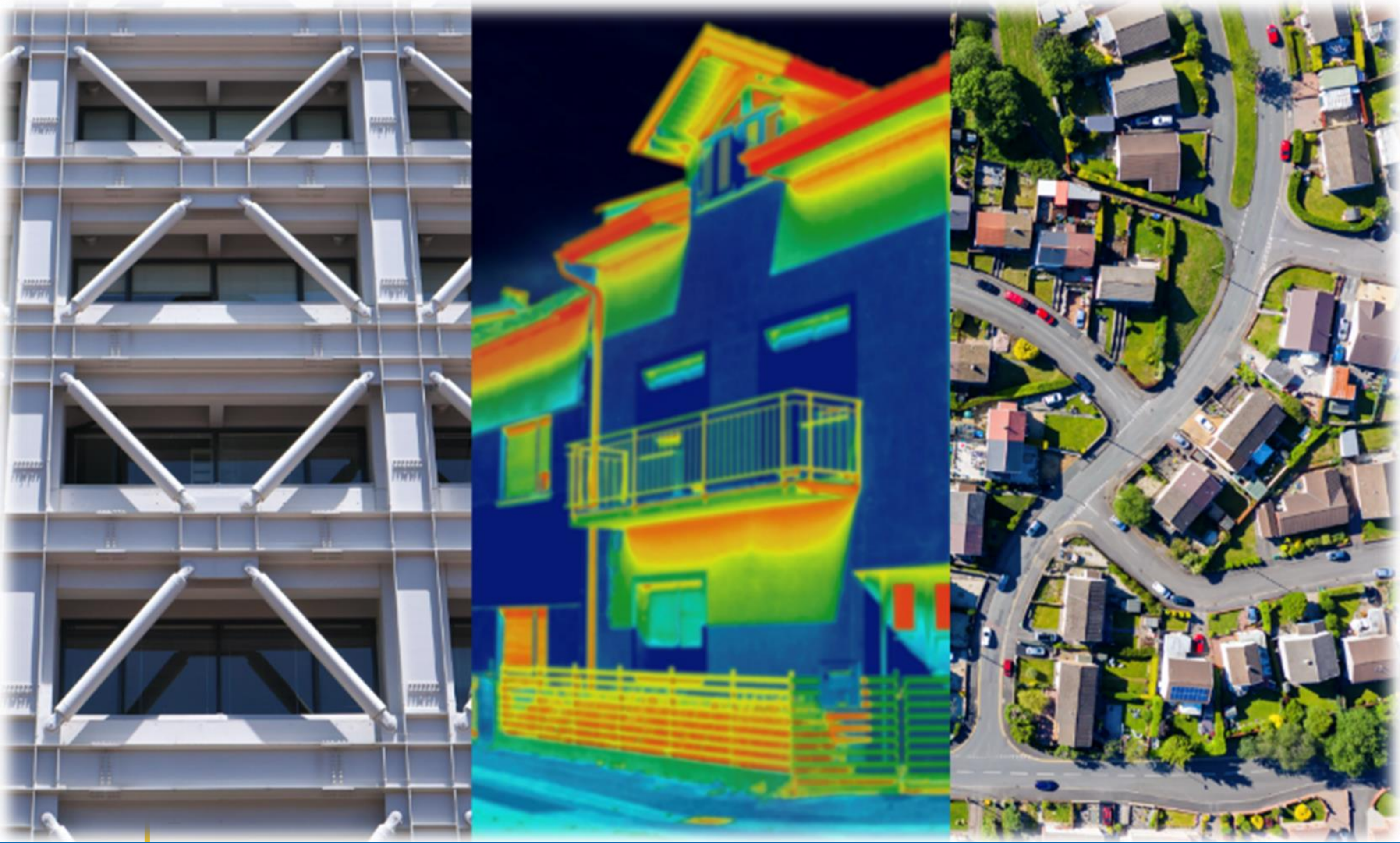
20-21 October 2021
Sofia

Building Engineering Forum
Строителен Инженерен Форум

BEF 2021



The challenge of the integrated seismic strengthening and energy upgrading of existing buildings

Paolo Negro
European Commission
Joint Research Centre

Impact of sustainability and energy efficiency on building design and retrofit: SAFESUST

- A JRC Institutional WP as a part of Safe&Clean Construction
- A holistic approach to include safety and sustainability in design: SAFESUST approach
- The Sustainable Structural Design (SSD) method for design/retrofit of buildings

Life Cycle Analysis (LCA, from cradle to grave)

Many LCA assessment procedures….

- Different criteria
- Lack interoperability
- Long and difficult

- Only a posteriori….

BREEAM

greenstar

SBTool

LEED

HQE CASBEE DGNB

How to match safety with sustainability?

The growing interests in achieving the environmental goals of the global agreements might be prevailing on other aspects of sustainability of buildings, such as seismic safety

How to optimize all performances?

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How to optimize all performances?

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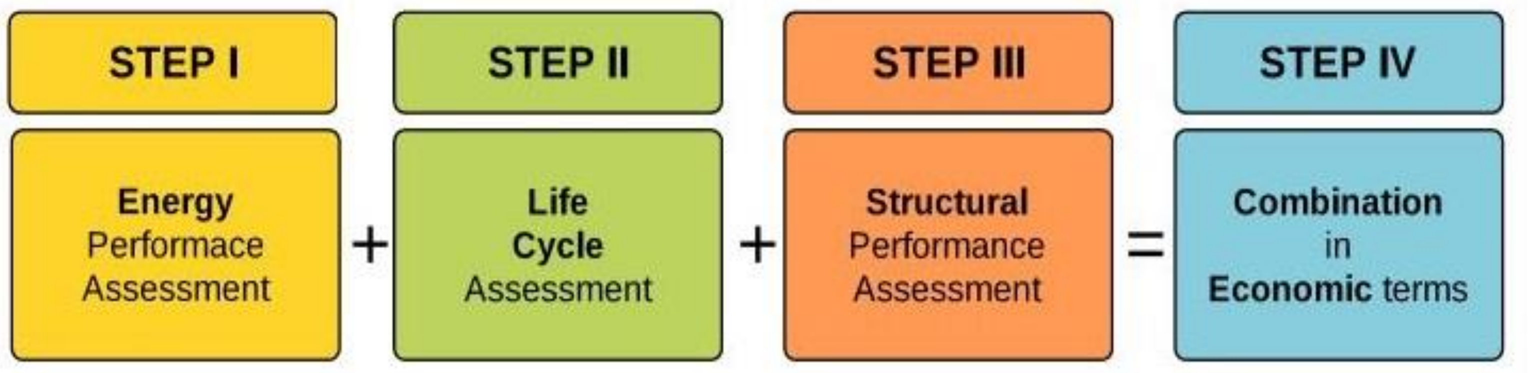
How to optimize all performances?

Sustainable Structural Design (SSD)
methodology



kWh **tCO_2eq** **€** **€**

kWh

- Energy performance is easily understood by owners, investors and decision makers.
- The advantages of energy upgrading can be measured in simple terms: reduction of operating costs, to be compared with investments.
- The first step of the method is the evaluation of the total expected energy consumption across the expected lifetime of the building.

Can we define a cost for safety?

- The "cost" associated to safety can be computed by adopting a Performance Based approach such as in the PEER method

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

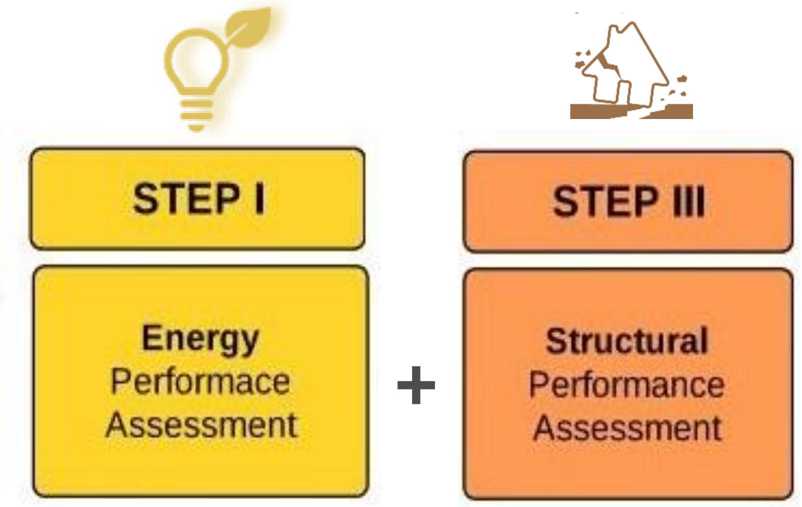
- The PEER method established a sound conceptual framework, but is by far too complicated to be used in practical design.

A Simplified Performance Based Assessment

- A set of limit states (minor damage, extensive damage, life safety…) is defined and the corresponding repair/replacement costs (possibly including downtimes) are evaluated
- A peak ground acceleration is associated to each limit state by a pushover curve
- The corresponding probability of exceedance is obtained by the return periods specified for the site by the design code
- The expected economic loss is the sum of the products of the probabilities of exceedance and the costs at each limit state

Reference: *Negro P., Mola E., A performance based approach for the seismic assessment and rehabilitation of existing RC buildings, Bulletin of Earthquake Engineering, 2017*

A total cost for the building



= €

kWh
transformed in
€

€

The cost of total expected energy consumption can be summed to the expected economic loss and compared to the investment for the construction cost or cost of upgrading

Reference: *Lamperti M., Loli A., Negro P., Balanced evaluation of structural and environmental performance in building design, Buildings, 2018.*

How about sustainability?

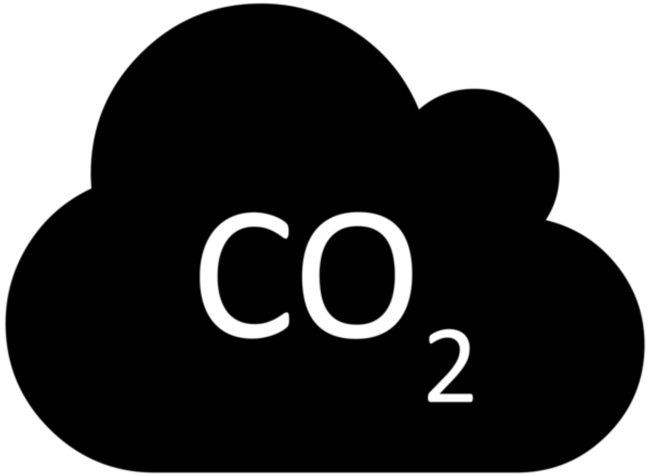
- Energy performance is related to environmental performance
- The cost of energy might (or might not) include a sort of environmental cost (carbon tax), but
- There is much more to sustainability than energy performance (embodied energy, raw material consumption, construction/demolition..)
- The latter might become dominant for nZEBs

Back to Life Cycle Analysis

tCO_2eq

The outcome of a LCA is typically expressed in terms of total equivalent CO_2 emissions across the whole life cycle of the buildings

A global performance indicator



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A global performance indicator

(*Abhijit Tembhekar*, 2009 - CC BY 2.0, via Wikimedia commons)

VS

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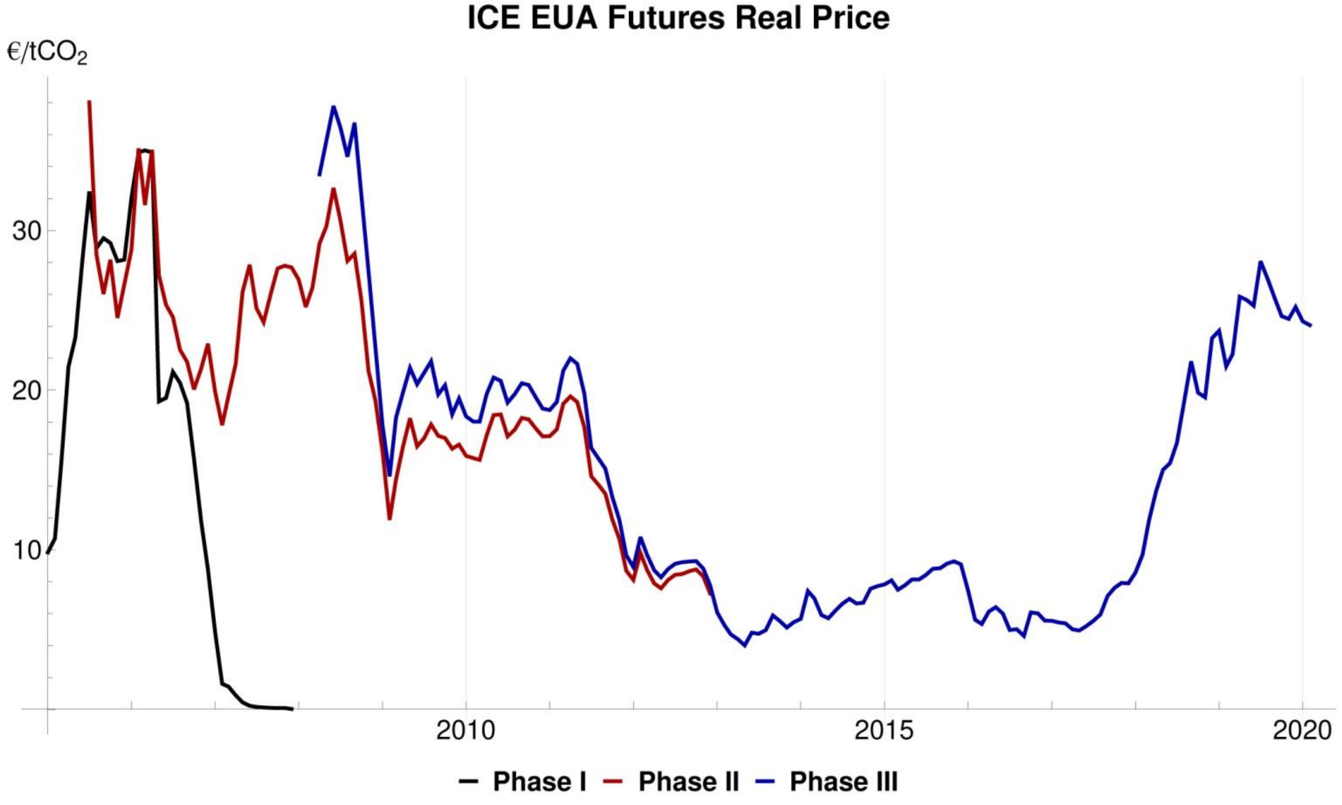
The *price* of Carbon

“*Carbon must have its price – because Nature cannot pay the price anymore*” (President von der Leyen, State of the Union Address)

European Commission

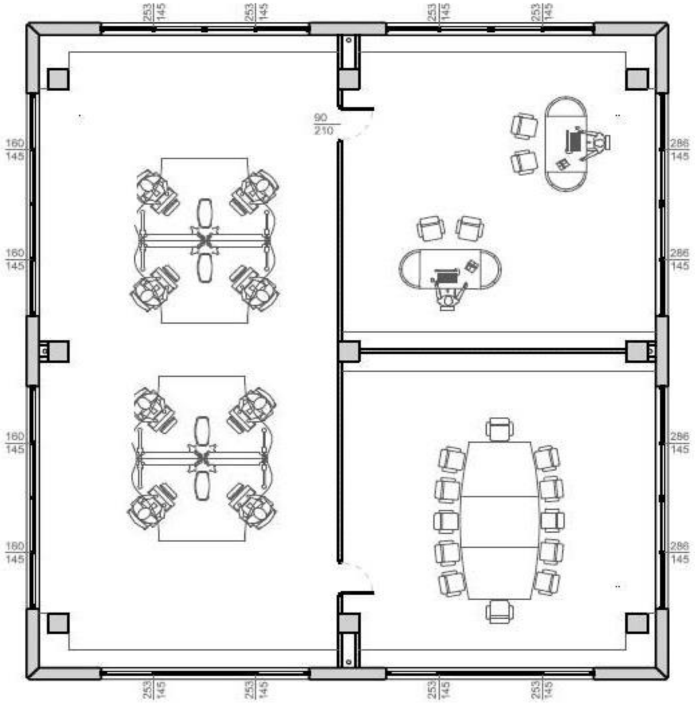
The *price* of Carbon

Cost of equivalent CO_2 emissions:
European Union Emission Trading System



(Nboccard, 2020 - CC BY-SA 4.0, via Wikimedia Commons)

Application to a building



- Three storey building
- 15.62m × 16.87m in plan
- 2 spans of 7m in X and Y dir.
- 9.9m (3.5+3.2+3.2) height

Location: ***Barcis (PN)***

PGA = 0.25 g

Zone F → U = 0.26 W/m^{2}K

Office occupancy

Service life 50 years

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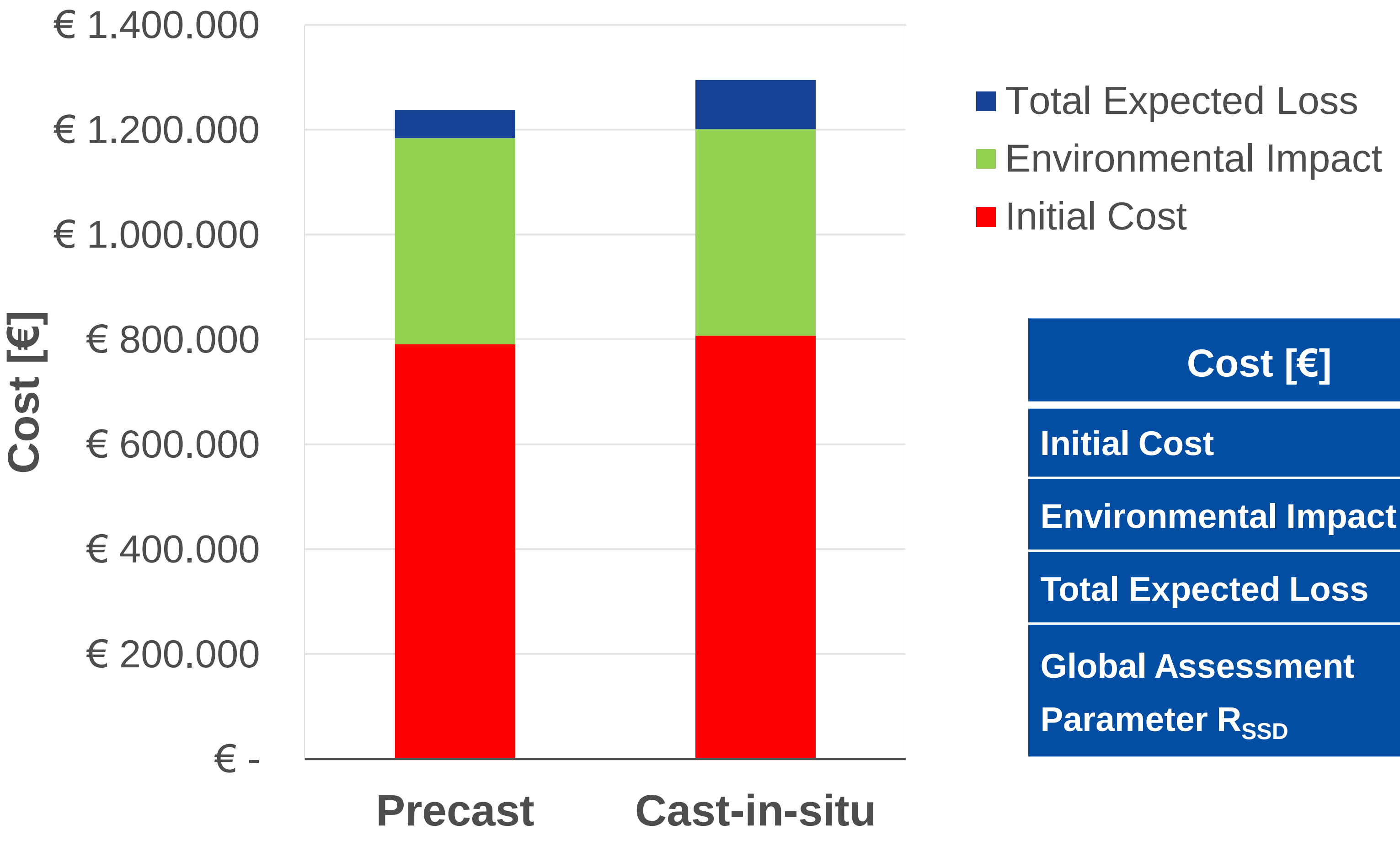
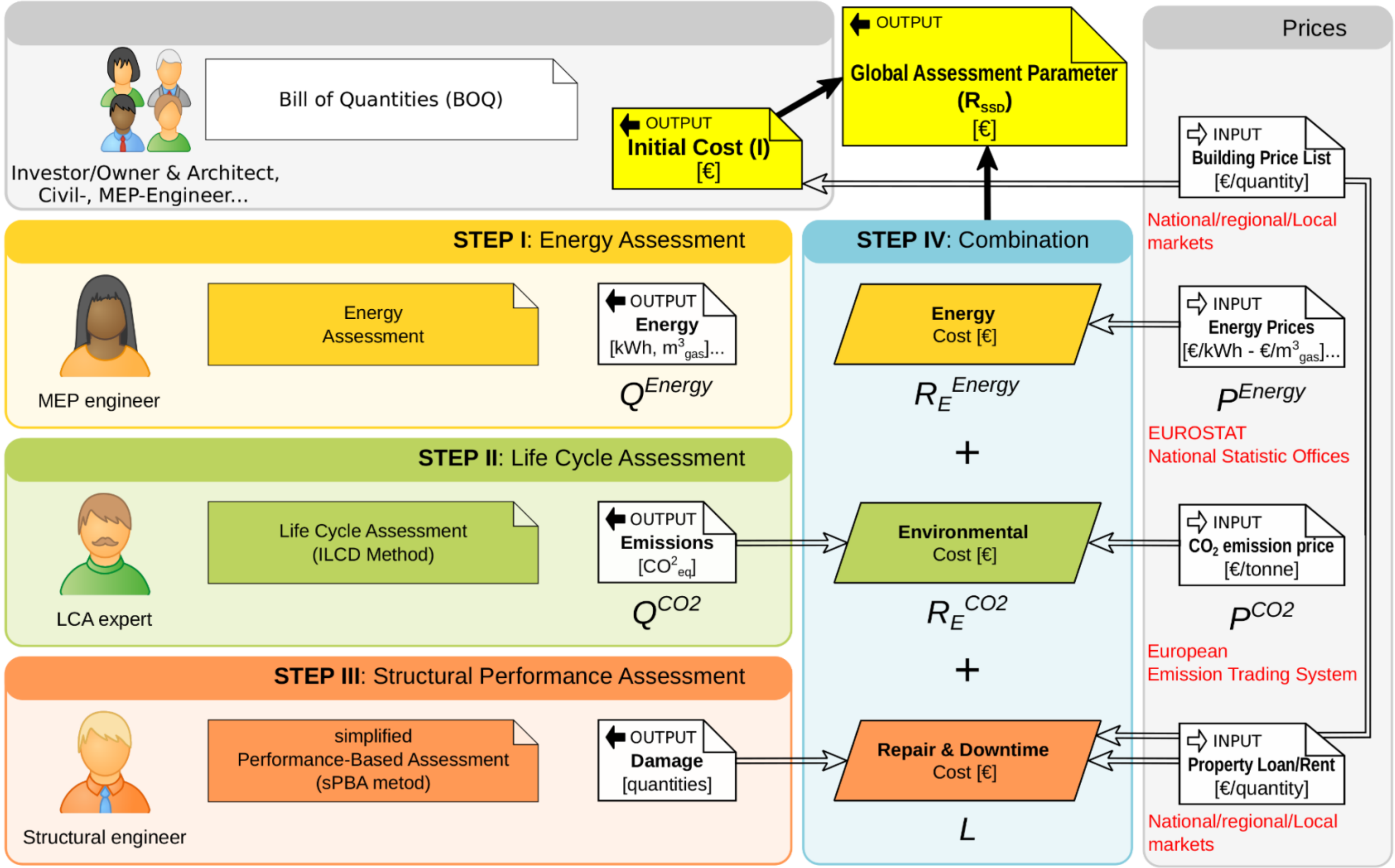
Application to a building



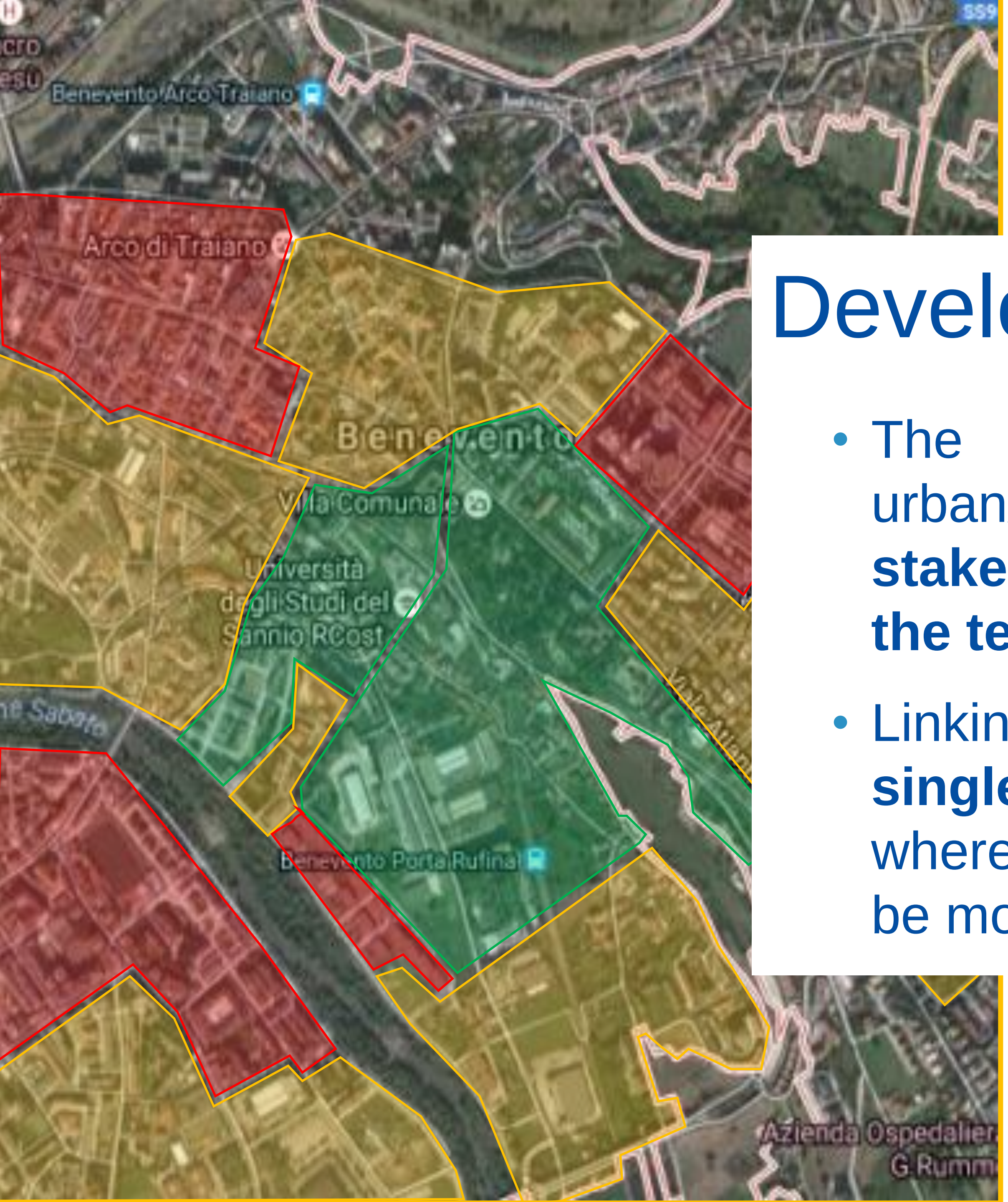
Cost [€]	Precast	Cast-in-situ
Initial Cost	790.530	807.055
Environmental Impact	393.218	394.054
Total Expected Loss	53.947	93.690
Global Assessment Parameter R_{SSD}	**1.237.695**	**1.294.799**

Costs as a common language….



(Lamperti et al, 2018)

Reference: *Lamperti Tornaghi M., Loli A., and Negro P., Balanced evaluation of structural and environmental performance in building design, Buildings, 8 (4), 52, 2018.*



Developments of the methodology

- The methodology can be used at urban/regional/national level for **supporting stakeholders** in addressing **policy projects on the territory**
- Linking all the buildings of a defined territory to **a single parameter** leads to identifying the areas where an intervention is more **urgent** and would be more **efficient**

Reference: *Caruso M.C., Lamperti M., Negro P. Applicability of the Sustainable Structural Design method at urban/regional/national level, Proc. 16ECEE, 2018.*

European Commission

Not only earthquakes

Structural safety
Higher live load requirements
Upgrading, transformations
Maintenance
Fire resistance
Climate change

SURECON:

A ROADMAP FOR A SUSTAINABLE INTEGRATED RETROFIT OF CONCRETE BUILDINGS

Reference: *A Roadmap for a SUstainable integrated REtrofit of CONcrete buildings, Iuorio, O. and Negro, P. editor(s), Publications Office of the European Union, Luxembourg, 2019. ISBN 978-92-76-23865-2*

European Commission

Pilot Project:
Integrated Techniques for the Seismic Strengthening & Energy Efficiency of Existing Buildings

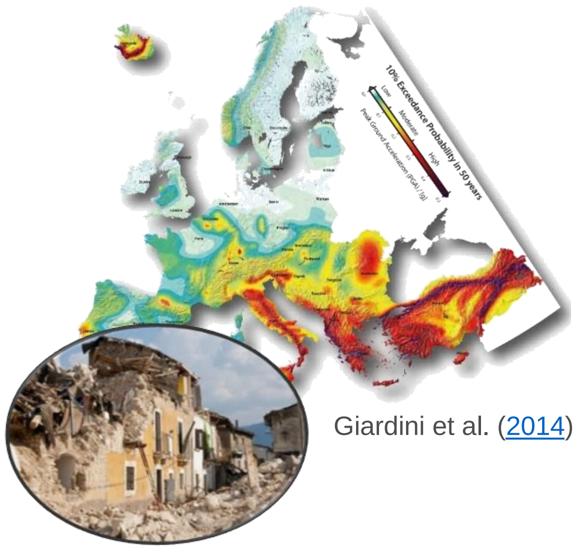
Currently being performed by the Joint Research Centre under mandate of the European Parliament

Joint Research Centre

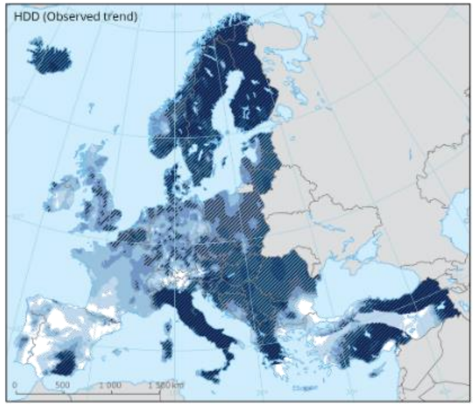
Introduction

Pilot Project scope

Define solutions that, at the same time and in the least invasive way, can both reduce seismic vulnerability and increase energy efficiency in such a way to produce a significant positive environmental impact



Giardini et al. (2014)



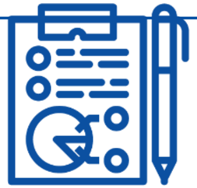
EEA (2019)

Buildings: 38.1% of energy consumption in EU

Main objectives

- Define tools and guidelines
- Stimulate use of integrated solutions
- Create awareness
- Increase resilience of built environment

Future EU Action Plan



References: Giardini, D., Wössner, J. & Danciu, L. (2014) ‘Mapping Europe’s seismic hazard’, *Eos Trans. AGU*, 95(29): 261–262, doi: 10.1002/2014EO290001

Policy goals

Green Deal

Renovation wave

New European Bauhaus

Energy Performance of Buildings

New Industrial Strategy for Europe

New Circular Economy Action Plan

Action Plan on the Sendai Framework

Sustainable Development Goal 11

European Framework for Action on Cultural Heritage

European Agenda for Culture

Pilot project actions

1. Technologies for seismic strengthening and energy upgrading

2.Technologies for combined upgrading

3. Methodologies for assessing the combined effect of upgrading

4. Regional impact assessment

5. Stakeholders’ engagement

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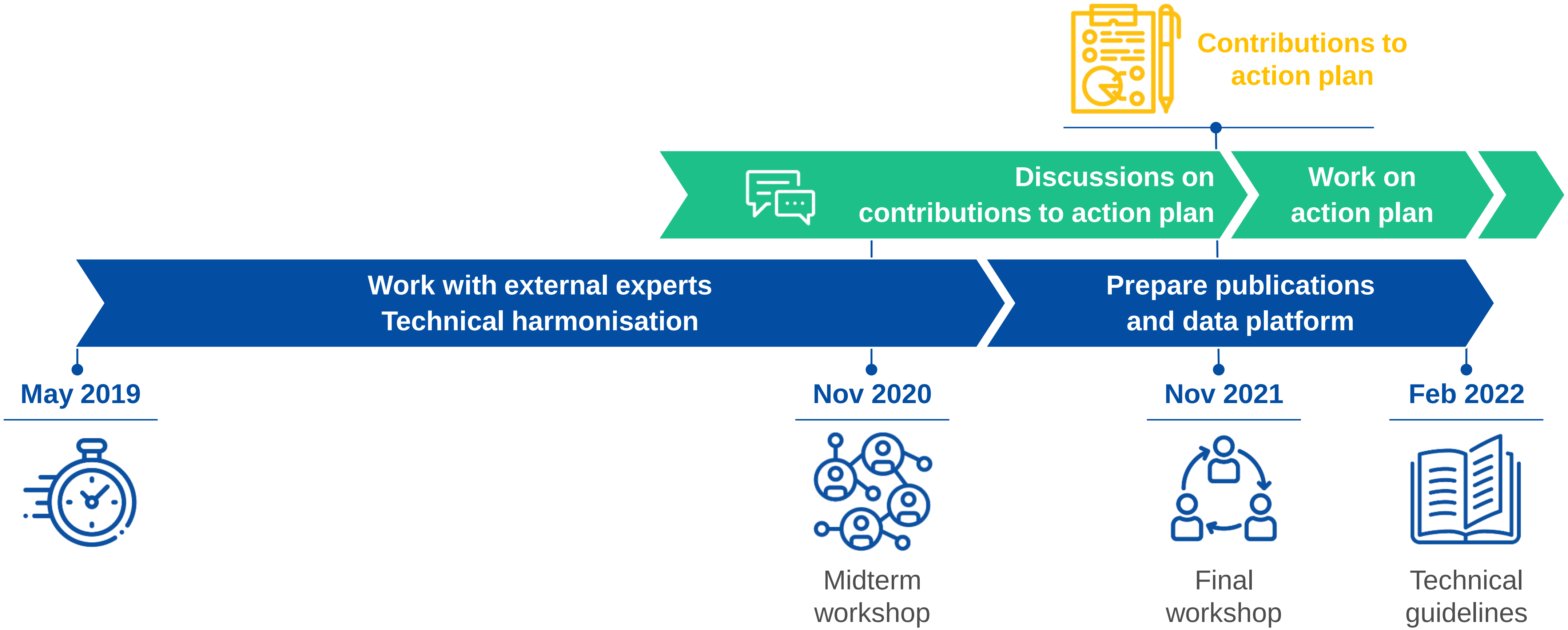
Timeline



European Commission

Action 1 - Overview

1 - TECHNOLOGIES FOR SEISMIC STRENGTHENING AND ENERGY UPGRADING

SUB-ACTION 1.1 - Building typologies needing upgrading

Identify representative classes of buildings regarding both seismic & energy performance

SUB-ACTION 1.2 - Technology options for seismic upgrading

Classify technologies in terms of expected seismic safety improvement, cost and disruption of service, use of raw materials, Life Cycle Analysis effects, and compatibility with energy upgrading technologies

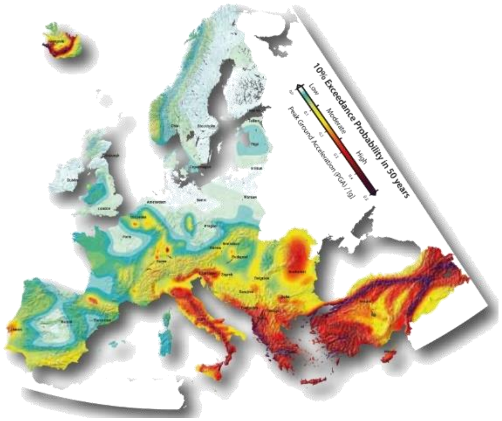
SUB-ACTION 1.3 - Technology options for energy upgrading

Classify technologies in terms of expected energy efficiency improvement, cost and disruption of service, use of raw materials, Life Cycle Analysis effects, and compatibility with seismic strengthening technologies

Building typologies needing upgrading

Distribution of building typologies by year of construction

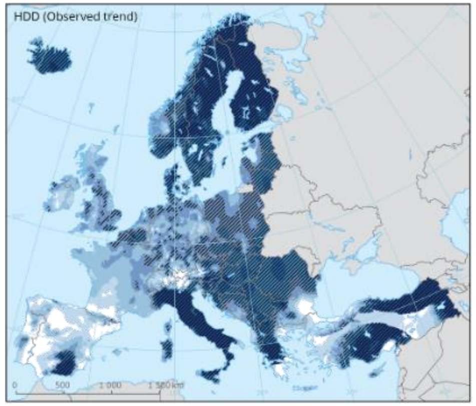
- 79% EU buildings built before 1991; 22 % before 1945
- Main EU building typology by construction material: masonry; RC in Greece, Cyprus and Portugal



Giardini et al. (2014)

European climatic zones & seismicity

- Identification of EU regions with high correlation of seismic and climatic exposure: (1) **Bulgaria**, (2) **Croatia**, (3) **Greece**, (4) **Italy** and (5) **Romania**



EEA (2019)

Building typologies most needing upgrading: focus in Italy

Seismic zone	Climatic zone	Combined demand	Number of masonry buildings	% of masonry buildings	Number of RC buildings	% of RC buildings
1-2	D-E-F	Very High	**2,413,644**	**33.4**	**1.169.256**	**31,07**
1-2	A-B-C	High	813,921	11.3	550.449	14,63
3-4	D-E-F	Medium	2,962,771	41.1	1.321.892	35,13
3-4	A-B-C	Low	1,022,432	14.2	721.242	19,17
Total			7,212,768	100.0	3.762.839	100.0

Action 2 - Overview

2 - TECHNOLOGIES FOR COMBINED UPGRADING OF EXISTING BUILDINGS

SUB-ACTION 2.1 - Technology options for combined upgrading of existing buildings

Review technologies for combined seismic and energy upgrading taking into account environmental effects in a life cycle perspective

SUB-ACTION 2.2 - Novel technology options for combined upgrading of existing buildings

Analyse novel technologies for combined seismic and energy upgrading and compare to conventional ones – define needs for successful marketing (e.g. research and standardisation needs)

Action 3: Overview

3 - METHODOLOGIES FOR ASSESSING THE COMBINED EFFECT OF UPGRADING

SUB-ACTION 3.1 - State-of-the-art on assessment methodologies for combined upgrading

Review methodologies used to assess the improvement in seismic safety and energy/environmental performance

SUB-ACTION 3.2 - Proposal of a simplified assessment method

Definition of a simplified/novel method for the combined assessment of upgrading

SUB-ACTION 3.3 - Case studies

Identification of case studies representative of building types needing both seismic and energy upgrading in order to investigate their retrofit solution with combined upgrading technologies through implementing the simplified method

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Proposal of a simplified assessment method

Requirements for a novel/simplifed method

LEVEL 1

GENERAL PRINCIPLES
- Sustainability principles
- Available legislations
- Life-Cycle perfomances

LEVEL 2

TECHNOLOGICAL CHARACTERISTICS
- Compatibility and feasibility
- Costs evaluations
- Incremental implementation

LEVEL 3

ENGINEERING COMPUTATION
- Site-dependent parameters
- Combined performance evaluation
- Dimensional scale of the application
- Simplification

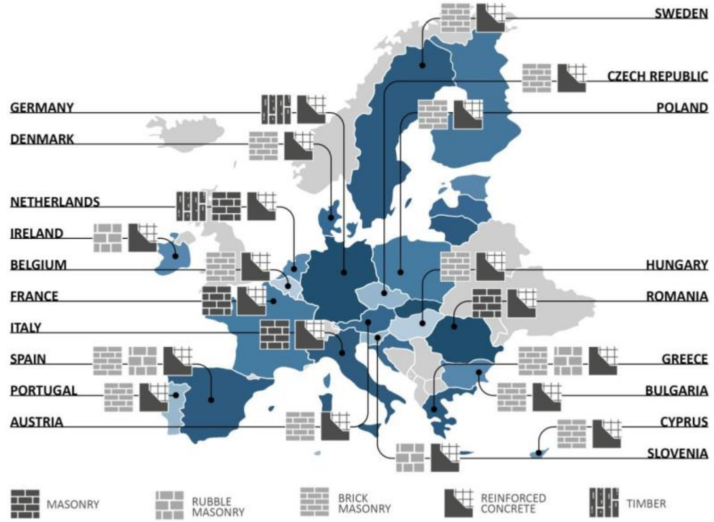
Simplified assessment method: main steps

- Results from **simulation-based procedures** to evaluate the effects of the seismic and energy performance of existing buildings in a combined manner through **equivalent economic parameters**
- Use of **simplified "simulation" box** to provide simple curves for building categories (**energy costs**) or tabular data for computing **seismic losses**

STEP 1	STEP 2	STEP 3	STEP 4
Input information	Selection of techniques	Integrated design retrofit	Optimised solutions
Collect performance data and boundary conditions of existing building	Identify set of compatible and feasible energy and structural techniques	Retrofit design tool consisting of different stages	Carry out comparative quantitative assessment of energy-structural solutions

Case studies

Case studies identification by construction technology



Masonry buildings

1. Monumental rubble masonry building
2. Residential brick masonry building

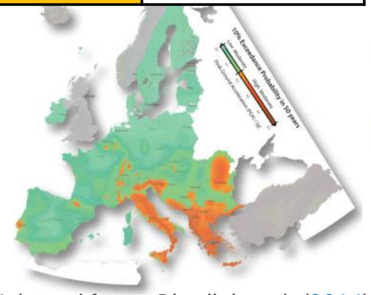
RC buildings

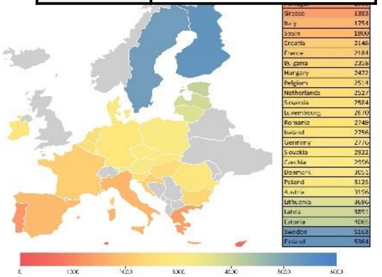
3. Residential reinforced concrete building
4. Public reinforced concrete building

Hazard matrix and case studies location

Seismic zone	Peak Ground Acceleration (PGA)
Low Moderate	PGA < 0,175 g
High Moderate	PGA ≥ 0,175 g

Climatic zone	Heating Degree Days (HDD)
A	HDD < 2200
B	2200 ≤ HDD ≤ 3500
C	HDD > 3500





Seismic zone	Low – Moderate (L–M)	Low – Moderate (L–M)	Low – Moderate (L–M)	High – Moderate (H–M)	High – Moderate (H–M)	High – Moderate (H–M)
Climatic zone	A	B	C	A	B	C
Case study		Dwellings in Toscolano Maderno (BS)	Dwellings in Dalmine (BS)	Santini Primary school (MC)	City Hall of Barisciano (AQ)	

Adapted from: *Giardini et al.* (2014)   Data source: 2017 data, *EUROSTAT Database*

Case studies

Standard methods application for independent and combined assessment of seismic and energy upgrading

RC public building
'Pietro Santini' primary school

Loro Piceno (MC)

PGA = 0.202g at Life Safety limit state
HDD = 2150

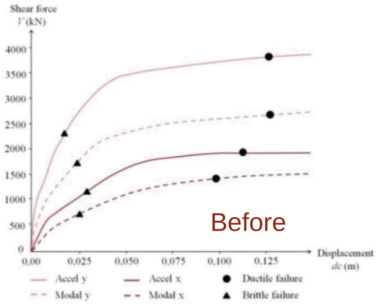
- **Seismic level**: H-M
- **Climatic Zone**: A
- **Case study**: r.c.

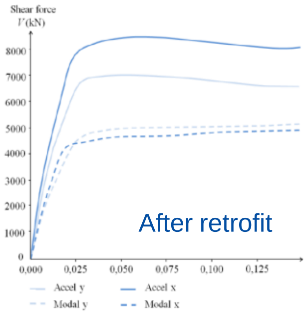
Retrofit technology (global)

- Exoskeleton: X-shaped concentric bracing frames (X-CBF)
- Double-skin envelope

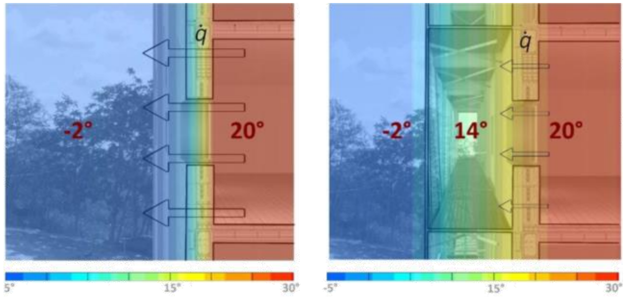
Standard independent methods

Seismic assessment
Increased lateral stiffness and strength





Energy assessment
51% savings



Standard combined method: **SSD methodology**

kWh + tCO_2eq + € = €

STEP I
Energy performance assessment

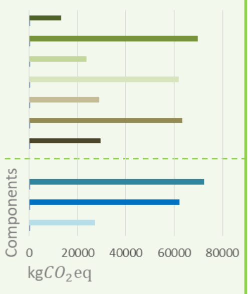
ANTE-OPERAM

	$\frac{Kwh}{m^2\ year}$
Electricity consumption	12.62
Heating consumption	121.20

POST- OPERAM

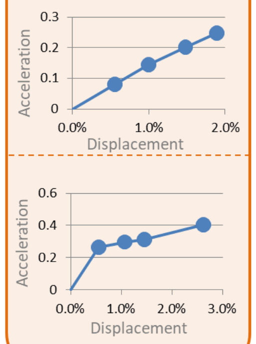
	$\frac{Kwh}{m^2\ year}$
Electricity consumption	6.15
Heating consumption	47.77

STEP II
Life cycle performance assessment



Evaluation of carbon footprint emissions of the building components in $kgCO_2eq$ according to IPCCGWP100Y

STEP III
Structural performance assessment



STEP IV
combination

	Costs (€)	%
Step I	589.333,87	23,5
Step II	2.098,47	0,1
Step III	1.919.392,00	76,4
TOT	2.510.824,34	100

	Costs (€)	%
Step I	526.862,44	49,6
Step II	3.402,57	0,3
Step III	532.773,00	50,1
TOT	1.063.038,01	100

Final cost of retrofitted solution =
60% less than the non-retrofitted building result

European Commission

Thank you

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https://ec.europa.eu/jrc/en/integrated-techniques-seismic-and-energy-retrofit-buildings

Some references (more in https://publications.jrc.ec.europa.eu/repository/)

- On the simplified seismic performance assessment:

Negro P., Mola E., *A performance based approach for the seismic assessment and rehabilitation of existing RC buildings, Bulletin of Earthquake Engineering,* 2017. *https://link.springer.com/article/10.1007/s10518-015-9845-8*

- On SSD method/SAFESUST approach:

Lamperti M., Loli A., Negro P., *Balanced evaluation of structural and environmental performance in building design, Buildings,* 2018. https://www.mdpi.com/2075-5309/8/4/52

- On the SAFESUST workshops:

Caverzan A., Lamperti M, Negro P., *A roadmap for the improvement of earthquake resistance and eco-efficiency of existing buildings and cities,* 2015. *https://publications.jrc.ec.europa.eu/repository/bitstream/JRC103289/lb0616142enn.pdf*
Iuorio O., Negro P., *Proceedings of the SURECON Workshop,* 2020. *https://publications.jrc.ec.europa.eu/repository/bitstream/JRC119041/surecon_proceedings_online.pdf*

- On the Pilot Project:

Gkatzogias K, et al., *Integrated techniques for the seismic strengthening and energy efficiency of existing buildings: Pilot Project Workshop*, 2020. https://ec.europa.eu/jrc/en/publication/integrated-techniques-seismic-strengthening-and-energy-efficiency-existing-buildings-pilot-project

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