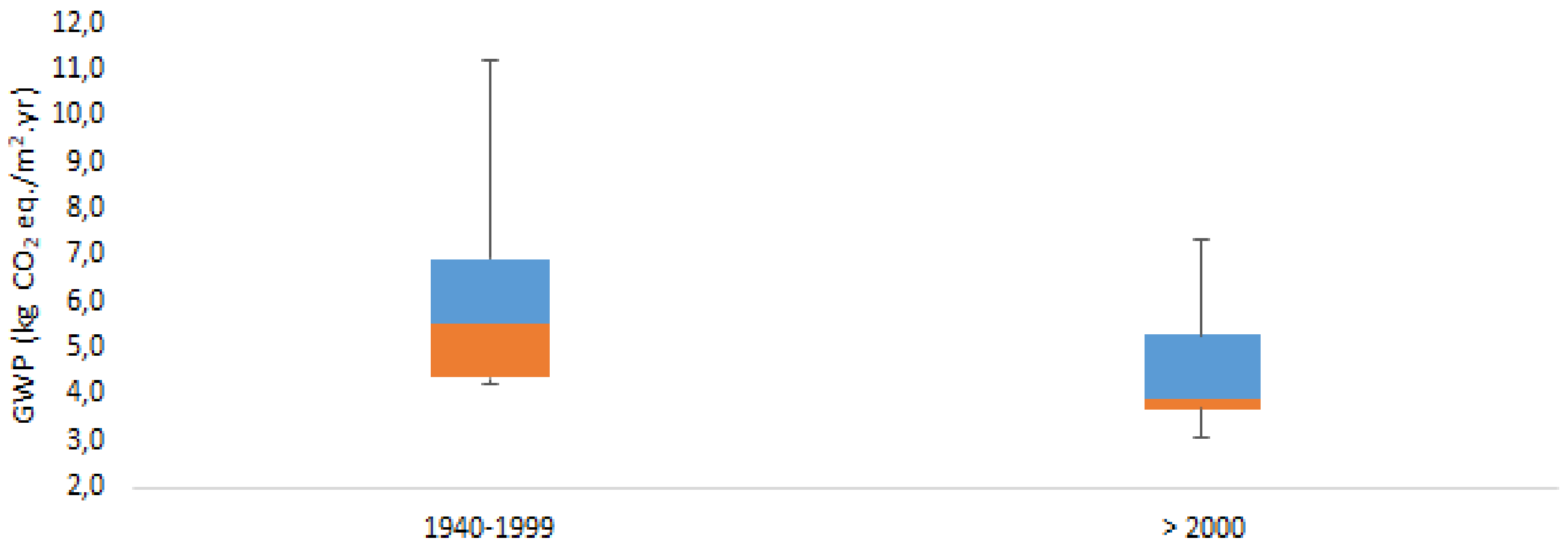
Benchmarks for residential buildings

Comparison of values (in terms of GWP) referring to building data from different periods of time



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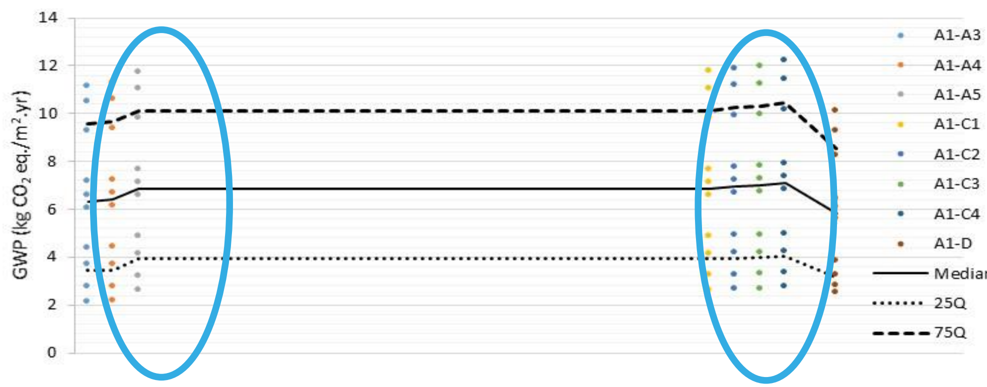
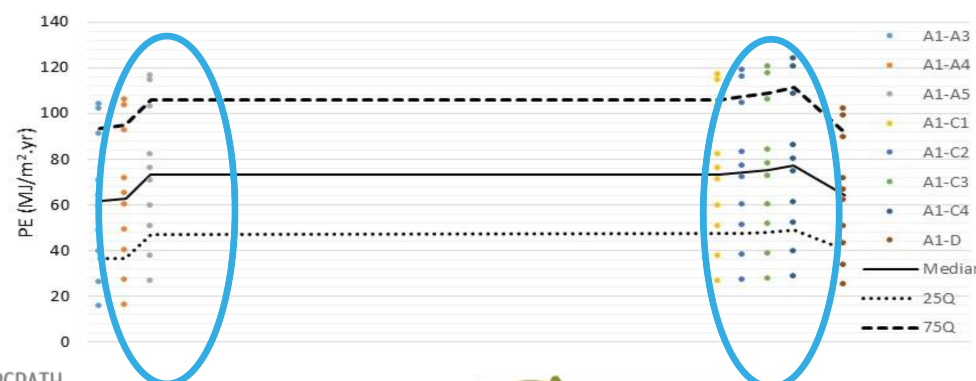
Benchmarks for office buildings

Range of values for GWP in each module



Range of values for PE in each module



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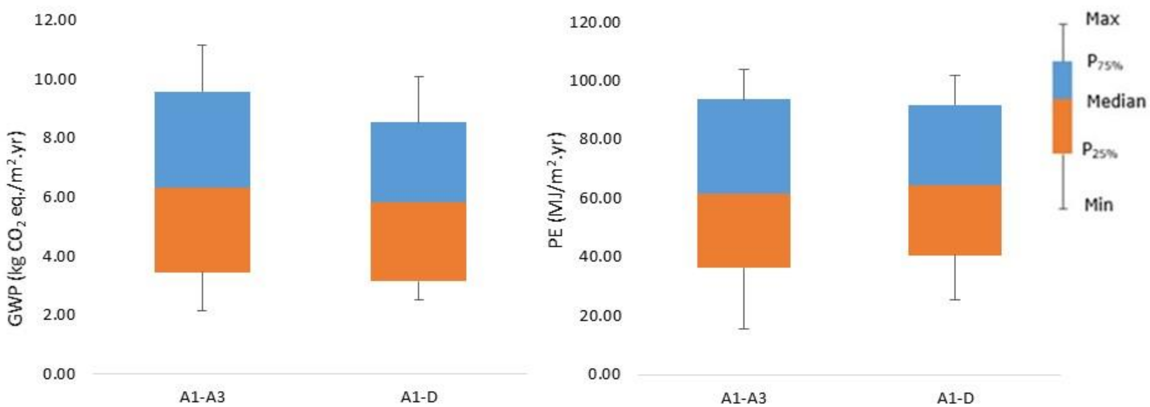
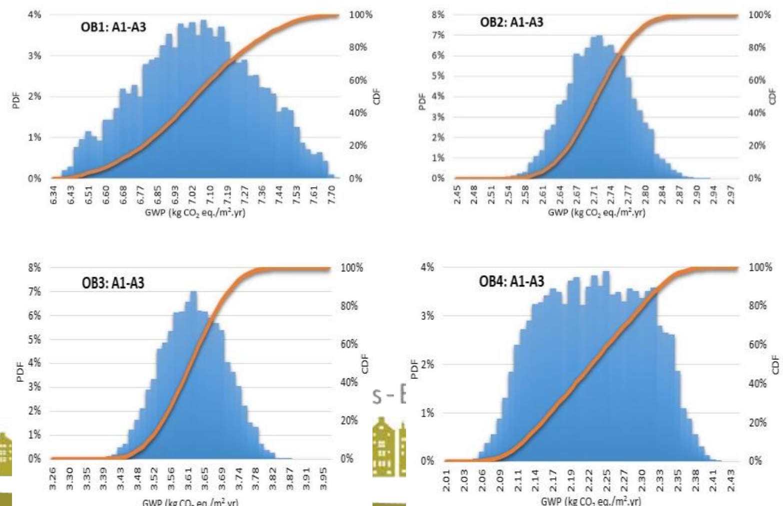
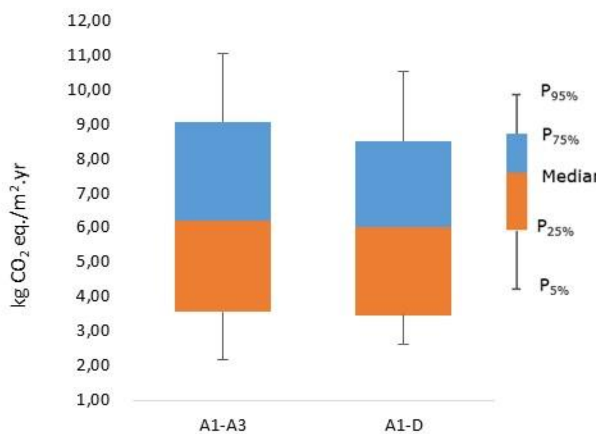
Benchmarks for office buildings

Range of values for GWP and PE in A1-A3 & A1-D



Uncertainty propagation and distribution of GWP values





Conclusions

- ✓ The proposed approach aims for the **harmonization between structural design and sustainability design of buildings**, and is based on the concept of '**limit state**', which is a concept that is familiar to architects and engineers.

- ✓ In the **limit state of sustainability** the environmental performance of the building is compared with a **benchmark**, given by the average life cycle environmental performance of a set of buildings, with the same typology, in a reference area.

- ✓ **Twofold achievement**:

  - Benchmarks enable an **easier interpretation of the performance of buildings** and the identification of **best practices**, thus motivating the pursuit of measures leading to an enhanced building performance;

  - Benchmarks provide a **transparent yardstick to measure the environmental performance of buildings** and allow to effectively reduce the potential environmental impact of the building stock.

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