Methodologies for assessing the benefit of combined renovation

REEBUILD - Integrated techniques for seismic strengthening and energy efficiency of buildings

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Final workshop, 21 March 2024

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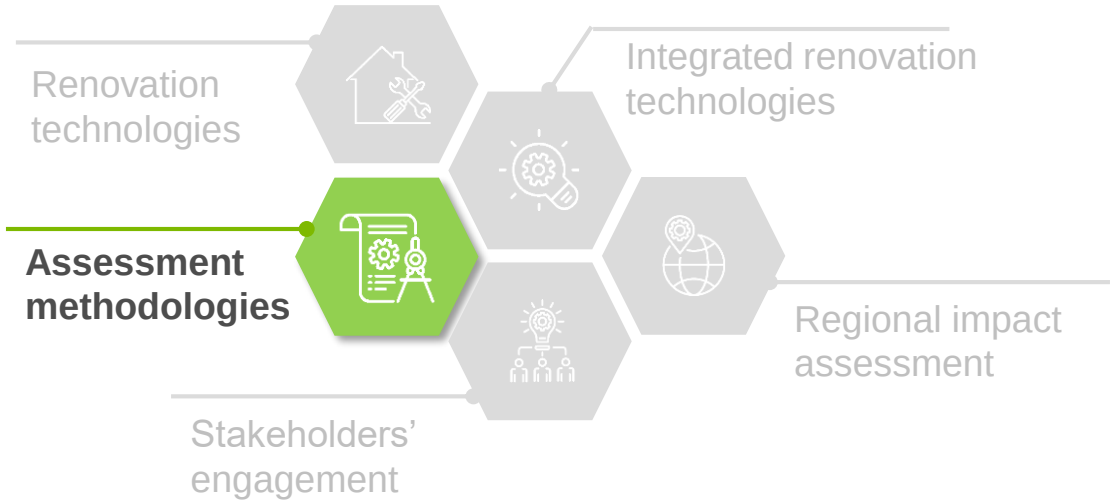

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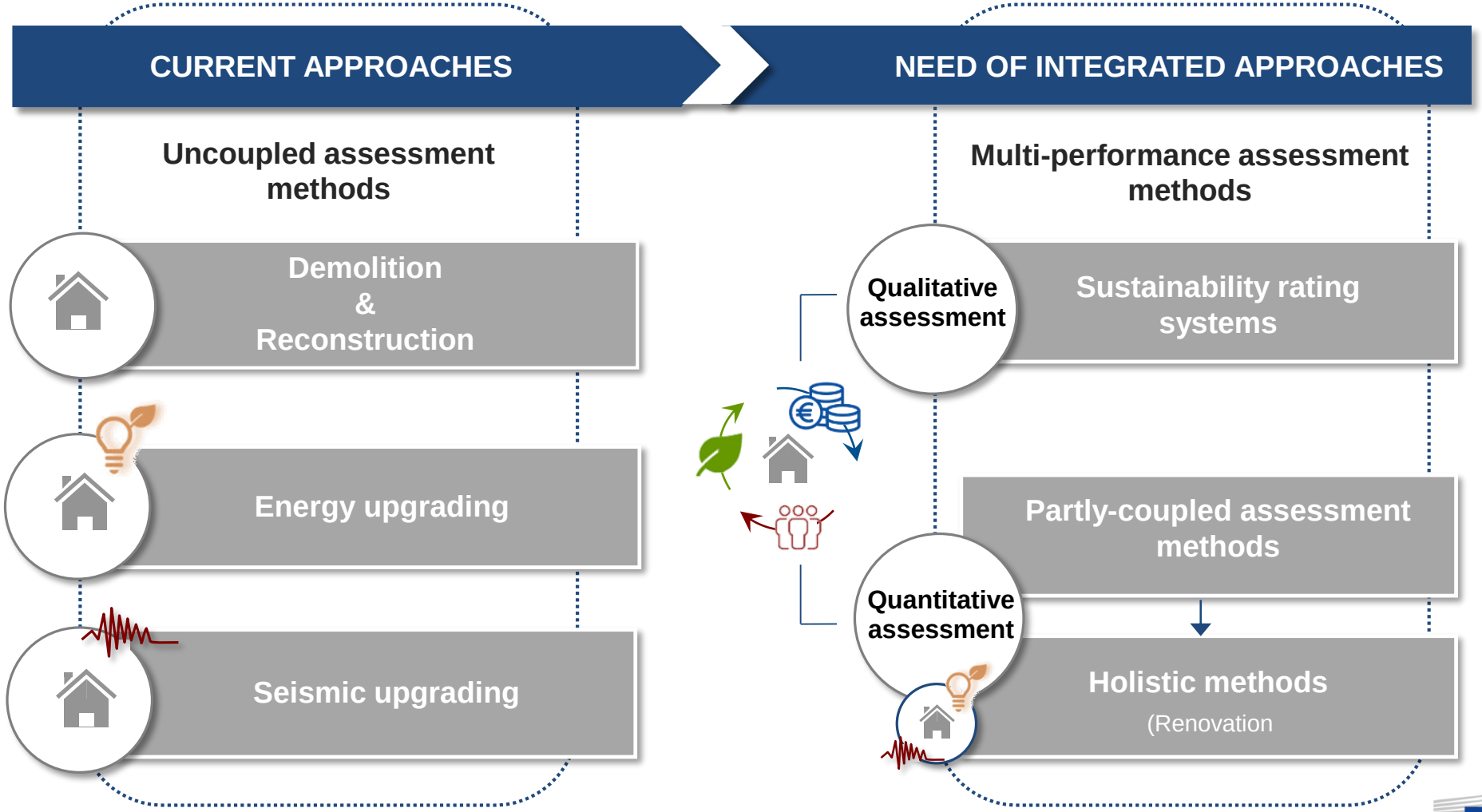
1. Review of methods for assessing the effects of combined renovation

Existing methodologies for combined retrofit



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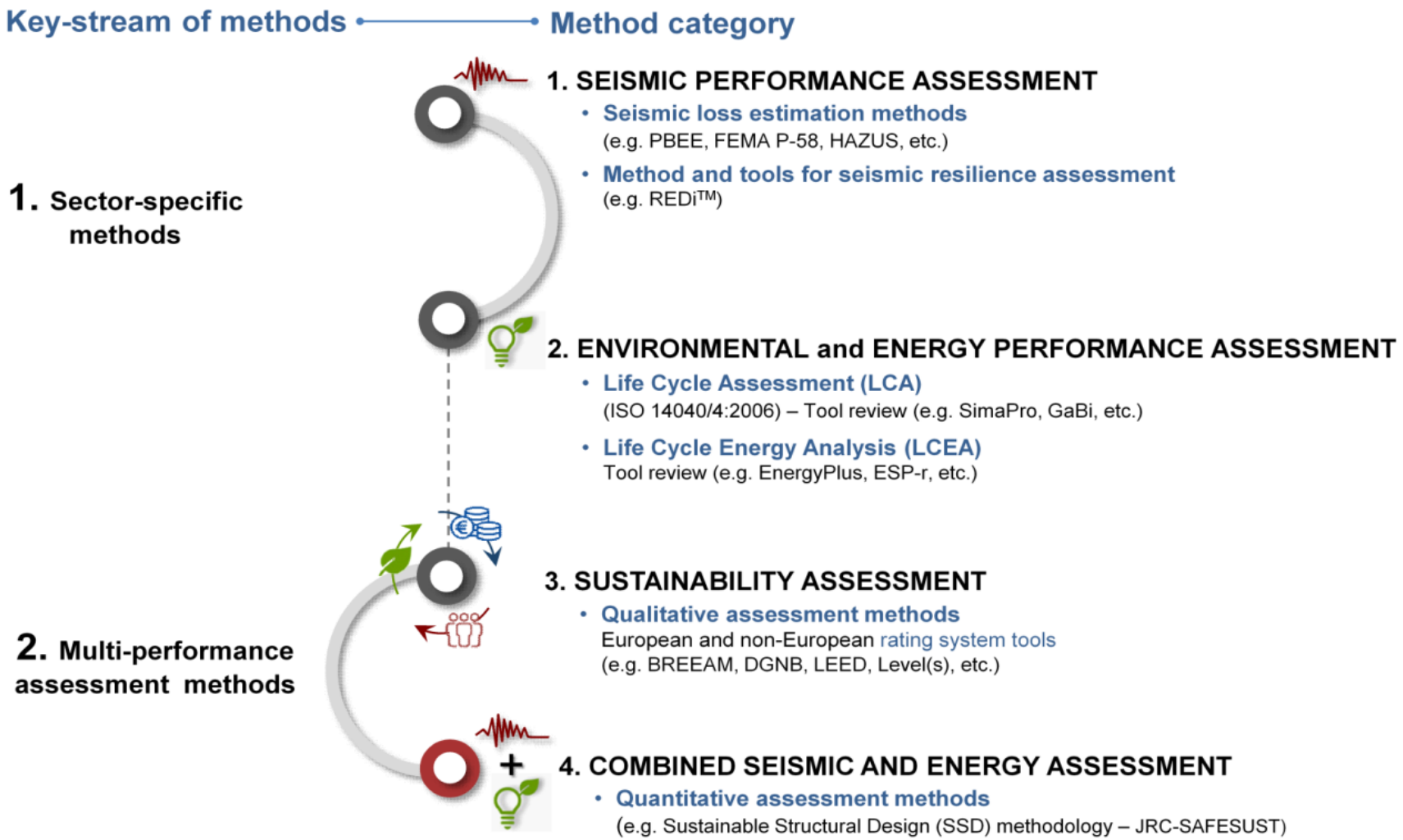
Existing methodologies for combined retrofit



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Sector-specific methods: Seismic performance assessment methods

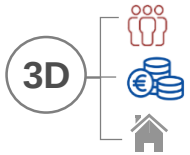
Seismic loss estimation methods and tools

Performance-based approach, PBEE approach, in which the **expected losses** (e.g. economic losses due to downtime, repair costs, life losses, etc.) become a key-parameter to quantify the seismic performance of a building during its service life.

1. Hazard analysis
2. Structural analysis
3. Damage analysis
4. Loss analysis

BUILDING LEVEL

- **Performance-based Earthquake Engineering (PBEE) – PEER methodology** (1997-2010)



Fully probabilistic method, developed by the Pacific Earthquake Engineering Research Center (PEER), consisting into the numerical integration of all conditional probabilities for determining performance assessment in terms of the so-called **3D's decision variables**, namely **Deaths** (loss of life), **Dollars** (economic losses), and **Downtime** (temporary loss of use of the facility).

- **FEMA P-58 methodology and tool** (USA 2001- 2018)

Performance-based assessment methodology and practical implementation in a dedicated tool (i.e. PACT); introduction of approaches to add indirect losses as probable environmental impacts due to repair for seismic-induced damages.

- **'Sisma-bonus' mechanism**

Italian guidelines for the seismic risk assessment of constructions based on the calculation of the **expected annual losses** (Ministerial Decree 28/02/2017, Ministerial Decree 09/01/2020) – Tax deductions for seismic strengthening interventions on private buildings.

REGIONAL LEVEL

- **HAzard US (HAZUS) Loss Estimation methodology and tool**

Geographic information system-based (GIS) natural hazard analysis and its dedicated tool (HAZUS), developed by FEMA, for estimating physical, economic and social losses from natural hazards to develop plans and strategies for natural hazards risk reduction and prepare for emergency response and recovery

Seismic resilience assessment methods and tools

Methods to assess the **post-disaster functionality** beyond the loss assessment through a recovery function

Methods based on recovery states - Resilience-rating systems

- **REDi™ - Resilience-based Earthquake Design Initiative**,

Holistic beyond-code design method, developed by ARUP (mandatory criteria referring to downtime, direct financial losses and occupant safety)

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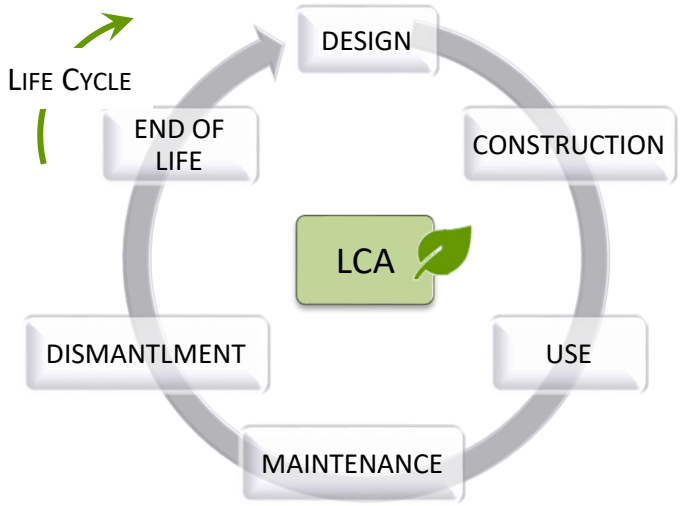
Sector-specific methods: Environmental and energy performance assessment methods

LIFE CYCLE ASSESSMENT (LCA)



ISO 14040-44:2006 (revision 2020)

Process to **quantitatively assess the environmental burdens** of a product, process or activity during the life cycle

Four-step framework

1. **G**oal and **S**cope definition (**G&S**)
2. **L**ife **C**ycle **I**nventory (**LCI**)
3. **L**ife **C**ycle **I**mpact **A**ssessment (**LCIA**)
4. **L**ife **C**ycle **I**nterpretation

LCA – Construction sector

LCA application – Increased in the first decade of 21th century

Advancements at **policy** and **legislative level**

- Standardisation building life cycle - 4 Modules (EN 15978:2011)

3-level of LCA **application**:

- **Construction product** ← **Environmental Product Declarations (EPDs)**
- **Building component**
- **Building as a whole** ← Demanding task
  - **(X)** Long lifespan
  - **(X)** Assessment of local impacts depending on building site
  - **(X)** LCA data collection

LCA tools

LCA tools

Generic LCA tools — Enviornmental impact assessment of building materials/components — **SimaPro**, **Gabi Software**

- ✓ Complete transparency processes
- ✓ Fully integrated with the latest science-based LCI databases (e.g. Ecoinvent)
- ✓ Consistent LCIA methods

Building-specific LCA tools — Enviornmental performance assessment of building as a whole

- Stand-alone softwares — **Athena Impact Estimator for Buildings**
- Plugs-in (BIM-LCA) — **One Click LCA**

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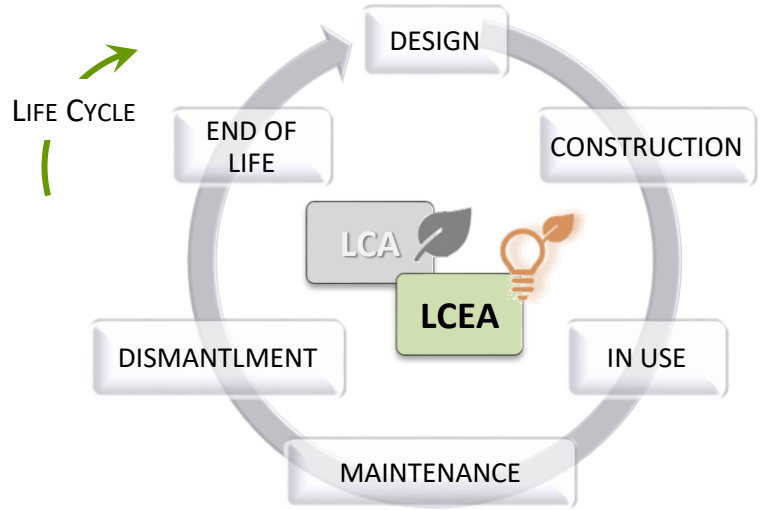
Sector-specific methods: Environmental and energy performance assessment methods

LIFE CYCLE ENERGY ASSESSMENT (LCEA)



Simplified version of the **LCA** methodology, considering **energy** as the **sole measure** of potential environmental impacts

Simplified four-step framework

1. Goal and Scope definition (**G&S**)
2. Life Cycle Inventory (**LCI**)
3. Life Cycle Impact Assessment (**LCIA**)
4. Life Cycle Interpretation

Single-issue oriented LCIA method – unique impact category, i.e. energy use

System boundaries	**Life Cycle Energy (E_{LC})**
Production phase	Embodied Energy (E_E)
Use phase	Operational Energy (E_O)
Demolition phase	Demolition Energy (E_D)

LIFE CYCLE

Energy bills method
National statistics-based method
Building Energy Simulation (BES) method

LCEA tools

EnergyPlus
ESP-r
TRNSYS

Multi-performance methods: Sustainability rating systems

Qualitative assessment

Framework components

1. Categories
2. Scoring system
3. Weigthing system
4. Output

Drawbacks:

- Absence of a common language
- Geographical dependence

Level(s)
(JRC 2015-2022)

European voluntary framework to improve the sustainability of buildings, based on a common system of indicators

	Rating system	General information			Type of building		Indicators		
		Year of launch	Country of launch	Issuer	New	Existing	Energy use	Climate change**	Natural disaster/ Seismicity
EUROPEAN	BREEAM	1990	UK*	BRE	✓	✓	●	●	
EUROPEAN	DGNB system	2009	Germany*	DGNB	✓	✓	●	●	●
EUROPEAN	HQE	1997	France*	HQE Association	✓	✓	●	●	
EUROPEAN	ITACA Protocol	2004	Italy	iiSBE Italia and ITC-CNR	✓		●	●	
NON-EUROPEAN	BEAM plus	1996	Hong Kong	HKGBC	✓	✓	●	●	
NON-EUROPEAN	CASBEE	2001	Japan	JSCB	✓	✓	●	●	●
NON-EUROPEAN	Green Star	2003	Australia	GBCA	✓	✓	●	●	
NON-EUROPEAN	LEED	1998	USA	USGBC	✓	✓	●	●	

* International use, apart from its origin country
** Climate change in terms of associate CO_2 emissions

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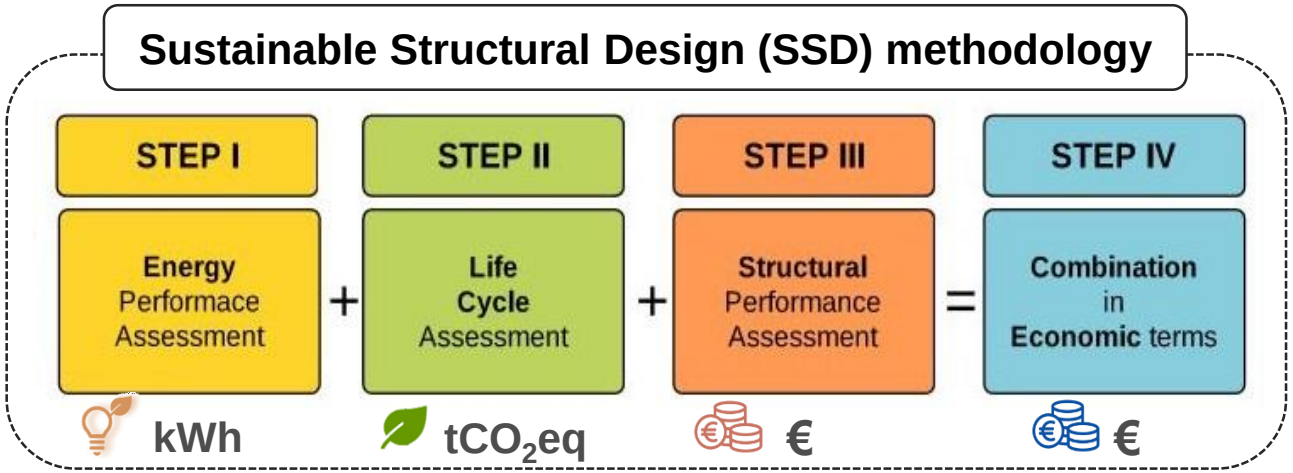
Multi-performance methods: Holistic method

Quantitative assessment

Integrated life cycle-based approaches

Challenege: integrate different performance metrics

- **Coupled assessment methods**
- **Environmental requirements and safety targets**
- **Economic and social aspects as consequence of seismic retrofit**
- **Seismic risk on economic management of energy retrofit processes**



(JRC – Ispra)

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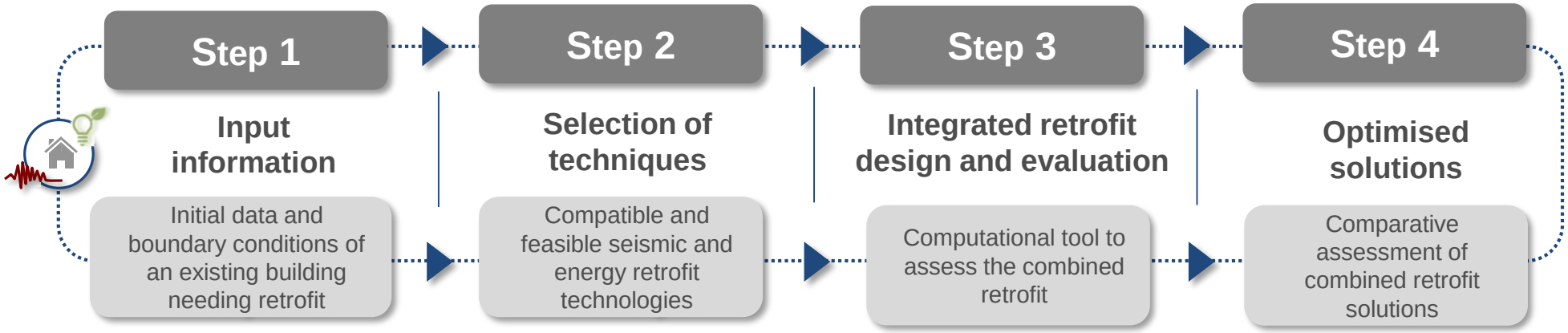
2. A simplified method to assess the benefits of the combined renovation

Requirements for the simplified method

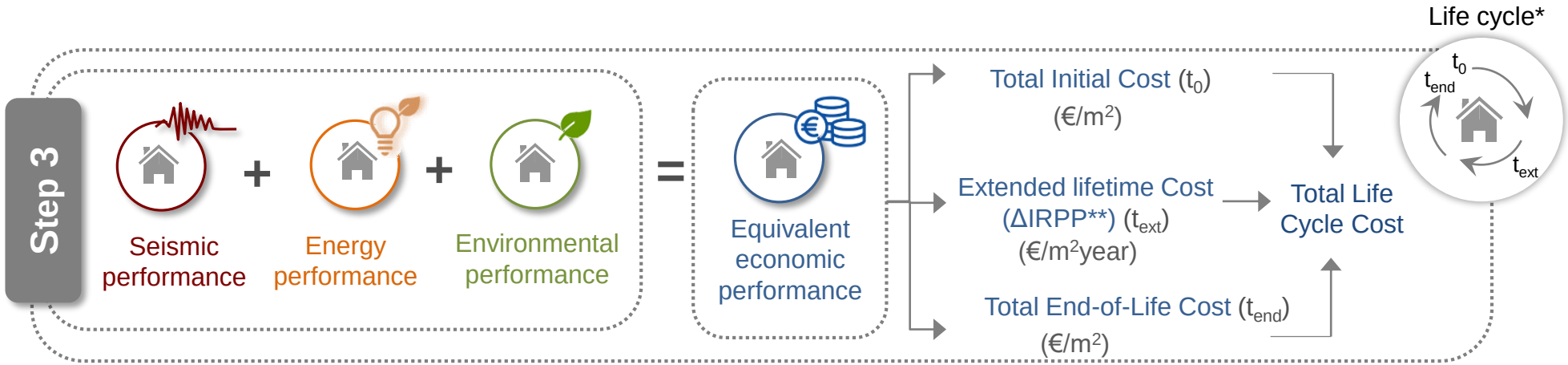
REQUIREMENTS	OUTCOMES
GENERAL PRINCIPLES • Sustainability principles • Available legislations • Life-Cycle perfomances	• Environmental efficiency, cost effectiveness, structural safety • Minimum performance targets foreseen by legislation • Perfomances from retrofit time to end-of-life
TECHNOLOGICAL CHARACTERISTICS • Compatibility and feasibility • Costs evaluations • Incremental implementation	• Feasibility matrix for combined retrofit technologies • Economic efficiency for seismic, energy, and environmental performances • Discretised combined performance improvements
ENGINEERING COMPUTATION • Site-dependent parameters • Combined performance evaluation • Dimensional scale of application • Simplification	• Site-dependent parameters for seismic and energy performances • Equivalent costs for seismic, energy, and environmental performances • Regional/national level of application • Simplified procedure for performances assessment

A simplified combined assessment methodology



(SSD methodology as reference)

Step 3: Simplified tool to assess the benefits gained from integrated retrofit over the lifetime of the building



*Life cycle → **t_0**:Initial time (time of retrofit intervention); **t_{ext}**: Extended lifetime stage; **t_{end}**: End-of-life time

ΔIRPP → **Annual economic savings due to retrofit and opportunity to consider **fiscal incentives**

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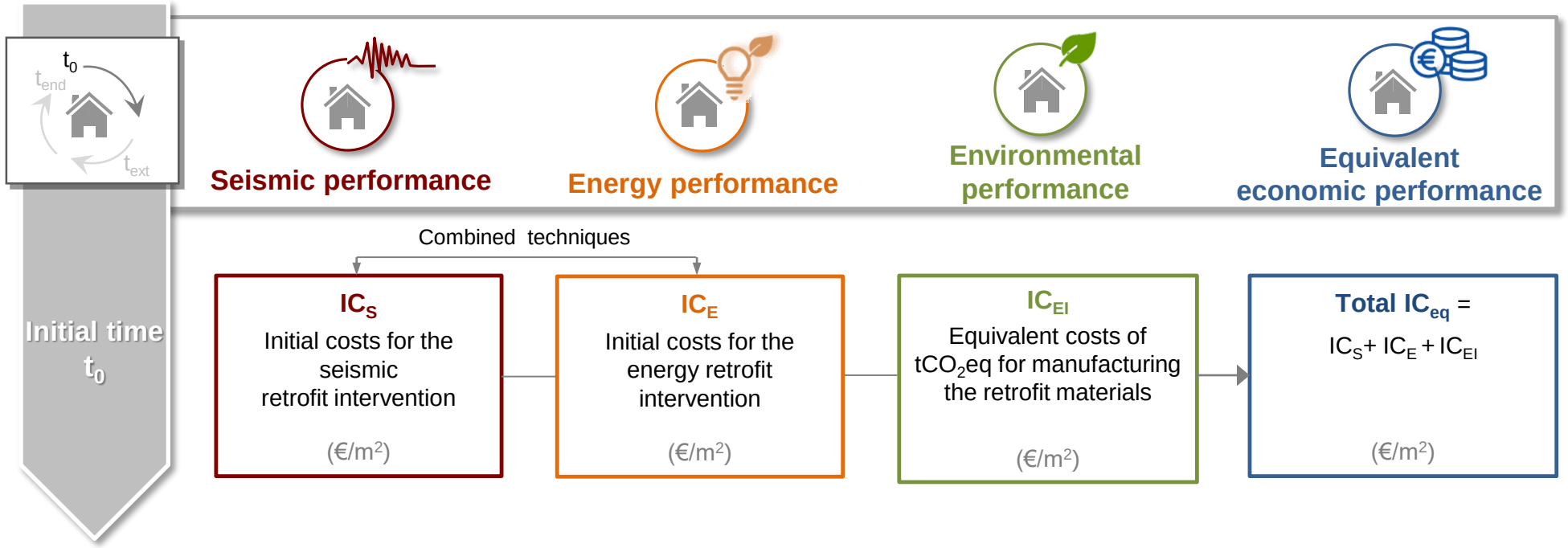
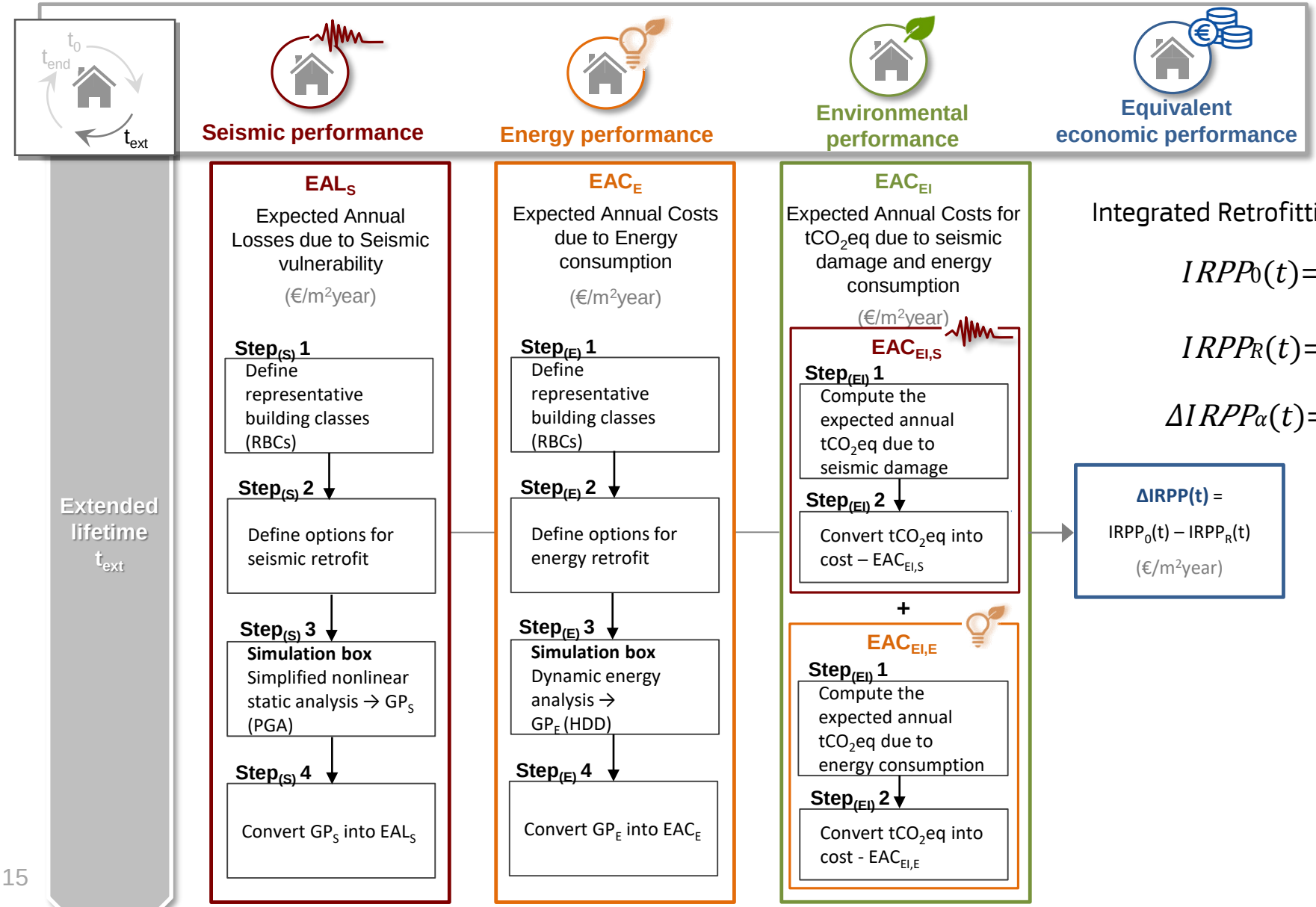
Step 3. The total initial cost



$$Total\ IC_{eq}(t_0) = IC_S + IC_E + IC_{EI}$$

Step 3. The total extended lifetime cost



Integrated Retrofitting Performance Parameter (IRPP)

$$IRPP_0(t) = EAL_{S,0} + EAC_{E,0} + EAC_{EI,0}$$

$$IRPP_R(t) = EAL_S + EAC_E + EAC_{EI}$$

$$\Delta IRPP_\alpha(t) = IPRR_0(t) - [\alpha(t) \cdot IPRR_R(t)]$$

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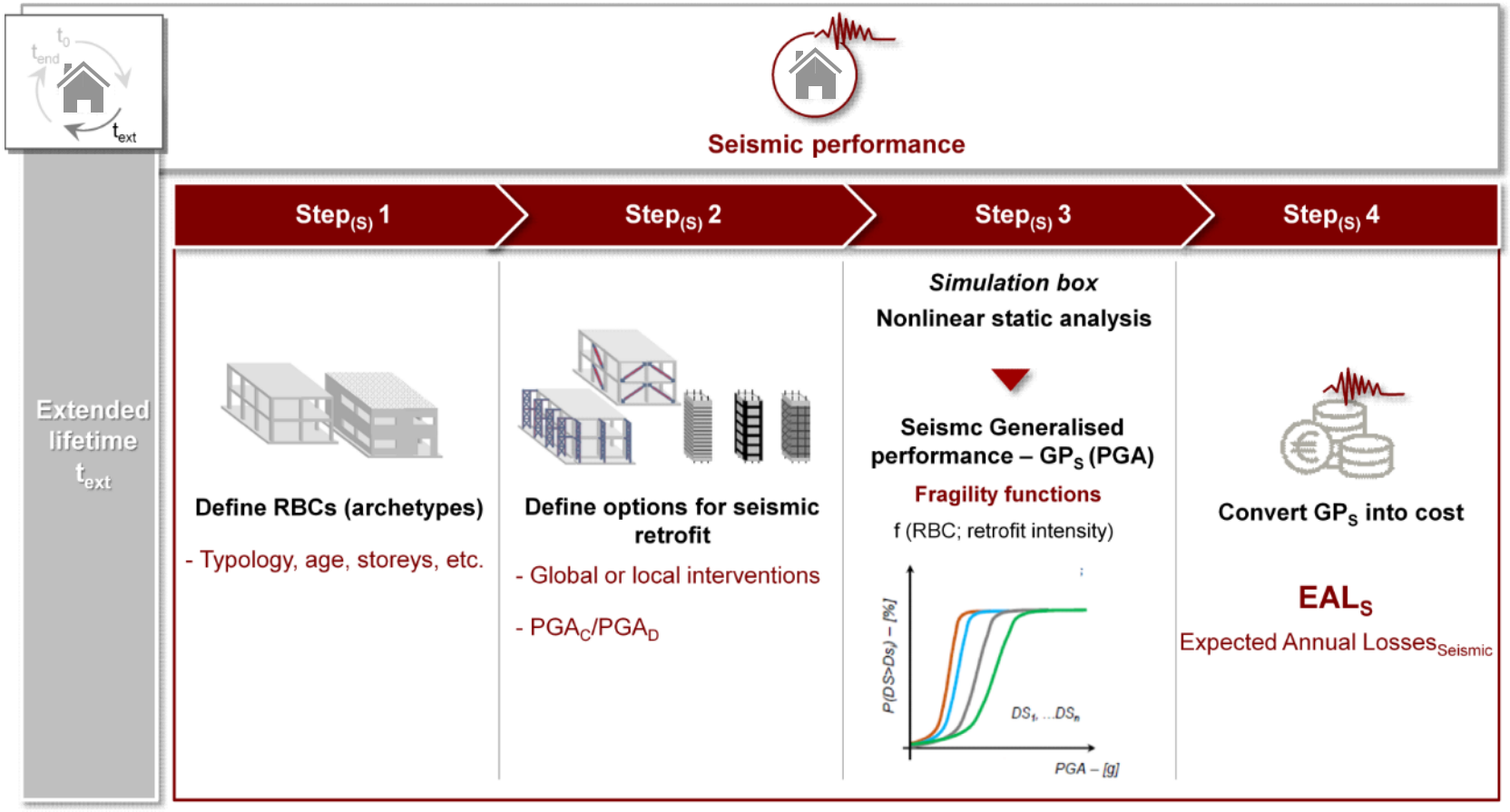
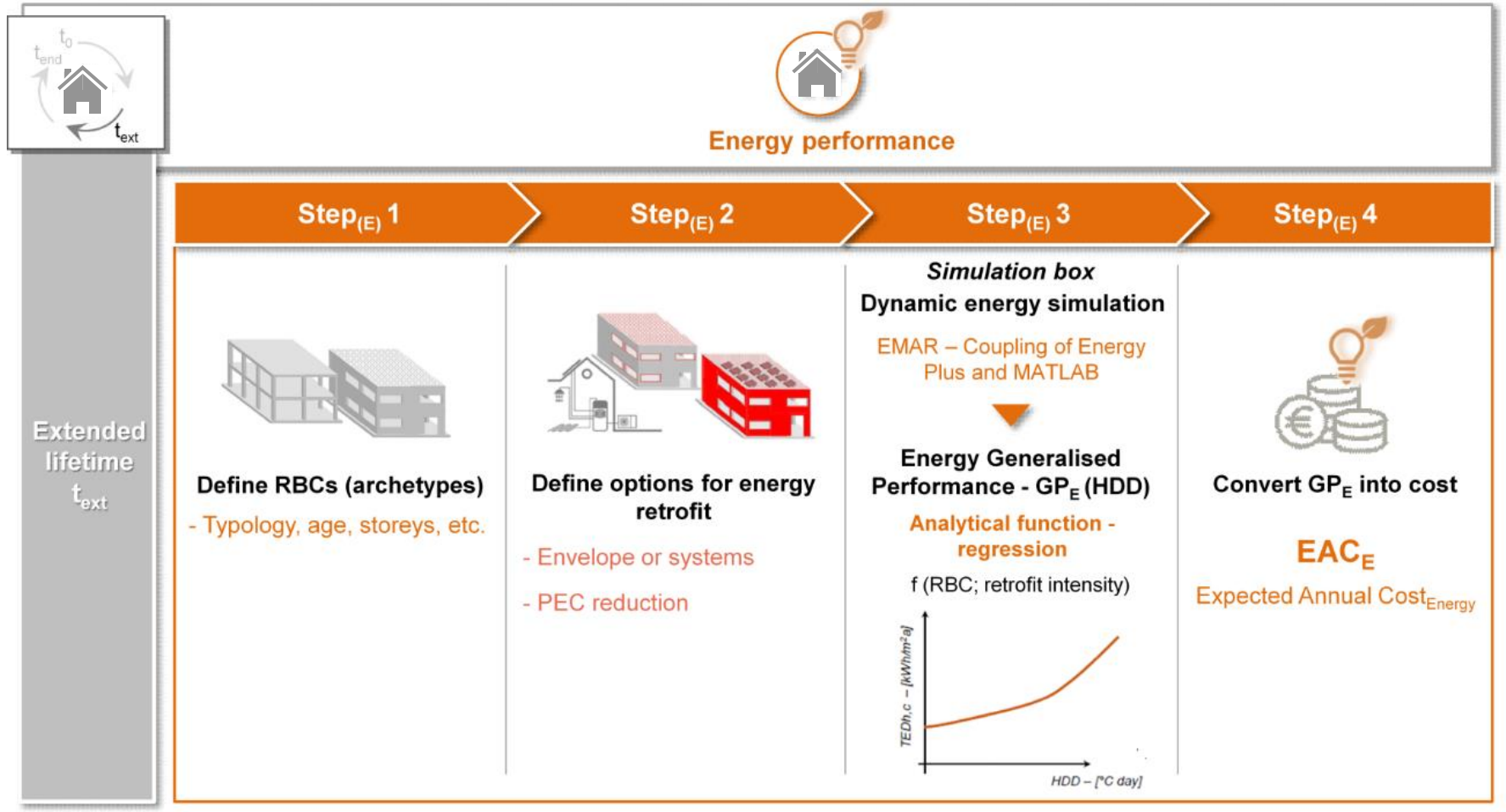
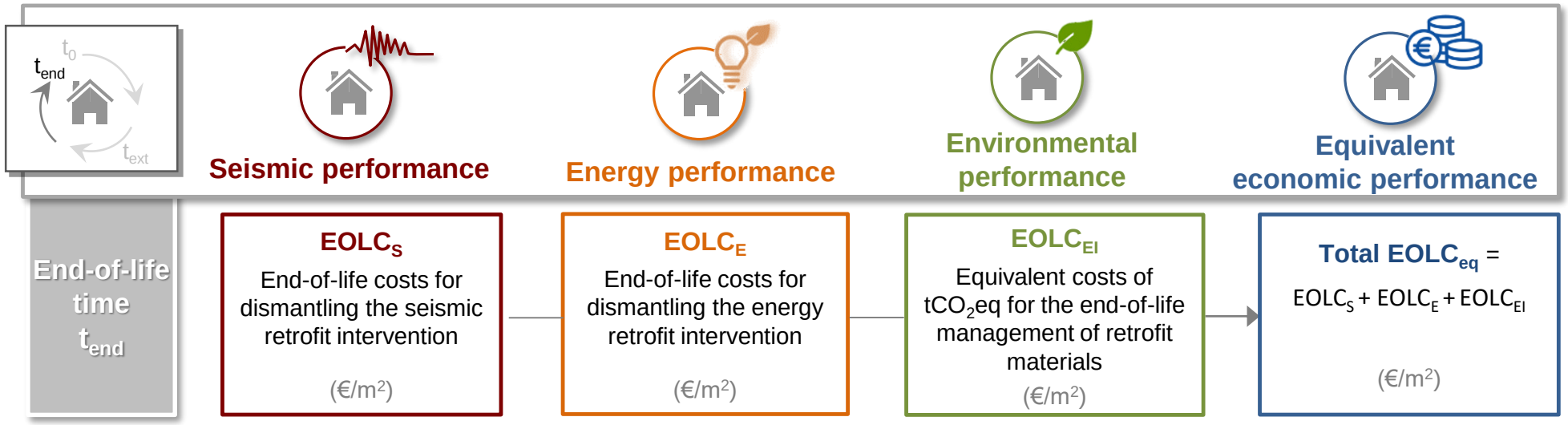
Seismic performance assessment at the extended lifetime stage



Energy performance assessment at the extended lifetime stage



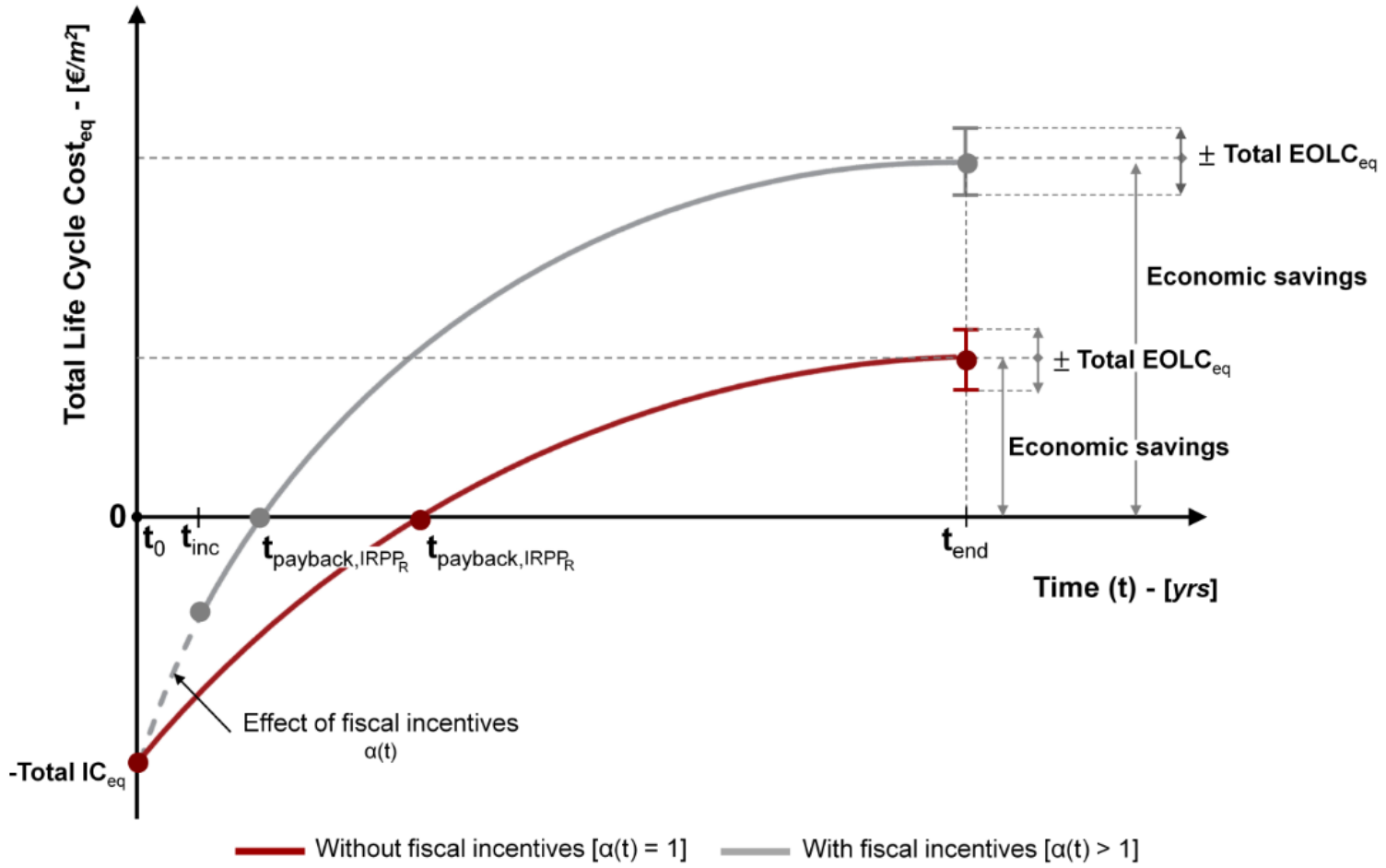
Step 3. The total end-of-life cost



$$Total\ EOLC_{eq}(t_{end}) = EOLC_S + EOLC_E + EOLC_{EI}$$

Total equivalent economic performance

$$Total\ Life\ Cycle\ Cost_{eq}(t) = -Total\ IC_{eq}(t_0) + D_R \cdot |\Delta IPRR_{\alpha}(t)| \cdot t \pm |Total\ EOLC_{eq}(t_{end})$$



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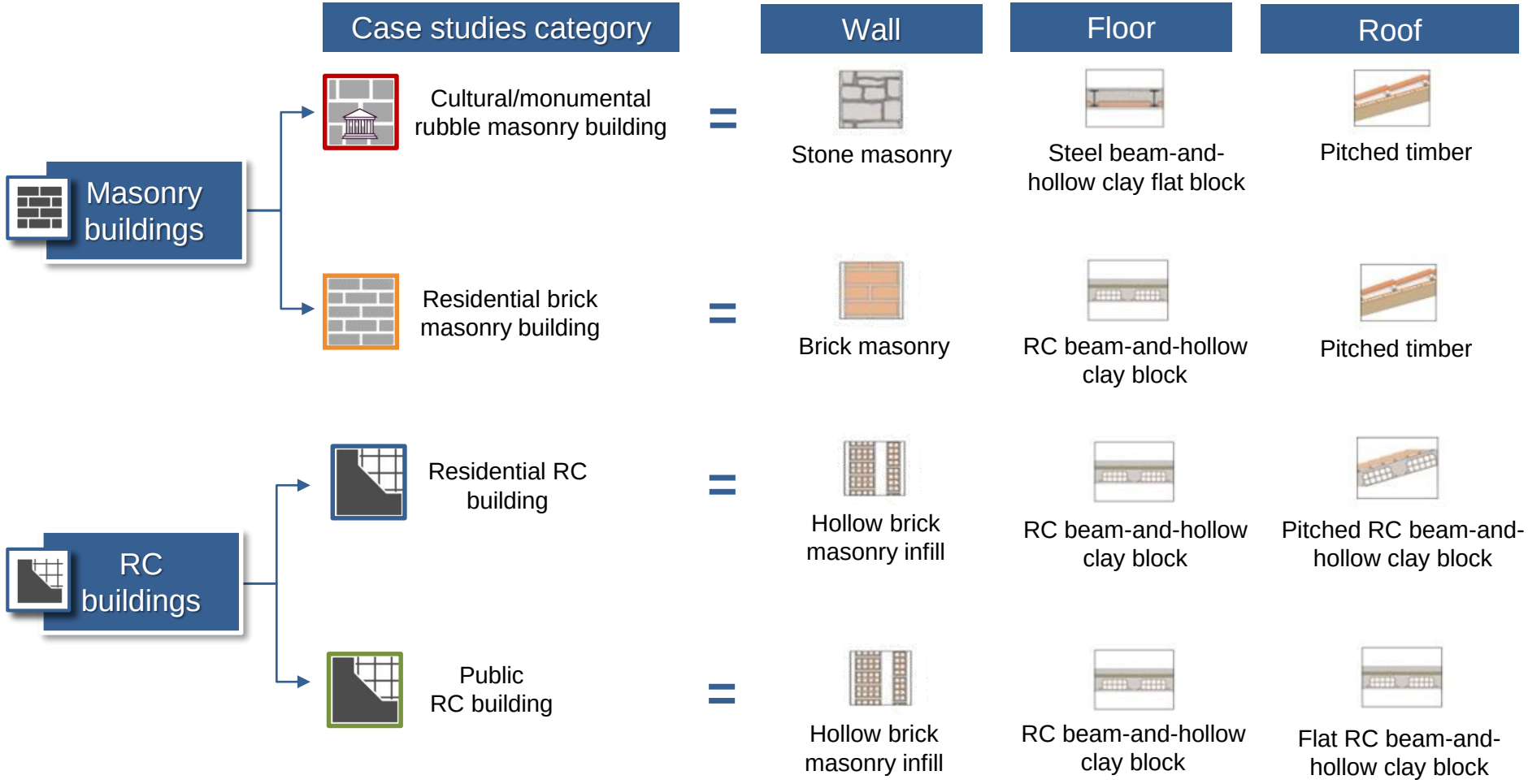
3. Case studies

Case studies: identification of categories



Case studies: identification of location and building selection

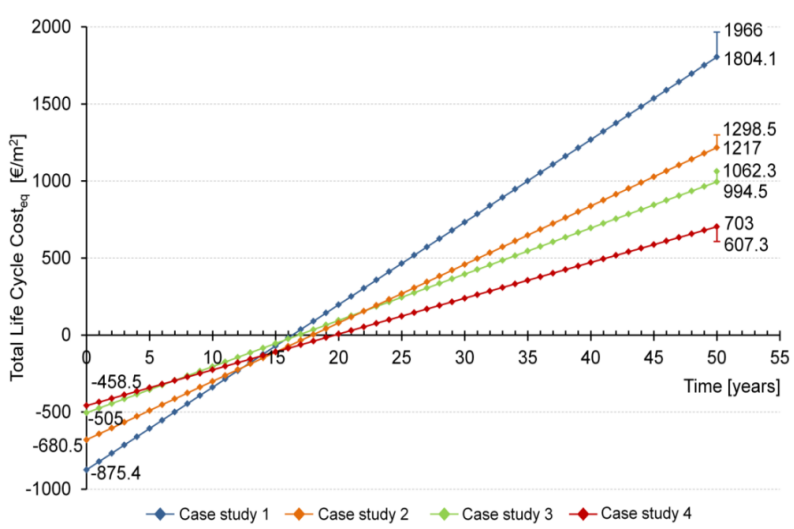
Seismic zone*	L-M	L-M	L-M	M-H	M-H	M-H
Climatic zone**	A	B	C	A	B	C
Case study		Residential building in Toscolano Maderno	Residential building in Dalmine	'Pietro Santini' primary school in Loro Piceno	City Hall of Barisciano	

* **L-M**: Low-to-Moderate (PGA < 0.175g); **M-H**: Moderate-to-High (PGA ≥ 0.175g)

** **A** (HDD < 2200); **B** (2200 ≤ HDD ≤ 3500); **C** (HDD > 3500)

	Case study	Retrofit interventions: Seismic retrofit	Retrofit interventions: Energy retrofit
1	3-storey residential RC building erected in 1967	Steel exoskeleton	External EPS cladding New heating system
2	3-storey residential brick masonry building erected in 1955	Prefabricated steel shear walls	Roof insulation Window replacement New heating system
3	3-storey RC primary school erected in 1965	Exoskeleton of steel x-CBFs	Double-skin envelope
4	4-storey rubble masonry building dating back to early 20th century	Local strengthening interventions	Window replacement New heating system

Case studies: Simplified method application

Total life cycle cost over time	Annual economic savings	Economic savings ΔIRPP (t_{ext})	Payback time (Service life = 50 years)
	Case study 1 53.59 €/m²year	71%	16 years
	Case study 2 29.99 €/m²year	55%	17 years
	Case study 3 37.59 €/m²year	61%	18 years
	Case study 4 23.22 €/m²year	39%	20 years

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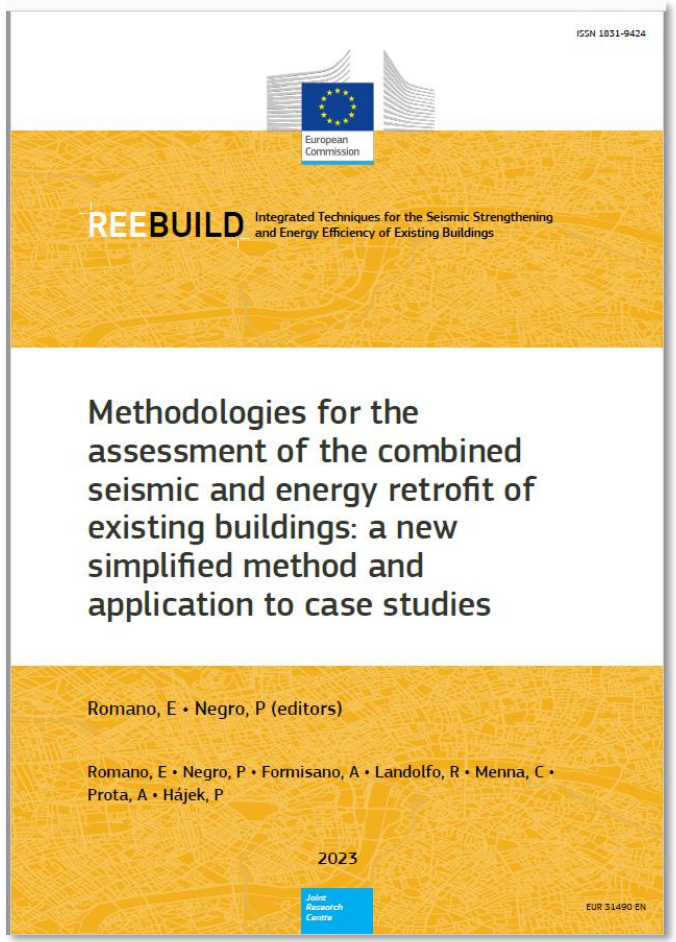
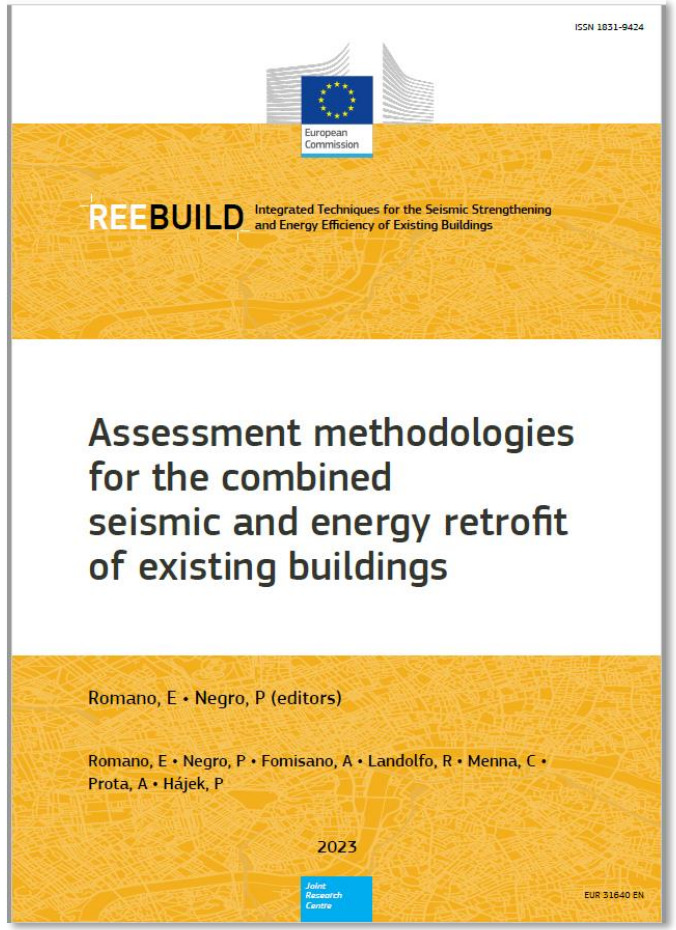
Conclusions

- **Quantitative multi-performance assessment methods** based on life-cycle thinking represent the most appropriate tool to evaluate the benefits of combined seismic and energy renovation
- A **simplified assessment method** for evaluating the combined seismic and energy renovation benefits in a common language (i.e. economic terms) was introduced, also facilitating the decision-making process thanks to the possibility to examine the final outcome of a **total life cycle cost over time**.
- The benefits of integrated renovation were demonstrated by applying the proposed simplified method to four representative residential and public buildings.
- The proposed simplified method demonstrated the renovation enhancement in terms of **annual economic savings** and **payback period**.

Publications

JRC Technical and Science for Policy reports





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Romano, E., Negro, P., Formisano, A. et al., Assessment methodologies for the combined seismic and energy retrofit of existing buildings, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/0562, JRC131412.

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