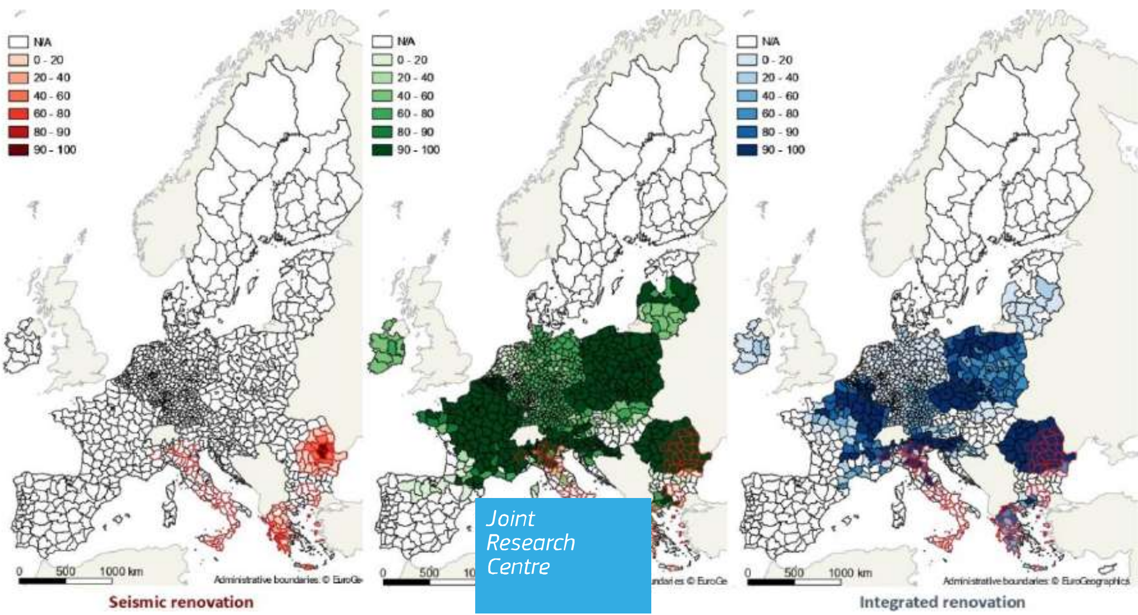
JRC CONFERENCE AND WORKSHOP REPORT

Proceedings of EAEE WG15 Summer Workshop

Felicioni, L., Negro, P.

2023



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Contents

Abstract

The Summer Workshop of the European Association of Earthquake Engineering (EAEE) Working Group 15 (WG15) was intended to provide a forum for the ad hoc assembly of knowledge to produce State-of-the-Art papers for dissemination at the European level. Based on the reported activities of the WG15 members and their collaborators, visions have been developed based on promising integrated techniques for environmental refurbishment and seismic retrofitting. The state-of-the-art results collected have been compared with the outcomes from each WG sub-group and will be used to develop a technical position paper for the scientific community, practitioners, and policymakers. The position paper will provide a comprehensive overview of the state-of-the-art results, identify key gaps in the current research, and make recommendations for future research and policy decisions. The contribution of the experts will ensure that the position paper is based on current evidence and best practices.

More than 30 experts have contributed their work to the workshop. This was ultimately successful in creating an understanding of the current research conducted in different seismic-prone regions, as well as potential areas of future development. The proceedings include the presentations and final discussion from the workshop.

Acknowledgements

This workshop has been held under the auspices of the European Association for Earthquake Engineering (EAEE), WG15 on "Combined seismic and environmental upgrading of existing buildings".

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Executive summary

EAEE WG15 Summer Workshop provides an overview of integrated interventions and methods applicable to existing buildings to support building renovation policies. This report summarizes the work of the WG15 members in their respective countries to (i) assessments of seismic and energy renovation technologies from an LCT perspective, (ii) reviews of combined renovation solutions, (iii) methods for evaluating integrated assessments, and (iv) results from EU projects implementing integrated approaches. These proceedings are beneficial to EU/national/regional authorities, academia, policymakers, and practitioners.

Policy context

Sustainable building renovation offers a unique opportunity to create a building environment that is less vulnerable to climate hazards and other risks, sustainable, and aligned with the current EU targets for a climate-neutral Europe by 2050. A renovation of the existing European building stock, of which 40% is more than 50 years old, would allow for meeting the latest safety and energy regulations. Also, the European Green Deal calls for a Renovation Wave, which is supported by the New European Bauhaus, to create a sustainable, inclusive, and beautiful environment. The Energy Performance of Buildings Directive (EPBD) is designed to reduce greenhouse gas and carbon emissions, as well as seismic risk to both new and existing buildings. The New Circular Economy Action Plan encourages the use of life cycle thinking (LCT) and circular economy principles in the construction industry. Thus, integrating renovation into the above policies accommodates both energy efficiency measures and LCT principles, whilst ensuring seismic/structural safety of the buildings.

Key conclusions

Enhancing seismic/structural safety at the same time as improving energy efficiency in existing buildings is a good opportunity to take advantage of. Sustainability, however, goes beyond energy efficiency. Indeed, LCT should be considered when renovating the existing building stock. In fact, much work and projects are focused on that, indicating that sustainable retrofits are on the right track. Material degradation and structural ageing should be taken into account in LCT-integrated interventions. Methodologies for integrated assessment should differ for newly constructed and existing buildings.

An overview of different methodologies for integrating assessments and technologies has been provided. A cost analysis based on the technologies would be interesting for future works.

Main findings

The presentations of current research activities in different European regions allowed for identifying areas for improvement and suggesting potential solutions. It was also helpful to identify areas of collaboration and new initiatives. The concept of combining interventions to achieve both short- and long-term sustainability for an existing building presents several challenges. These include compliance with minimum performance targets, historical significance, non-invasiveness, reversibility, and compatibility with traditional materials, repairability and maintenance, as well as total demountability-recyclability/reuse at the end of the lifecycle. A continuous research effort should be undertaken to address these concerns.

Related and future EAEE WG work

WG15 does not pursue any research actions per se, but it aims at integrating and disseminating state-of-the-art knowledge regarding integrated techniques and methods to a wider audience.

Quick guide

The workshop consisted of presentations (30 minutes each) given by members of the WG15 grouped according to their geographical location. The sub-groups were required to present running research in their countries to understand better what was happening regarding integrated methodologies and techniques for existing buildings across Europe. Therefore, the proceedings collect all nine presentations presented at the workshop.

1 Introduction

Over 35% of European buildings are over 50 years old. There is an urgent need to foster an integrated renovation of the European building stock in the perspective of a competitive, sustainable, and resilient building sector, contributing to the UN Sustainable Development Goal (SDG) 11 – Sustainable cities and communities - of the 2030 Agenda action plan (UN 2015/A/Res/70/1).

Renovating these buildings will reduce energy consumption and improve the quality of life for the inhabitants. In addition to improving energy efficiency, renovations of existing buildings and urban spaces can also improve structural performance. Additionally, renovations provide the opportunity to create a safe, sustainable, and resilient built environment in accordance with the New Bauhaus initiative. It is, therefore, possible to minimize costs and impacts associated with production, construction, and other life cycle phases (such as maintenance and end-of-life stages) and to ensure that climate change and future occupant demands can be adapted to simultaneously by implementing sustainable and life cycle thinking-based retrofitting interventions.

Thus, under the European Association of Earthquake Engineering mandate, a Working Group focused on "Combined seismic and environmental upgrading of existing buildings" organized a workshop as a forum for an ad hoc assembly of knowledge on this topic.

It was the goal of this workshop to present state-of-the-art combined methods and techniques and to develop visions based on information provided by experts from the European scientific community who are members of the Working Group regarding promising integrated techniques for environmental rehabilitation and seismic retrofitting in their respective countries. Ultimately, this activity is intended to develop a position paper aimed at disseminating technical information regarding integrated technologies, solutions, and methods for retrofitting European building stock. This will result in increased energy efficiency, decreased structural vulnerability, and a significant reduction in environmental impact and maintenance costs.

2 Agenda

Morning session

9.00 – 9.30 Aims of the EAEE WG15 and current European trends for renovating the building heritage

resp. P. Negro, co-authors L. Felicioni and WG15 members

9.30 – 10.00 Integrated retrofitting of existing buildings considering a life cycle thinking approach: a literature review

resp. L. Felicioni, co-authors M. Caruso, C. Passoni, N. Kyriakides, N. Ademovic

10.00 – 10.30 A new methodology for combined seismic and energy assessment of buildings

resp. S. Stefanidou, co-authors O. Markogiannaki, A. Karatzetzou, C. Zaki, A. Diamanti

15-min break

10.45 – 11.15 Integrated seismic and energy renovation of buildings

resp. G. Tsionis, co-authors D. Bournas, S. Dimova, K. Gkatzogias, P. Negro, D. Pohoryles, E. Romano

11.15 – 11.45 The Greek Legislative framework for pre-earthquake evaluation of buildings, and their connection with energy efficiency programs. The existing ΟΑΣΠ regulations for the three levels of evaluation.

resp. A. Chatzidakis, co-author S. Stefanidou

11.45 – 12.15 ReLuis project: the Italian experience on integrated interventions

resp. C. Menna, co-authors A. Prota, F. Da Porto

60-min lunch break

Afternoon session

13.15 – 13.45 Innovative seismic and energy retrofitting of the existing building stock (iRESIST+)

resp. D. Bournas, co-authors D. Pohoryles, S. Kallioras

13.45 – 14.15 Enhancing seismic safety and environmental sustainability of buildings: Integrated technologies and multi-criteria performance-based design methods

resp. S. Bianchi, co-authors J. Ciurlanti, M. Overen, S. Pampanin, G. Lori, V. Hayez, G. Manara

5-min break

14.20 – 14.50 Sustainability and resilience of built environment – *fib* contribution

resp. P. Hajek

14.50 – 15.30 Final wrap-up and outcomes discussion

resp. P. Negro and K. Pitilakis

3 Presentations

More than 30 experts have contributed their work to the workshop. This was ultimately successful in creating an understanding of the current research conducted in different seismic-prone regions, as well as potential areas of future development. The presentations can be found below.

Aims of the EAEE WG15 and current European trends for renovating the building heritage

Paolo Negro, Licia Felicioni and WG15 members

European Commission

Synopsis

- Aims of the EAEE WG15
- Recent JRC research activities on the combined (safety/environmental) design/redesign of buildings
- Expected outcomes of this workshop, towards an EAEE position paper

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European Commission

Combined seismic and environmental upgrading of existing buildings: the programme of the EAEE Working Group

Licia Felicioni et al.

Czech Technical University in Prague – Czech Republic
Faculty of Civil Engineering – Department of Building Structures

licia.felicioni@cvut.cz

Objectives

EAEE WG15 established since March 2022

WG's Objectives - help disseminate the technical content of the current research activities aimed to combine seismic/structural and environmental retrofit using innovative technologies and proper design methods.

Current Working Group

17 members from 6 countries

Convener	Secretary							
Paolo Negro Ispra, Italy JRC - ISPRA	**Licia Felicioni** Prague, Czechia CTU	**Andrea Belleri** Bergamo, Italy UNIBG	**Naida Ademovic** Sarajevo, Bosnia and Herzegovina IUS	**Martina Caruso** Pavia, Italy IUSS	**Petr Hajek** Prague, Czechia CTU	**Nicholas Kyriakides** Limassol, Cyprus CUT	**Alessandra Marini** Bergamo, Italy UNIBG	**Costantino Menna** Naples, Italy UNINA

Andrea Prota Naples, Italy UNINA	**Chiara Passoni** Bergamo, Italy UNIBG	**Rui Pinho** Pavia, Italy UNIPV	**Dimitris Pitilakis** Thessaloniki, Greece AUTH	**Kyriazis Pitilakis** Thessaloniki, Greece AUTH	**Viorel Popa** Bucharest, Romania UTCB	**Elvira Romano** Ispra, Italy JRC - ISPRA	**Georgios Tsionis** Ispra, Italy JRC - ISPRA

Introduction

BUILDINGS

The single largest **energy consumer** in EU responsible for

40%
of the EU's **energy consumption**

CO_2 **36%**
of energy-related **greenhouse gas emissions**

Source: European Commission, 2020

The most vulnerable and densely inhabited places affected by climate change effects.

They should be designed to be **resilient** to extreme events to keep the occupants safe.

Reference: European Commission, *Renovation Wave: doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty*, Press Release, Brussels, 14 October 2020.

Europe has often to face the **geophysical events** because it is on the Eurasian tectonic plate adjacent with the African one.

The level of seismicity is very high along the Mediterranean coast, principally in **Italy** and **Greece**.

Northern Europe is mostly free of significant earthquake zones, but the **Human-Induced Earthquakes.**

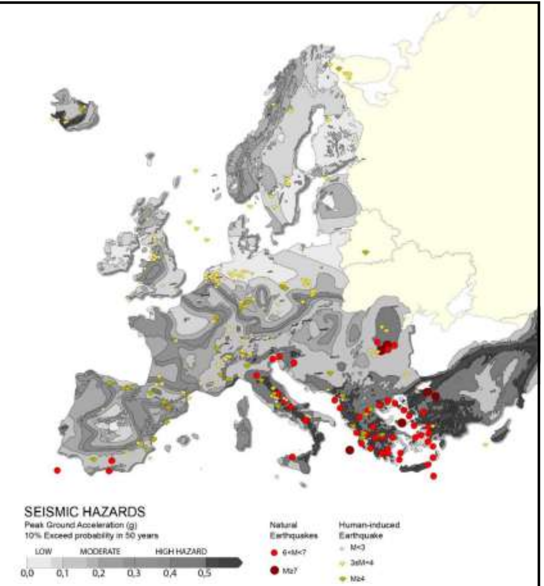

Image source: Menna et al., 2022 ©The Authors, 2022

Reference: Menna, C., Felicioni, L., Negro, P., Lupisek, A., Romano, E., Prota, A. and Hajek, P. 'Review of methods for the combined assessment of seismic resilience and energy efficiency towards sustainable retrofitting of existing European buildings', *Sustainable Cities and Society*, Vol. 77, 2022, Article No. 103556, https://doi.org/10.1016/j.scs.2021.103556.

35%
of the EU's buildings are over **50 years old**

almost **75%**
are energy **inefficient**

Only about ***1%*** *of buildings are energy-renovated each year*

Source: European Commission, 2020

Building interventions often do not extend the **structural building life cycle**, and structural safety is not always adequately ensured.

Buildings' energy efficiency must be followed by **seismic retrofitting** when a country has a high seismic hazard, which increases intervention costs.

The **principal challenge** to reduce seismic vulnerability and improve energy efficiency is generally the **total cost of the intervention**.

Reference: European Commission, *Renovation Wave: doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty*, Press Release, Brussels, 14 October 2020.

Activities

1. Fostering **research results**;

2. Contribution to **high-level academic** and **professional courses**;

3. Dedicated **workshops**, **webinars** and special sessions for international conferences;

4. Dissemination to the wider public and stakeholders.

Fostering research results

Goal: identify methods that can be used to facilitate the implementation of large-scale combined **energy-seismic retrofits**.

- Review the **state-of-the-art knowledge** regarding the options available for improving seismic safety and energy efficiency.
- **Independent state-of-the-art papers** to disseminate recent knowledge - legislation, incentives, guidance, and standards - that exist in the EU Member States regarding the retrofit of buildings aiming at enhanced energy and seismic performance.

Menna, C., Felicioni, L., Negro, P., Lupisek A., Romano, E., Prota, A. and Hajek, P.
'Review of methods for the combined assessment of seismic resilience and energy efficiency towards sustainable retrofitting of existing European buildings', *Sustainable Cities and Society*, Vol. 77, 2022, Article No. 103556, pp. 103556 - 103574 [Scientific article]

Contribution to high-level academic and professional courses

Goal: widen the **knowledge** about combined seismic and environmental techniques for existing buildings to students and professionals.

- Pertinent to countries with **medium to high seismic hazard** (Southern and Eastern Europe).
- Results from the state-of-the-art publications should be introduced in **engineering schools** and **professional courses**.
- It can be helpful for even low seismic hazard (Central Europe) with a specific focus on **structural safety against flood events**.

Coordination of workshops, webinars and special sessions at international conferences

Goal: spread knowledge about the retrofitting of existing buildings with a **holistic renovation approach**.

- Disseminate the **state-of-the-art knowledge** regarding the options available for improving seismic safety and energy efficiency.
- Encourage the opportunity to **effectively retrofit** the existing building stock considering safety and resilience

Negro, P. and Romano, E.
'The Challenge of the Integrated Seismic Strengthening and Environmental Upgrading of Existing Buildings', *Springer Proceedings in Earth and Environmental Sciences,* 2022, pp. 363–378 [Book chapter]

Dissemination to the wider public and stakeholders

Goal: support the awareness, dissemination, and outreach of the **results gathered**.

Potential stakeholders:

- representatives of European Institutions
- the EU Member States
- Regional Authorities
- academia and research institutions
- industrial associations and product manufacturers
- the insurance sector
- design professionals
- experts
- communities of practice
- students

Conclusions

- Measures to improve the **sustainability of the existing constructions**, as highlighted by European Union Policies – SDGs, EU Green Deal and the New European Bauhaus should go hand-in-hand with the **seismic risk reduction**.

- The EAEE WG does not pursue any research actions per se, but it aims at **independently integrating and disseminating the state-of-the-art knowledge** regarding integrated techniques to a wider audience.

- Think about a new paradigm and concepts on how to **retrofit the building stock.** A new challenge and fundamental goal is to develop ideas and methods for environmental and energy retrofitting of the building stock in damaged parts of Ukraine.

What's Next?

- ☑ **3ECEES THEME LECTURE** (*Monday 5th*)
  "The challenge of the integrated seismic strengthening and environmental upgrading of existing buildings"
  Paolo Negro

- ☑ **Special 3ECEES Session** (*Wednesday 7th*)
  Session 06: Life Cycle Thinking: integrated renovation strategies targeting safety and sustainability of existing buildings
  Alessandra Marini, Andrea Prota, Paolo Negro, Andrea Belleri

- ☑ **Special 3ECEES Session** (*Wednesday 7th*)
  Session 09: Integrated seismic and energy retrofit of buildings
  Silvia Dimova, Georgios Tsionis, Paolo Negro, Dionysios Bournas

- ☐ **WG15 ONLINE SUMMER WORKSHOP** (*Summer 2023*)

- ☐ **POSITION PAPER** (*Summer 2024*)
  more info: TBD

3rd European Conference on Earthquake Engineering and Seismology — September 7th, 2022

Recent JRC research activities on the combined (safety/environmental) design/redesign of buildings

Paolo Negro

European Commission, Joint Research Centre

Project SAFESUST:

Impact of sustainability and energy efficiency on building design and retrofit

Paolo Negro, Elvira Romano and many others

European Commission

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

- A JRC Institutional WP in the Action *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

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European Commission

Costs as a common language….

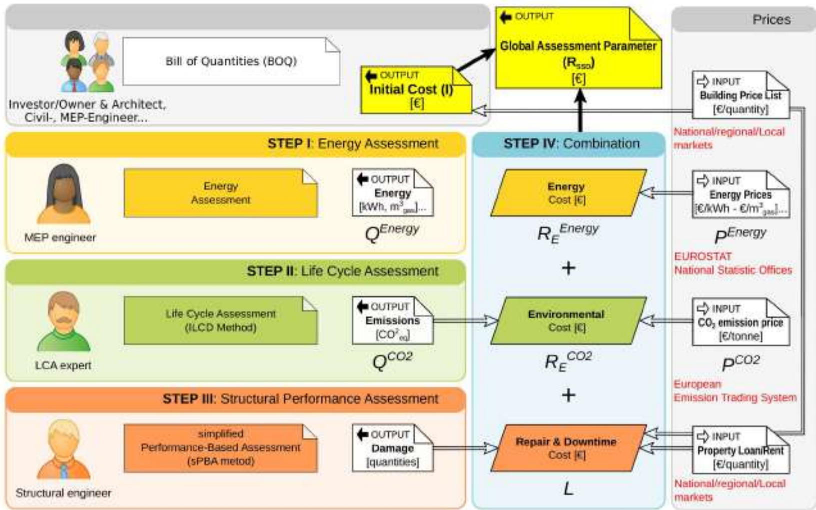

Image source: Lamperti Tornaghi et al., 2018 ©The Authors, 2018

Reference: Lamperti Tornaghi, M., Loli, A. and Negro, P., 'Balanced Evaluation of Structural and Environmental Performances in Building Design', *Buildings*, Vol. 8, 2018, article No 52, https://doi.org/10.3390/buildings8040052

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Innovative seismic and energy retrofitting of the existing building stock (iRESIST+)

***Dionysios BOURNAS**, Team Leader*

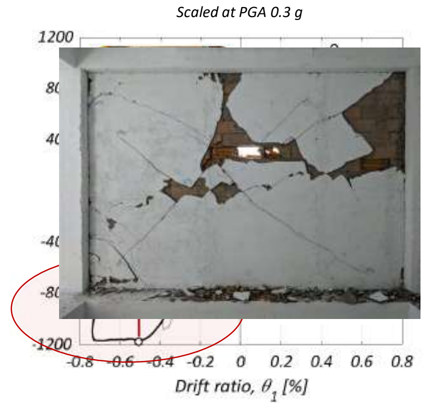
Co-authors: Daniel Pohoryles and Stylianos Kallioras

Joint Research Centre (JRC), European Commission

Innovative Seismic and Energy Retrofitting of the Existing Buildings (iRESIST+)

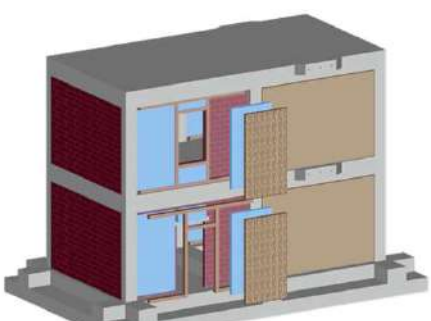
Seismic assessment of a full-scale masonry-infilled RC building

Seismic Testing at a PGA of 0.3g



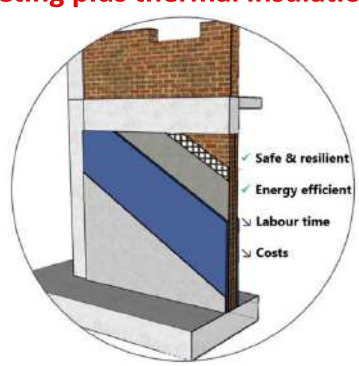
Innovative Seismic and Energy Retrofitting of the Existing Buildings (iRESIST+)

Cross-laminated timber panels plus thermal insulations



MSCA-IF: Project ***NOTICE*** *EUB*

Textile-reinforced mortar (TRM) jacketing plus thermal insulation



Both systems exhibited excellent seismic and energy performance …

Pilot Project: Integrated seismic and energy renovation of buildings

S. Dimova, D. Bournas, J. Cavestro, M. Fabregat, K. Gkatzogias, P. Mariotto, P. Negro, D. Pohoryles, E. Romano, G. Tsionis

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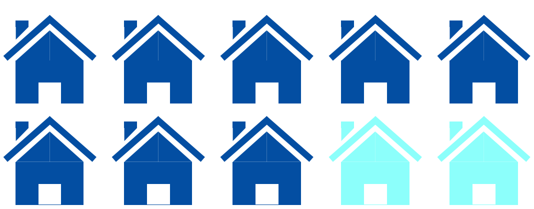
Building stock



8 out of 10 buildings in EU were constructed before 1990

→ high energy consumption
→ vulnerable to earthquakes

New Industrial Strategy for Europe
New Circular Economy Action Plan

EU Disaster Resilience Goals
Action Plan on Sendai Framework
Sustainable Development Goal 11

Green Deal / Renovation wave
New European Bauhaus
Energy Performance of Buildings

European Framework for Action on Cultural Heritage
European Agenda for Culture

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Technologies for seismic & energy renovation

- **Building typologies for combined renovation**
  simplified analysis to identify EU building typologies, focus on Italian building stock
- **Seismic renovation technologies**
  review and classification by life cycle thinking-based criteria and cost analysis
- **Energy renovation technologies**
  review and ranking using a multi-criteria decision-making analysis

Rank	Envelope component	Energy efficiency technologies	Attractiveness for potential investments
1	Wall	Insulation of wall air chamber	High
2	Roof	Internal insulation	High
3	Wall	Internal insulation by cladding	High
4	Roof	External insulation of flat roofs	High
5	Door Window	Weather stripping	Medium
6	Door Window	Replacement	Medium
7	Floor	Insulation systems	Medium
8	Wall	System of façade renovation with cement panels sheathing	Low
9	Roof	External insulation of pitched roofs	Low
10	Wall	Prefabricated units for external wall insulation	Low
11	Wall	External Thermal Insulation Composite System (ETICS)	Low

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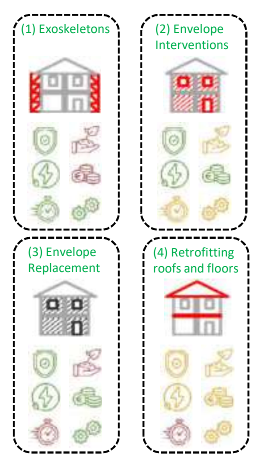
Technologies for combined renovation

- **Novel seismic retrofitting materials**
  analysis of novel seismic renovation technologies highlighting local and global measures to be combined for economic strengthening scheme
- **Technologies for combined renovation**
  assessment of effectiveness, environmental impact and market-readiness of latest developments of materials and technologies



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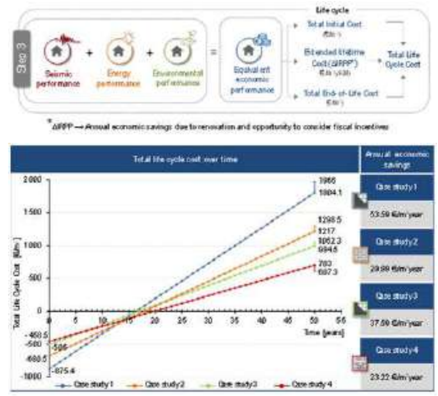
Assessment methodologies

- **Review of methodologies**
  for assessing the benefit of seismic and energy renovation
- **A simplified method**
  a four-step method to assess equivalent costs from a life cycle perspective without employing complex analyses
- **Case study**
  application of methods to four indicative of residential and public buildings



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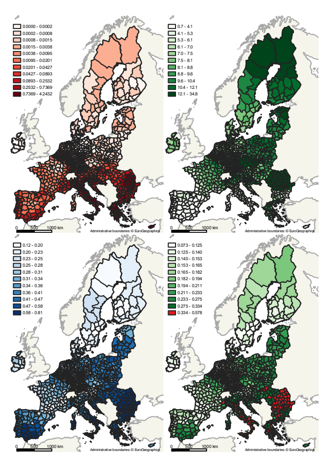
Regional prioritisation and impact

- **State-of-practice in policy measures**
  understand gaps and best practices
- **Priority regions for building renovation**
  integrated analysis framework prioritise regions for building renovation across the EU-27
- **Renovation impact**
  regional impact assessments and cost-benefit analysis for alternative renovation scenarios across the EU-27



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Outreach and dissemination

- **5 science for policy reports**
  foreword by Commissioner Mariya Gabriel
- **7 technical reports**
- **Buildings' renovation makerspace**
  data visualisation
- **Dissemination material**: video, leaflets
- **Events**
  First pilot project workshop 2020
  European Week of Regions and Cities 2020, 2021
  STOA virtual visit 2021
  Youth4Climate 2021
  EU Sustainable Energy Week 2023 (proposal)
  Final pilot project workshop 2023

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Recommendations for policy

- State-of-the-art **evidence** and user-friendly **impact evaluation tools** to **design renovation plans** that are tailored to local needs and leave no one behind
- **Best practices** for enriched **regulatory framework**, financial **instruments**, strategies and digital tools to maximise the benefits of building renovation
- Transfer of knowledge to **standards to accelerate** the implementation
- Increase **awareness of risks and benefits** of renovation
- **Training and certification** of professionals to ensure skills and know-how
- **Research and knowledge needs** to provide improved output: renovation technologies; exposure, performance and cost data

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Preparatory Action: New European Bauhaus Knowledge Management Platform

D. Bournas, S. Dimova, M. Fabregat, K. Gkatzogias, E. Martorana,
P. Negro, D. Pohoryles, M. Poljansek, E. Romano, G. Tsionis

European Commission

Background: Launch of the New European Bauhaus

2020 State of the Union Address

- President Ursula von der Leyen -

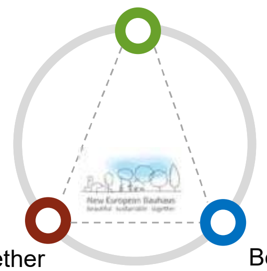
The **New European Bauhaus (NEB)** is an environmental, economic, social and cultural project to combine sustainability, investment, affordability, accessibility and design in order to help deliver the **European Green Deal** and its overarching goal to make **EU** the world's first '**climate-neutral bloc' by 2050**.

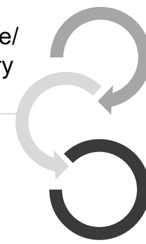
European Commission

The *original* Bauhaus

"form follows function"

NEB Dimensions - Integration | **NEB Principles**





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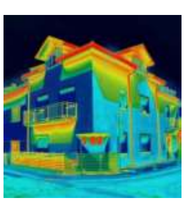
Starting objective: Building and Living spaces

Ageing built infrastructure



High energy consumption

Images source: (top to bottom) Built environment, Jorge Vidal, @unsplash.com; Thermal vision image, smuki, ©stock.adobe.com

2020 State of the Union Address

- President Ursula von der Leyen –

*"Our **buildings generate 40% of our emissions**. They need to become less wasteful, less expensive and more sustainable.*

*I want NextGenerationEU to **kickstart a European renovation wave** and make our Union a leader in the **circular economy**".*

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European Commission

Preparatory Action: Objectives

Aims

- Streamline standards, guidelines, codes of practice related to the **dimensions** of **NEB**.
- Facilitate the access to **funding opportunities** for NEB projects

1. Identification and classification of the available requirements, standards, guidelines, codes of practices related to the **dimensions** of **NEB**.
2. Creation of the **NEB Knowledge Management Platform** to both disseminate the data collected within (1) and serve as a depository of ideas, discussion platform.
3. Development of a **methodology** and an **IT tool** for **self-assessment** of projects by establishing a number of indicators and evaluation criteria related to the **dimensions** of **NEB**.

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Preparatory Action: Activities

Identification and mapping of **sub-areas** relevant to NEB dimensions for **buildings and living spaces**

Overview and classification of existing knowledge (**requirements, standards and codes of practice)** relevant to NEB dimensions **for buildings and living spaces**

Development of **NEB self-assessment method** and IT tool

Handbook on the self-assessment method and IT tool

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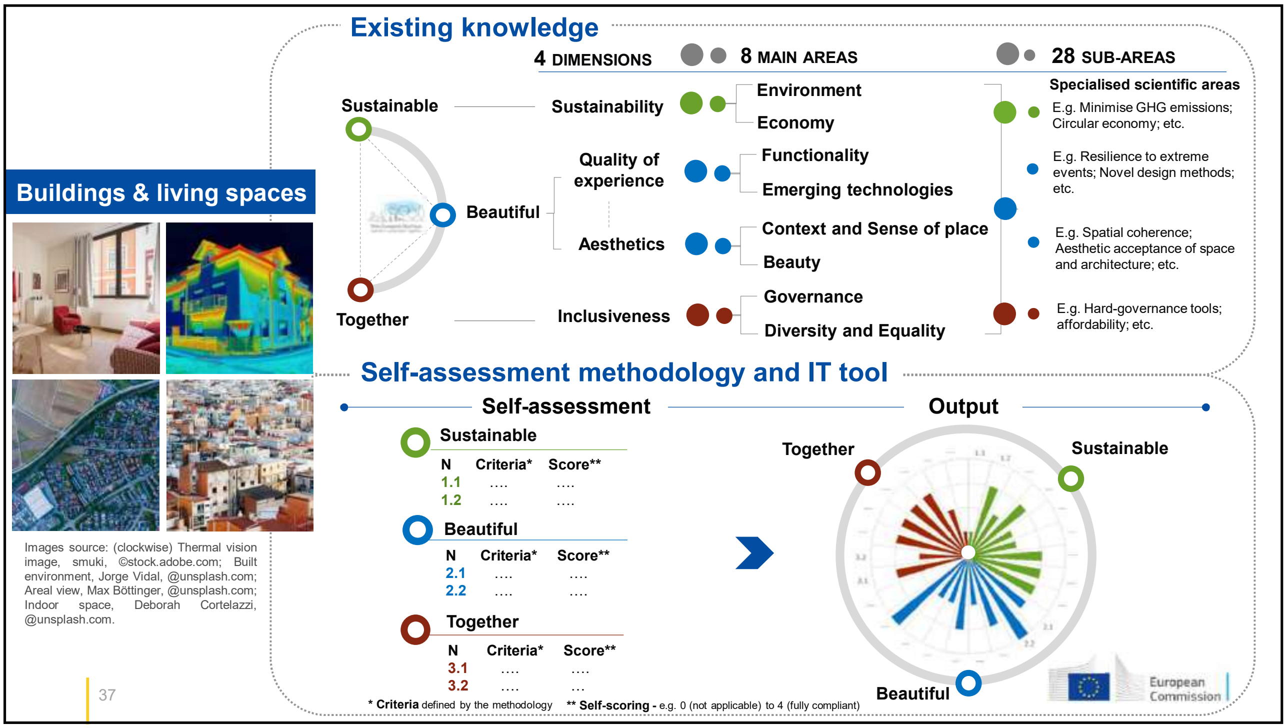
European Commission



Existing knowledge
4 DIMENSIONS
8 MAIN AREAS
28 SUB-AREAS
Sustainable
Beautiful
Together
Sustainability
Quality of experience
Aesthetics
Inclusiveness
Environment
Economy
Functionality
Emerging technologies
Context and Sense of place
Beauty
Governance
Diversity and Equality
Specialised scientific areas
E.g. Minimise GHG emissions; Circular economy; etc.
E.g. Resilience to extreme events; Novel design methods; etc.
E.g. Spatial coherence; Aesthetic acceptance of space and architecture; etc.
E.g. Hard-governance tools; affordability; etc.
Buildings & living spaces
Images source: (clockwise) Thermal vision image, smuki, ©stock.adobe.com; Built environment, Jorge Vidal, @unsplash.com; Areal view, Max Böttinger, @unsplash.com; Indoor space, Deborah Cortelazzi, @unsplash.com.
Self-assessment methodology and IT tool
Self-assessment
Output
Sustainable
N Criteria* Score**
1.1 ....
1.2 ....
Beautiful
N Criteria* Score**
2.1 ....
2.2 ....
Together
N Criteria* Score**
3.1 ....
3.2 ....
* Criteria defined by the methodology
** Self-scoring - e.g. 0 (not applicable) to 4 (fully compliant)
Together
Sustainable
Beautiful
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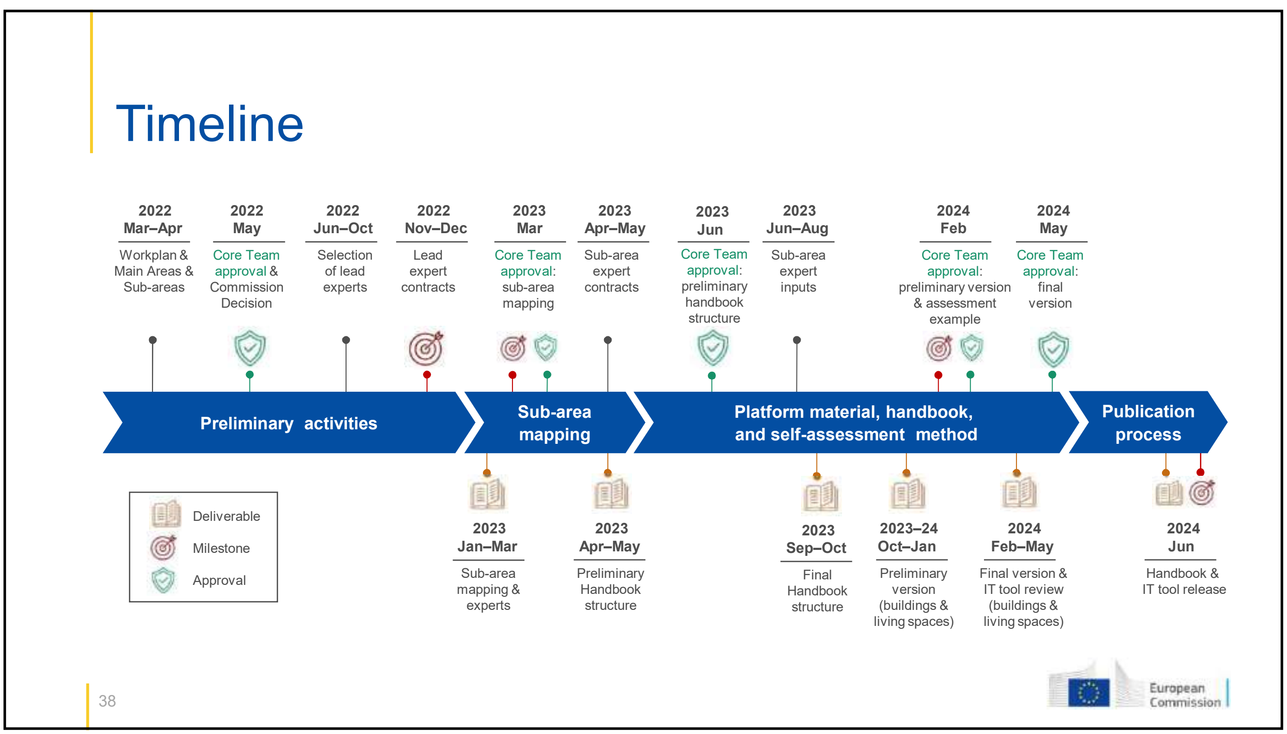
European Commission



Timeline
2022 Mar–Apr
Workplan & Main Areas & Sub-areas
2022 May
Core Team approval & Commission Decision
2022 Jun–Oct
Selection of lead experts
2022 Nov–Dec
Lead expert contracts
2023 Mar
Core Team approval: sub-area mapping
2023 Apr–May
Sub-area expert contracts
2023 Jun
Core Team approval: preliminary handbook structure
2023 Jun–Aug
Sub-area expert inputs
2024 Feb
Core Team approval: preliminary version & assessment example
2024 May
Core Team approval: final version
Preliminary activities
Sub-area mapping
Platform material, handbook, and self-assessment method
Publication process
Deliverable
Milestone
Approval
2023 Jan–Mar
Sub-area mapping & experts
2023 Apr–May
Preliminary Handbook structure
2023 Sep–Oct
Final Handbook structure
2023–24 Oct–Jan
Preliminary version (buildings & living spaces)
2024 Feb–May
Final version & IT tool review (buildings & living spaces)
2024 Jun
Handbook & IT tool release
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European Commission

where is seismic safety?

- **SUSTAINABLE**: Retrofitting older buildings to incorporate seismic safety can help to **reduce** the need for future **repairs** or **replacements**, which ultimately reduces **waste**, conserves **resources**, and minimizes the environmental **footprint** of buildings.

- **TOGETHER**: By making buildings safer in the event of an earthquake, people of all abilities can feel more **secure** and **confident** in using and occupying these spaces.

- **AESTHETICS**: seismic safety measures can be integrated into the design of buildings in a way that enhances their visual appeal. By incorporating the **latest technology** and architectural design techniques into seismic safety measures, buildings can look **modern**, **sleek**, and **stylistically appealing**.

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European Commission

Expected outcomes of this workshop

Paolo Negro

European Commission, Joint Research Centre

European Commission

Today's aims

- To present an updated state-of-the-art of published results, being prepared by a team of WG members.
- To complement the state of the art with recent and ongoing relevant activities performed in EU countries.
- To discuss the possibilities for aligning the current European efforts for the renovation of buildings with the increase of seismic safety.
- To produce an informal set of proceedings which will represent the starting point towards an EAEE position paper.

I have a dream…

- Improving the **energy efficiency** of existing buildings in Europe is not just a noble goal, but a crucial necessity in meeting climate change objectives.
- Failing to seize this opportunity to simultaneously enhance their **seismic safety** would be a waste of valuable resources.
- **There is much more than energy efficiency in environmental performance**. A thorough **life cycle analysis approach** that addresses both **energy efficiency** and **safety** would lead to the **environmental rehabilitation** of the European building stock.
- By also incorporating ideals of **inclusion** and **aesthetic** into this holistic approach, this would result in a unique and proud **European strategy for building rehabilitation.**

Integrated retrofitting of existing buildings considering life cycle approaches: a literature review

State-of-the-art review paper

resp. L. Felicioni[1], M. Caruso[2], C. Passoni[3], N. Kyriakides[4], N. Ademovic[5]

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PAPER STRUCTURE

PART A

Systematic literature research on sustainable retrofitting strategies

PART B

Review of integrated retrofitting techniques and qualitative LCT evaluations

WG15 Summer Workshop

PAPER OUTLINE

1. **Introduction: the evolution of the concept of sustainable retrofit interventions**
   - pillars of sustainability (economic, environmental, social)
   - integrated retrofitting interventions
   - green building rating systems (GBRSs)
   - taxonomy of sustainable retrofitting strategies
   - evolution of the concept of sustainability

1. **State-of-the-art literature review**
   - systematic literature review: keywords
   - identification of common clusters
   - interpretation of results

PART A

1. **Review of integrated retrofitting techniques**
   - review of integrated and LCT-compliant techniques
   - qualitative LCT evaluations
   - case-study applications

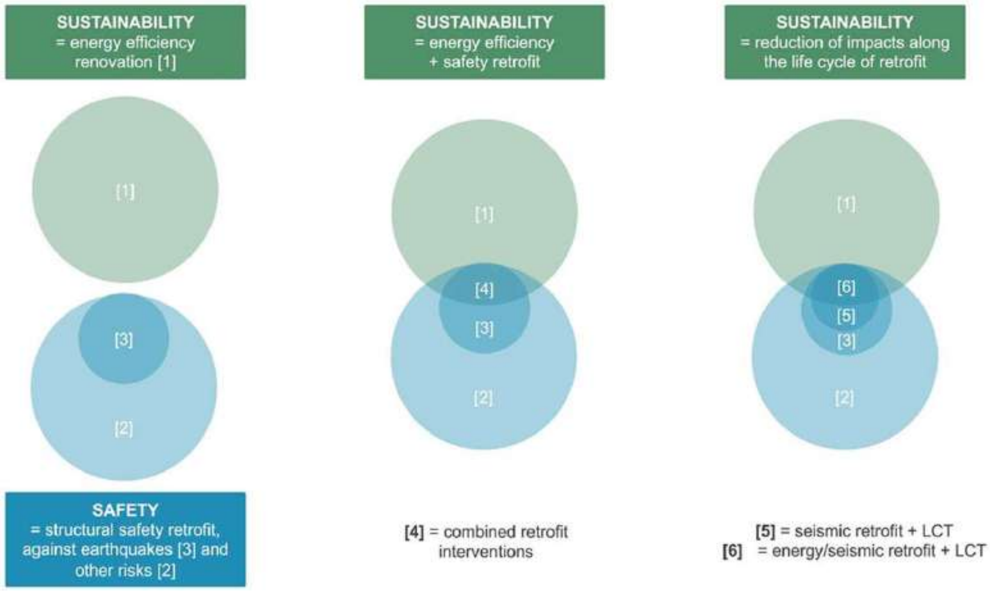
PART B

1. **Concluding remarks**

TAXONOMY OF SUSTAINABLE RETROFITTING STRATEGIES

	ECONOMIC SUSTAINABILITY	ENVIRONMENTAL SUSTAINABILITY	SOCIAL SUSTAINABILITY
ENERGY EFFICIENCY INTERVENTIONS	•Value creation •Use phase costs minimization	•Use phase impacts minimization	•Thermal comfort •Lighting/visual comfort
COMFORT/ ARCHITECTURAL INTERVENTIONS	•Value creation		•Indoor air quality •Acoustic comfort
STRUCTURAL SAFETY INTERVENTIONS	•Value creation •Use phase costs minimization	•Use phase impacts minimization	•Injuries and fatalities limitation •Downtime and homeless reduction •Property loss avoidance
INTEGRATED INTERVENTIONS (energy + comfort/architectural + structural interventions)	+ •Construction phase costs minimization	+ •Construction phase impacts minimization	+ •Downtime reduction during construction •Inhabitant disturbance reduction during construction
LCT-BASED INTERVENTIONS AND CIRCULARITY	+ •Production / Construction / Use / End-of-Life phase costs minimization	+ •Production / Construction / Use / End-of-Life phase costs minimization	+ •Adaptability

EVOLUTION OF THE CONCEPT OF SUSTAINABILITY



PART A

SYSTEMATIC LITERATURE REVIEW

PART A

SYSTEMATIC LITERATURE REVIEW

Keywords selection

BUILDINGS

RETROFIT

SEISMIC SAFETY

ENERGY EFFICIENCY

EARTHQUAKE

LIFE CYCLE

STRUCTURE

LCT

DURABILITY

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PART A

SYSTEMATIC LITERATURE REVIEW

Records **screening**

692 records (Scopus, Web of Science and manual research)
2012-2022

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PART A

SYSTEMATIC LITERATURE REVIEW

Records
eligibility

1st step | 166 records
2nd step | **64 records**

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PART A

SYSTEMATIC LITERATURE REVIEW

Clustering

2 main clusters
4 sub-clusters
9 sub-groups

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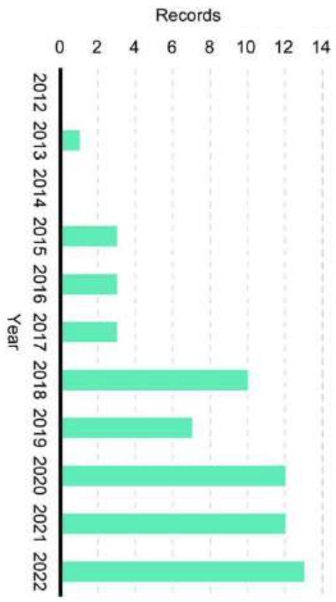
SYSTEMATIC LITERATURE REVIEW

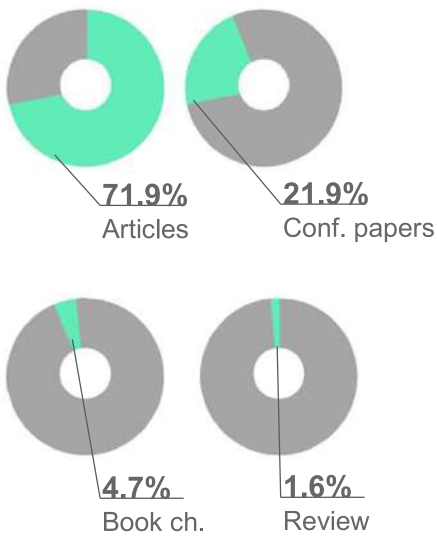
Results
interpretation

Starting point for PART B

ELIGIBLE PAPERS ANALYSIS

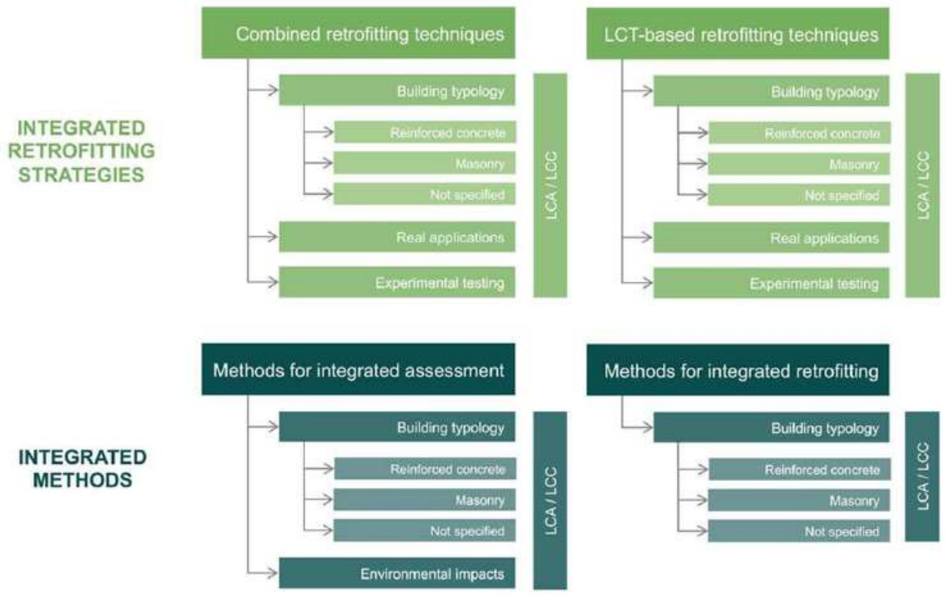


Last 5 years
Increased interest
for this topic



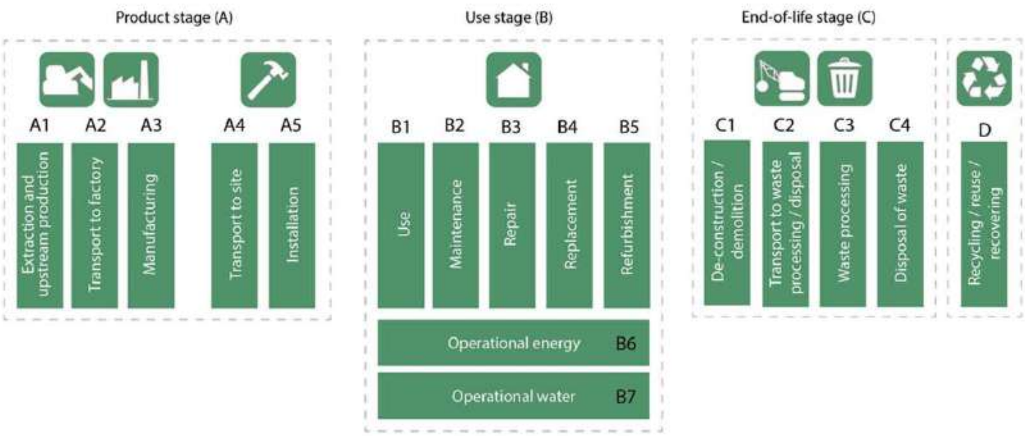
PART A

IDENTIFICATION OF COMMON CLUSTERS



PART B

EXAMPLE OF LCT-BASED RETROFITTING TECHNIQUE



- Sustainable materials
- Dry technique
- Prefabrication

- Modularity
- Adaptability
- Localization of damage

- Demountability
- Recyclability
- Reusability

Thank you very much for your attention!

resp. L. Felicioni, co-authors M. Caruso, C. Passoni, N. Kyriakides, N. Ademovic

Integrated retrofitting of existing buildings considering a life cycle thinking approach: a literature review

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1. Background

In the European Union, the existing building stock contributes to 50% of raw material depletion and 40% of energy consumption, being responsible for 36% of greenhouse gas emissions and a third of waste production [1], while 75% of the existing built environment is vulnerable to earthquakes and energy inefficient and fails to meet modern seismic and energy efficiency requirements [2]. In the last years, many studies focused on the integrated retrofitting of the existing building stock, proposing new combined retrofit techniques and strategies. In addition, some other studies and EU guidelines (such as Level(s)), proposed to further improve the sustainability of the existing buildings by integrating some Life Cycle Thinking (LCT) principles in the retrofitting and strengthening processes, i.e., by using materials and components with low embodied impacts, by reducing the operational impacts of buildings (e.g., earthquake-induced losses, energy consumption, etc.), etc. [3]. Specifically, this sustainable integrated approach will result in a reduction of CO_2 emissions along the whole building life cycle beyond the sole operational phase [4].

Working Group 15 of the European Association of Earthquake Engineering aims to identify methods to facilitate the implementation of large-scale combined energy-seismic retrofits [5]. For this reason, extensive literature research has been conducted on integrated interventions, going beyond purely combined energy and seismic retrofitting, and including LCT aspects such as durability, adaptability, and recyclability. The research was indeed focused on sustainable retrofitting and identified the current state of the art in terms of materials, technologies, and methods proposed for the sustainable retrofitting of existing buildings. Despite the fact that a number of review papers on integrated solutions are available in the current scientific literature - for example, the study published by [6] - the most significant innovation presented by this literature review is the analysis of different solutions adopting a life cycle thinking (LCT) approach - as suggested by [3].

2. Paper structure

The review paper starts with an introduction that provides a brief overview of the history and development of the concept of sustainable retrofitting of buildings. This will be followed by a more detailed analysis of the current global best practices for the sustainable retrofitting of buildings, including a discussion of the different renovation strategies used in different countries. Finally, the paper will discuss the potential implications of these strategies for green building rating systems (GBRSs) in terms of economic, environmental, and social sustainability. The paper is divided into two main sections, as shown in Figure 1.

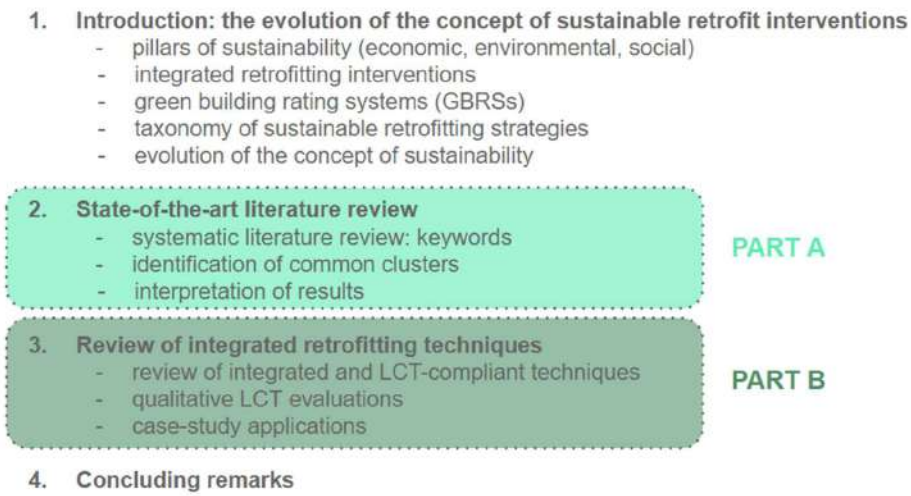

Figure 1. Review paper outline. Visualization made by authors.

In Part A, a systematic literature review is conducted on sustainable retrofitting strategies, including both retrofitting techniques and methods. Instead of focusing solely on energy efficiency and structural safety, this review takes into account LCT principles as well. It was, moreover, the objective of this study to investigate the potential of retrofitting strategies to address a variety of hazards (e.g., floods, heavy storms, fires, etc.) rather than solely earthquakes while simultaneously improving energy efficiency and structural safety. However, no results have been obtained regarding other hazards besides earthquakes.

Part B of the paper provides an exhaustive review of integrated retrofitting techniques, followed by a thorough qualitative evaluation of case studies that are grounded in LCT principles.

3. Taxonomy of sustainable retrofitting strategies

A comprehensive taxonomy of retrofitting measures has been developed under a sustainable perspective, which includes their contribution to the enhancement of the economic, environmental, and social sustainability of buildings using some of the indicators developed within the Level(s) framework [7] (Figure 2).

Energy efficiency interventions contribute to the buildings' economic value increase, the minimisation of costs and environmental impacts related to operational energy use, and the improvement of thermal comfort inside the building, as well as lighting/visual comfort.

Architectural interventions in the building, including e.g., the introduction of new lighting systems or acoustic insulation layers, increase the economic value of the building while also improving the lighting/visual, acoustic, and living quality indoors.

Structural safety interventions to improve buildings' vulnerability against seismic hazard, climate change-related risks, and any other kind of risk (e.g. wind or fire) do contribute as well to the increase of economic value, but more importantly, are intended to limit direct and indirect economic, environmental and social losses due to damage and repair after any kind of hazardous event (for instance, reducing potential injuries and fatalities, business inactivity, property loss in case of severe damage, etc.).

Combined/integrated (seismic + energy + architectural) strategies, instead, provide all the economic, environmental, and social improvements described for 'sectorial' retrofitting interventions above while also taking advantage of the reduction of cost, environmental impact, and duration of the shared construction activities (with consequently limited disturbance to occupants).

Lastly, retrofitting techniques designed according to LCT principles, in addition to all the advantages discussed for integrated retrofitting strategies, also explicitly address the minimisation of other life cycle stages' costs and environmental impacts (e.g., those related to maintenance and end-of-life treatment) while also guaranteeing the adaptability to climate change and the potential future needs of occupants [3]. This taxonomy of sustainable retrofitting strategies undoubtedly highlights the multiple advantages of LCT-based techniques if compared to all the other approaches.

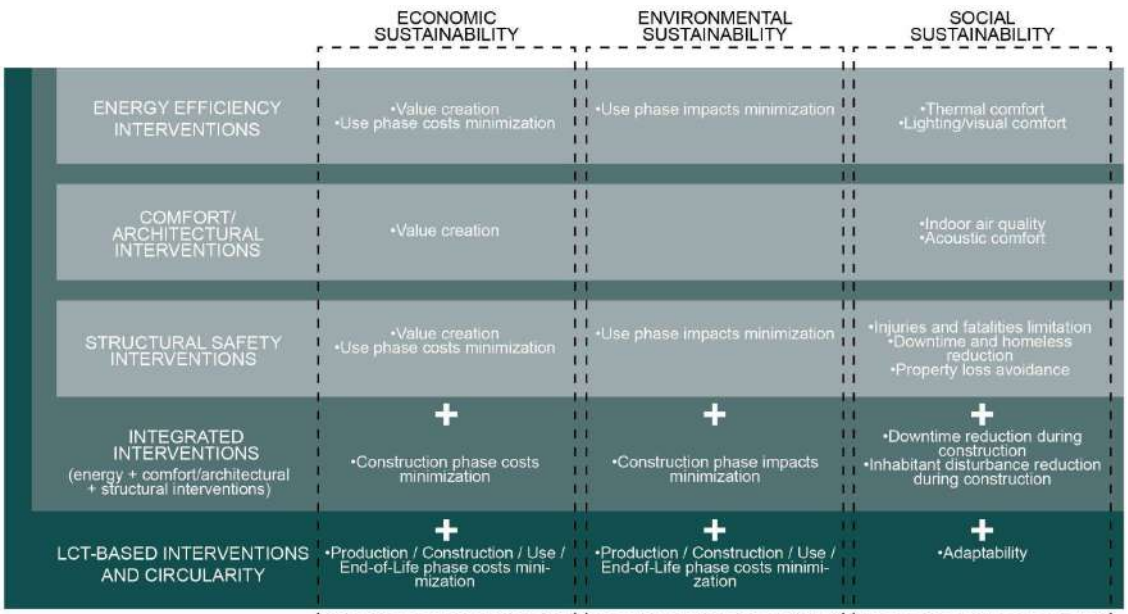

Figure 2. Sustainable retrofitting strategies: a taxonomy. Visualization made by authors.

4. Systematic literature review

The first step of the literature research was to define keywords (Figure 3). This allowed us to narrow our research by focusing on specific topics and concepts. We then used these keywords to search for relevant articles in the Web of Science and Scopus electronic databases in a 10-year time range (2002-2022).

Figure 3. Systematic literature review steps. Visualization made by authors.

4.1 Evolution of the concept of sustainability

Throughout the past several decades, a progressive evolution of the concept of sustainability in the construction sector has led to differences among the different types of retrofitting strategies described in the above-shown taxonomy (Figure 2).

Figure 4 shows a graphical representation of the results obtained at the beginning of the review process. The concept of sustainability was indeed initially associated only with energy efficiency [1], whereas structural safety [2] and safety against seismic risk [3] were typically treated separately. More recently, structural safety (including seismic risk mitigation) was recognized as one of the relevant targets of a broader concept of sustainability [4].

Specifically, the group [4] refers to seismic and energy retrofitting strategies that are integrated or combined. Nowadays, a comprehensive and holistic view of building renovation promotes, however, a more comprehensive and holistic approach addressing the life cycle impact of retrofits as well as the building itself. Group [5] refers to seismic strengthening techniques specifically designed according to LCT principles. Lastly, group [6], which is still the smallest group, is instead representing the limited number of papers where LCT-compliant seismic/energy retrofitting techniques are collected.

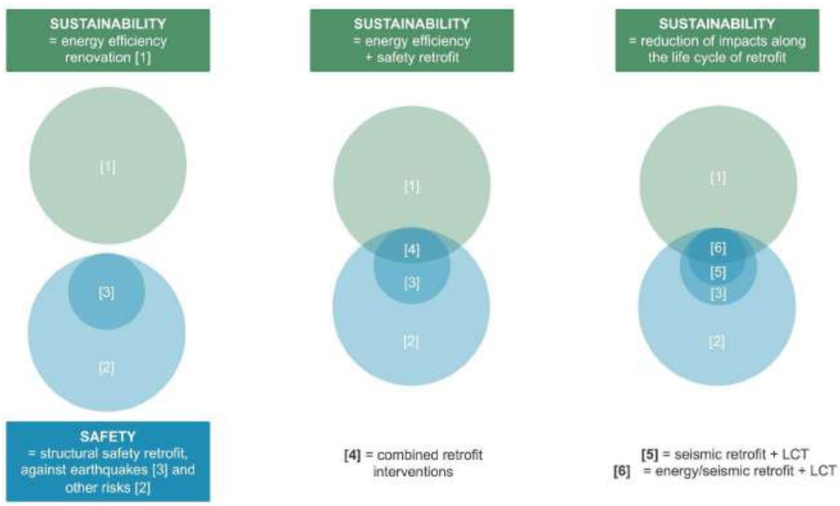

Figure 4. Definition of the domain of investigation. Visualization made by authors.

4.2 Eligible papers analysis

As a result of the first results screening, based on the selected keywords, 692 records were identified from two databases and manual research over a 10-year period. There was then a two-step eligibility process (i.e. full-text reading) that resulted in 64 records being eligible. According to those results, interest in this topic has significantly increased over the past five years, while it was close to zero from 2012 to 2014. It is also important to note that the majority of the records are peer-reviewed articles, and the remaining ones are conference papers (Figure 5).

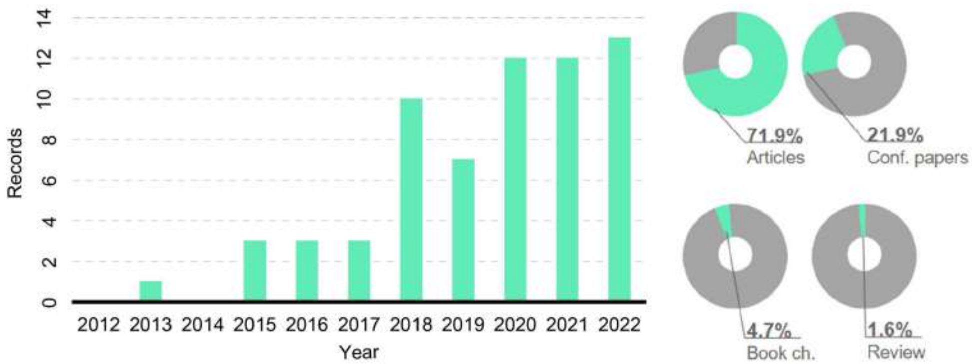

Figure 5. On the left: eligible records. On the right: Records divided per typology. Visualizations made by authors.

4.3 Identification of common clusters

As a result of the analysis of the selected records, two main clusters were identified, namely integrated retrofitting strategies and integrated methods (Figure 6). Within the first cluster, there are two subclusters: the first is concerned with retrofitting techniques that are coupled or integrated (e.g., [8,9]), and the second with LCT-based techniques (e.g., [10]). Additionally, another subdivision has been made according to the building typology in which the retrofitting strategy has been applied, and based on the fact that it was adopted in a real application (e.g., [11]) or experimentally tested (e.g., [12]). Within the second cluster, instead, there are two subclusters: the former is related to methods for the integrated assessment (e.g., [13]), while the latter to methods for the integrated retrofitting (e.g., [14]). Nevertheless, an additional subdivision has been made based on the building type (e.g., [15,16]).

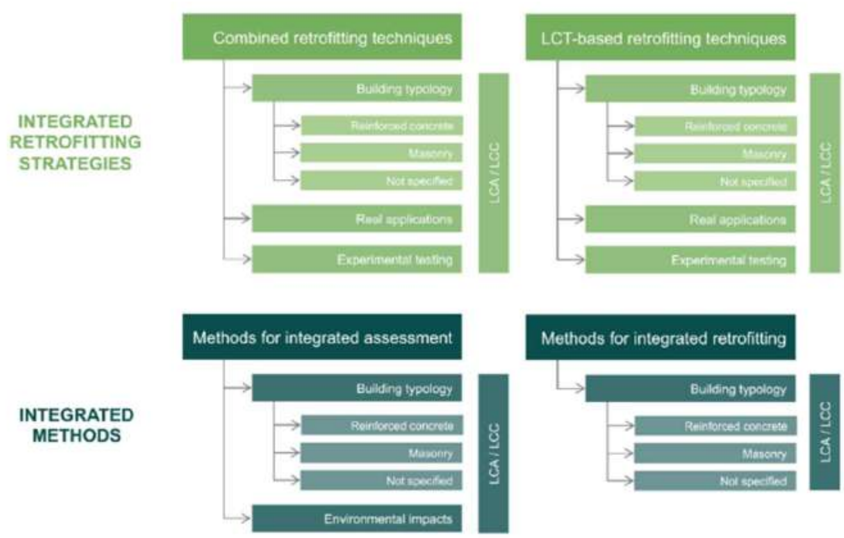

Figure 6. Clusterization of results. Visualization made by authors.

5. Example of an LCT-based retrofitting technique

A detailed description of some examples of LCT-based integrated retrofitting techniques (group [6] from Figure 4) is expected as part B of the paper, as well as a qualitative evaluation of the potential to adopt an LCT approach to reduce the environmental impact at various stages of the life cycle of retrofit components. Here is an example of an application to a wood exoskeleton designed by [17] in Italy. Starting from the product stage, the choice of sustainable materials, the use of a dry technique and the prefabrication of retrofit components are only a few of the LCT principles that were considered for a significant reduction of impacts related to the production and construction phases. Additionally, the use of modular techniques, which are adaptable to future building needs and designed to minimize damage to individual components during use, may be useful in limiting the impact of such activities during operation. As a final point, the use of easily demountable components and recyclable and reusable materials will undoubtedly reduce the environmental impact of end-of-life processes for components and materials.

6. Concluding remarks

This paper discusses the literature review effort carried out by a group of researchers of the Working Group 15 of the European Association of Earthquake Engineering. In the literature review, it was noted that the topic of integrated retrofitting of buildings is gaining interest in the scientific community, but that there is still a limited amount of literature addressing retrofit interventions inspired by LCT principles, which is a missed chance to really improve the sustainability of the existing building stock, as envisioned by the New European Bauhaus [18] and the international climatic goals.

Acknowledgements

This work has been done under the auspices of the European Association for Earthquake Engineering (EAEE), WG15, on "Combined seismic and environmental upgrading of existing buildings".

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EAEE Summer Workshop WG15
June 22nd , 2023

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Sotiria Stefanidou *Dr. Civil Engineer AUTh*
Vice President & Director SURE , Vice President of the Hellenic Society of Earthquake Engineering (ETAM)
Olga Markogiannaki *Dr. Civil Engineer AUTh, President & Director SURE*
Anna Karatzetzou *Dr. Civil Engineer AUTh*
Charoula Zaki, *Civil Engineer AUTh* & Anna Diamanti, *Chemical Engineer UoWM*

SURE Competence Center, Greece

02

Introduction

03

Introduction

1
Earthquake event

2
Damage and losses

3
Pre-earthquake assessment
Ranking of buildings within inventories (seismic classes)
Retrofit prioritization

1
Climate change and C02 emissions

2
EU targets for energy consumption decrease

3
Energy efficiency estimation of existing structures
Energy class calculation

Summer Workshop WG15

Introduction | Methodology | Case Study | Conclusions

SURE

04

State of the art

- Seismic performance assessment
  - Based on fragility & vulnerability curves relating damage to monetary losses
  - Direct loss functions & functionality curves
  - Indexes for prioritization : Seismic Resilience Index (SRI), Robustness Index
  - Risk ranking system, building score 1st and 2nd stage assessment
- Energy efficiency assessment
  - Energy classes according to primary energy consumption
  - Classification system
- Combined seismic & energy assessment
  - Mainly in economic terms (EAL)

Summer Workshop WG15

Introduction | Methodology | Case Study | Conclusions

SURE

05

Study Objectives

- Propose a new methodology for the combined seismic & energy assessment of buildings introducing a bivariable Structural & Energy Index for ranking and prioritization
- Introduce a performance-based Structural Prioritization Index (SPI) that accounts for performance at different limit states and hazard scenarios (relating LS to T_p)
- Introduce an Energy Prioritization Index (EPI) based on the primary energy consumption and classification to energy classes

Summer Workshop WG15

Introduction | Methodology | Case Study | Conclusions

SURE

06

Methodology

- Structural Prioritization Index
- Energy Prioritization Index
- Combined SPI & EPI

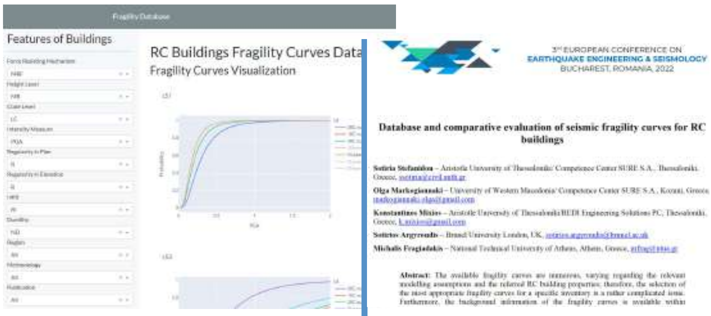
Summer Workshop WG15

Introduction | Methodology | Case Study | Conclusions

SURE

07

Structural Prioritization Index



Step 1 Identification of the building (or buildings within inventory) properties

Step 2 Building classification according to the structural properties to the classes of the database

Step 3 Input of the building parameters to the fragility curve database

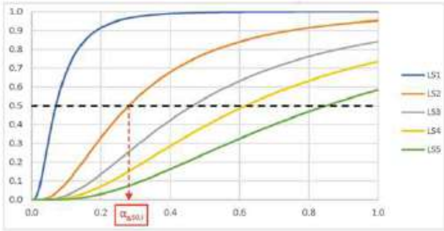
Stefanidou et al. (2022)

Limit State / Engineering Demand Parameter	LS1 (Light)	LS2 (Minor)	LS3 (Moderate)	LS4 (Major)	LS5 (Collapse)
Global Drift (%)	0.18 – 0.27	0.118 – 0.78	0.457	0.847 – 1.51	
Interstorey Drift (%)	0.05–0.1	0.3 – 0.5	0.5–1.15	0.8–2.8	1.0–4.36
1st Storey Drift (%)	-	0.57	-	1.2	2.3
Park Ang Damage Index	0.1	-	0.25	0.4–0.5	0.5–1.0
Loss Index	0.5	1	10	30	60
% Loss (%)	2	-	10	50	100

Step 4 Fragility curves of the selected buildings at 5 Limit States (LS)

$$SF_i = \frac{a_{g,50,i}}{a_{g,LSi}}$$

$ag_{,50,i}$ calculation



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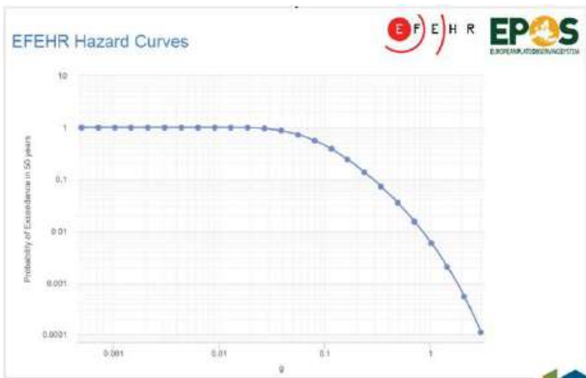
Structural Prioritization Index

Step 5 Correlation of LS_i to the corresponding Performance Level (PL) and return period (T_p), i.e. the hazard scenario

Matching between LS_i (Limit State) / PL_i (Performance Level) and T_p (return period)					
Building Consequence Class (CC)	T_p (years)				
	LS: LS1 (Slight) PL: OP (Operationality)	LS: LS2 (Minor) PL: DL (Damage Limitation)	LS: LS3 (Moderate) PL: SD (Significant Damage)	LS: LS4 (Major) PL: NC (Near Collapse)	LS: LS5 (Collapse) PL: C (Collapse)
CC1 - Minor importance for public safety	30	50	50	250	800
CC2 - Ordinary	40	60	60	475	1600
CC3a - Important consequences associated with collapse	40	60	60	800	2500
CC3b - Vital importance for civil protection	80	100	100	1600	5000

seismic hazard assessment using EFEHR web platform

$ag_{,LSi}$ calculation



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Structural Prioritization Index

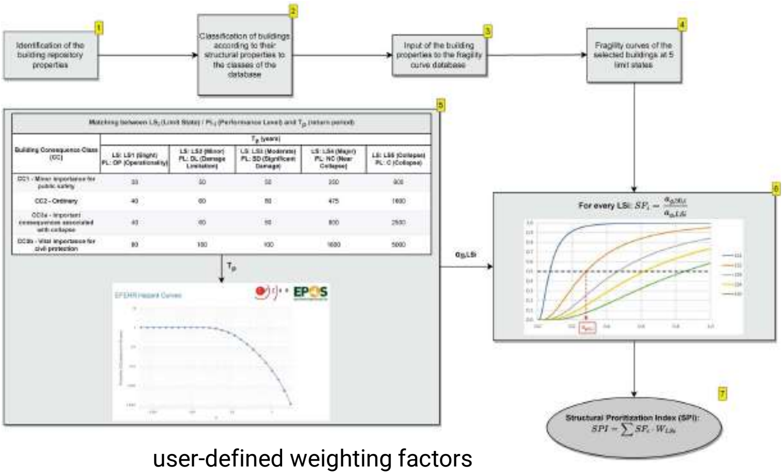
Step 6 Calculation of Safety Factor (SF_i) for every Limit State (LS_i)

$$SF_i = \frac{a_{g,50,i}}{a_{g,LSi}}$$

SFi < 1.0 , high prioritization

Step 7 SPI calculation using weighting factors for each Performance Level

$$SPI = \sum_{i=1}^{5} SF_i \cdot W_{LSi}$$



user-defined weighting factors for each Performance Level

Wi				
LS1	LS2	LS3	LS4	LS5
0.125	0.125	0.125	0.50	0.125

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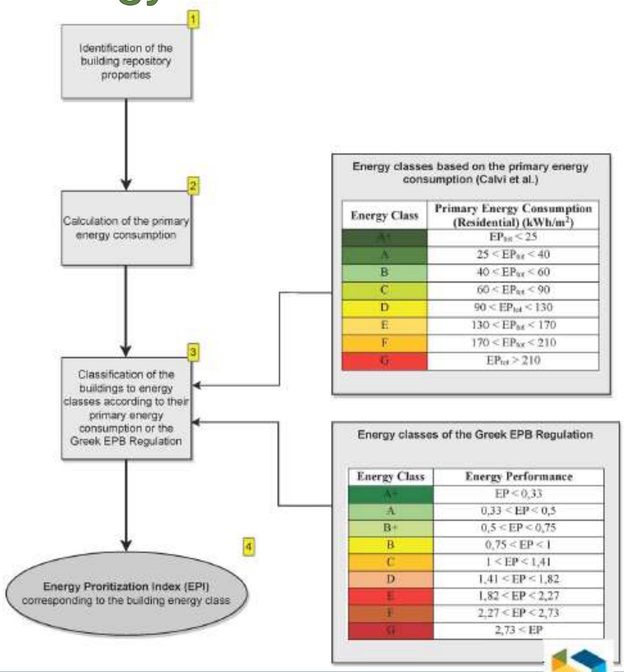
Energy Prioritization Index

Step 1 Identification of the building (or buildings within inventory) properties

Step 2 Calculation of the primary energy consumption

Step 3 Building classification to energy classes according to their primary energy consumption or Greek EPB (Energy Performance of Buildings) Regulation

Step 4 Energy Prioritization Index (EPI) estimation based on the building energy class



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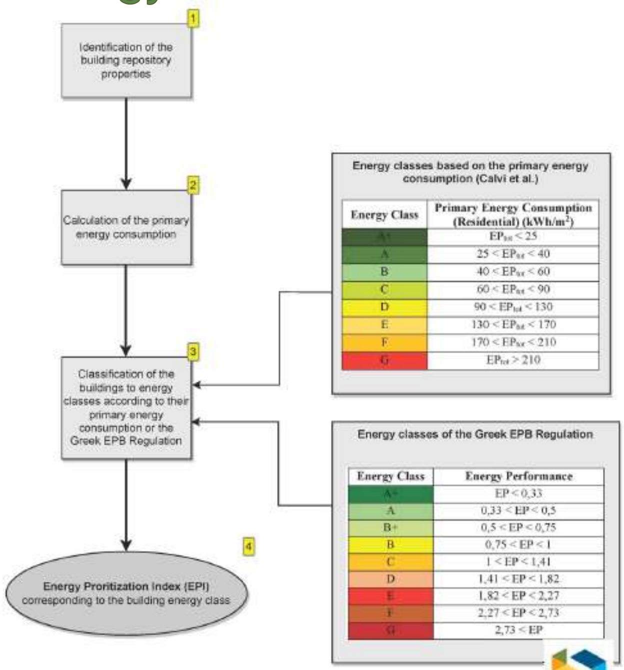
Energy Prioritization Index

Energy Class	EPI
A+	1
A	2
B+	3
B	4
C	5
D	6
E	7
F	8
G	9



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SPI and EPI index

Combined index estimation for the prioritization of seismic and energy retrofit interventions

Prioritization Level	SPI
High (S1)	<1
Medium (S2)	1 - 2.5
Low (S3)	>2.5

Prioritization Level	EPI
High (E1)	1, 2, 3
Medium (E2)	4, 5, 6
Low (E3)	7, 8, 9

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Case Study

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Structural Prioritization Index

1 Identification of the building properties

2 Building classification according to the structural properties to the classes of the database

3 Input of building parameters to the fragility curve database

4 Case Studies

Building	Properties							
	Force Resisting Mechanism	Height Level	Code Level	Intensity Measure	Plan/ Elevation Regularity	Infill	Ductility	Energy class
A	Moment-Resisting Frame	Mid Rise (4-7)	Low Code	PGA	Regular/ Regular	Regular Infill	Non-Ductile	F
B	Moment-Resisting Frame with shear Walls	Low Rise (1-3)	Non-Code	PGA	Irregular/ Irregular	Regular Infill	Non-Ductile	G
C	Moment-Resisting Frame	Low Rise (1-3)	Low Code	PGA	Regular/ Regular	Regular Infill	Non-Ductile	G
D	Moment-Resisting Frame	Mid Rise (4-7)	Low Code	PGA	Regular/ Regular	Irregular Infill	Non-Ductile	E

Stefanidou et al. (2022)

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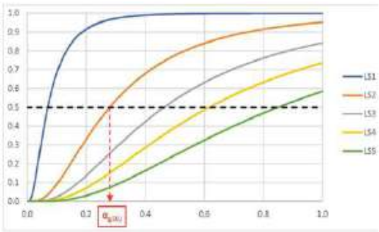
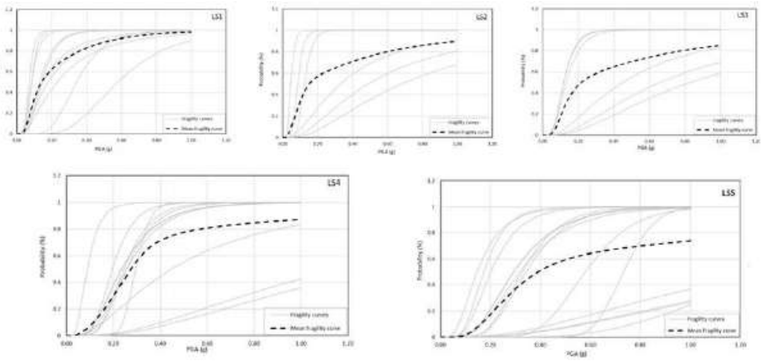
Structural Prioritization Index

4 Fragility curves of the selected buildings for 5 Limit States (LS)

↓

$ag_{,50,i}$ calculation





Building	LS1 (Slight)	LS2 (Minor)	LS3 (Moderate)	LS4 (Major)	LS5 (Collapse)
	$a_{g,50,i}$				
A	0.021	0.090	0.199	0.218	0.311
B	0.070	0.280	0.464	0.618	0.850
C	0.142	0.152	0.217	0.276	0.391
D	0.020	0.021	0.083	0.117	0.283

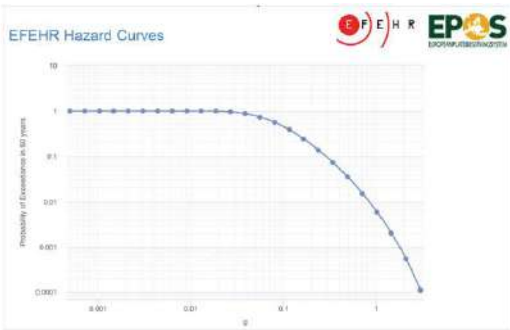
Structural Prioritization Index

5 Correlation of LS_i to the corresponding Performance Level (PL) and return period (T_p), i.e. the hazard scenario

↓

$a_{g,LSi}$ calculation

Matching between LS_i (Limit State) / PL_i (Performance Level) and T_p (return period)					
Building Consequence Class (CC)	T_p (years)				
	LS: LS1 (Slight) PL: OP (Operationality)	LS: LS2 (Minor) PL: DL (Damage Limitation)	LS: LS3 (Moderate) PL: SD (Significant Damage)	LS: LS4 (Major) PL: NC (Near Collapse)	LS: LS5 (Collapse) PL: C (Collapse)
CC1 - Minor importance for public safety	30	50	50	250	800
CC2 - Ordinary	40	60	60	475	1600
CC3a - Important consequences associated with collapse	40	60	60	800	2500
CC3b - Vital importance for civil protection	80	100	100	1600	5000



Building	LS1 (Slight)	LS2 (Minor)	LS3 (Moderate)	LS4 (Major)	LS5 (Collapse)
	$a_{g,LSi}$				
	T_P years (CC2)				
	40	60	60	475	1600
A	0.049	0.066	0.066	0.223	0.397
B	0.052	0.069	0.069	0.227	0.380
C	0.058	0.078	0.078	0.279	0.511
D	0.058	0.078	0.078	0.270	0.490

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Structural Prioritization Index

6 SPI calculation using weighting factors for each Performance Level

$$SPI = \sum_{i=1}^{5} SF_i \cdot W_{LSi}$$

Building	SPI
A	1.19
B	3.16
C	1.49
D	0.50

Building	SFi				
	LS1	LS2	LS3	LS4	LS5
A	0.429	1.364	3.015	0.978	0.783
B	1.346	4.058	6.725	2.722	2.237
C	2.448	1.949	2.782	0.989	0.765
D	0.345	0.269	1.064	0.433	0.578

Wi				
LS1	LS2	LS3	LS4	LS5
0.125	0.125	0.125	0.50	0.125
0.125	0.125	0.125	0.50	0.125
0.125	0.125	0.125	0.50	0.125
0.125	0.125	0.125	0.50	0.125

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Energy Prioritization Index

1 Identification of the building properties

2 Calculation of the primary energy consumption

3 Building classification to energy classes according to the Greek EPB (Energy Performance of Buildings) Regulation

4 Energy Prioritization Index estimation

Building	Total primary energy consumption (kWh/m2)		Energy class	EPI
	Inspected building	Reference building		
A	316.3	128.6	F	2
B	491.2	177.0	G	1
C	1041.7	183.6	G	1
D	335	174.3	E	3

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Combined SPI & EPI Index

Building	SPI	EPI
A	1.19	2
B	3.16	1
C	1.49	1
D	0.50	3

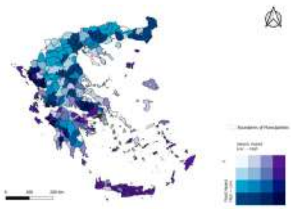
Prioritization Level	SPI
High (S1)	<1
Medium (S2)	1 - 2.5
Low (S3)	>2.5

Prioritization Level	EPI
High (E1)	1, 2, 3
Medium (E2)	4, 5, 6
Low (E3)	7, 8, 9

Building	SPI	EPI
A	S2 (Medium)	E3 (High)
B	S1 (Low)	E3 (High)
C	S2 (Medium)	E3 (High)
D	S3 (High)	E3 (High)

3x3 color cell matrix

	E1 (Low)	E2 (Medium)	E3 (High)
S1 (Low)			Building B
S2 (Medium)			Building A, C
S3 (High)			Building D



Karatzetzou et al., 2022

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Conclusions

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CONCLUSIONS

- Further investigation on the combined seismic and energy assessment of RC structures.
- The applicability of the proposed methodology is confirmed through the implementation of a case study with a minimal set of required parameters.
- A qualitative index is proposed, to prioritize seismic and energy interventions. Include to code provisions, funding schemes (e.g. Sismabonus, Italy)

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Acknowledgments

This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme "Competitiveness Entrepreneurship Innovation 2014-2020" in the action «Competence Centers» in the context of the project "Competence Center for a Sustainable and Resilient Built Environment using smart technologies" (MIS 5130744).

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✓ SURE's establishment (1/12/2021) is funded by the European Union

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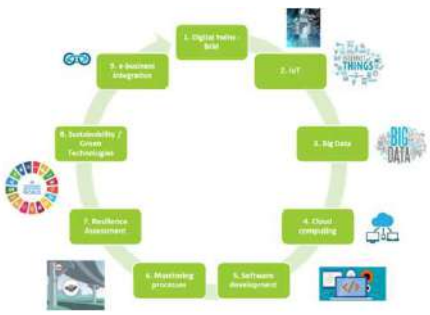
✓ 3 Construction Companies

✓ 1 Real Estate Company

✓ 1 Software development start-up company

✓ 1 IT research driven start-up company

✓ Subcontractors: NTUA National Technical University of Athens, Institute of Engineering Seismology and Earthquake Engineering, Greece



Research, Training Center, Networking, Dissemination

Thank you

Sotiria P. Stefanidou, Dr. Civil Engineer AUTh
Vice President & Director SURE
Vice President of the Hellenic Society of Earthquake Engineering (ETAM)

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Integrated seismic and energy renovation of buildings

EAEE WG15 summer workshop, 22 June 2023

K. Gkatzogias, D. Pohoryles, E. Romano, D. Bournas, P. Negro, G. Tsionis, S. Dimova
European Commission, Joint Research Centre

European Commission

European pilot project

https://www.youtube.com/watch?v=cS5Rjf05BMc

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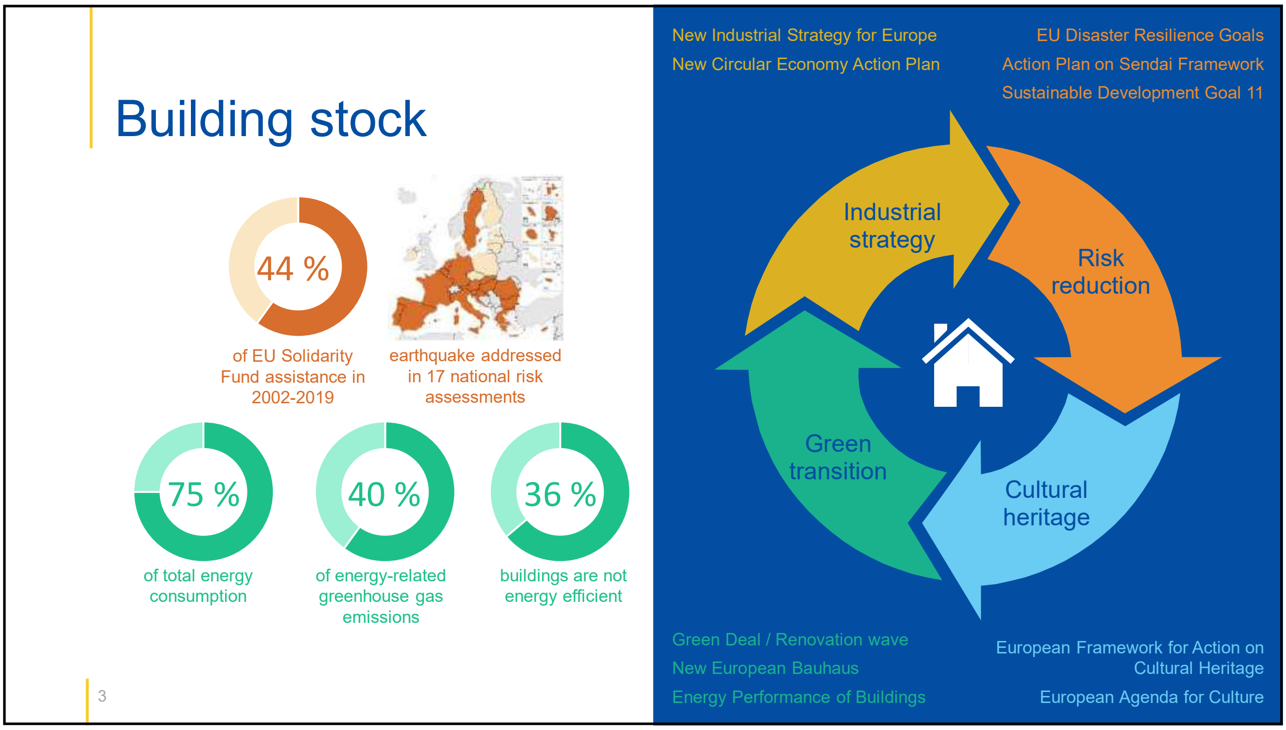
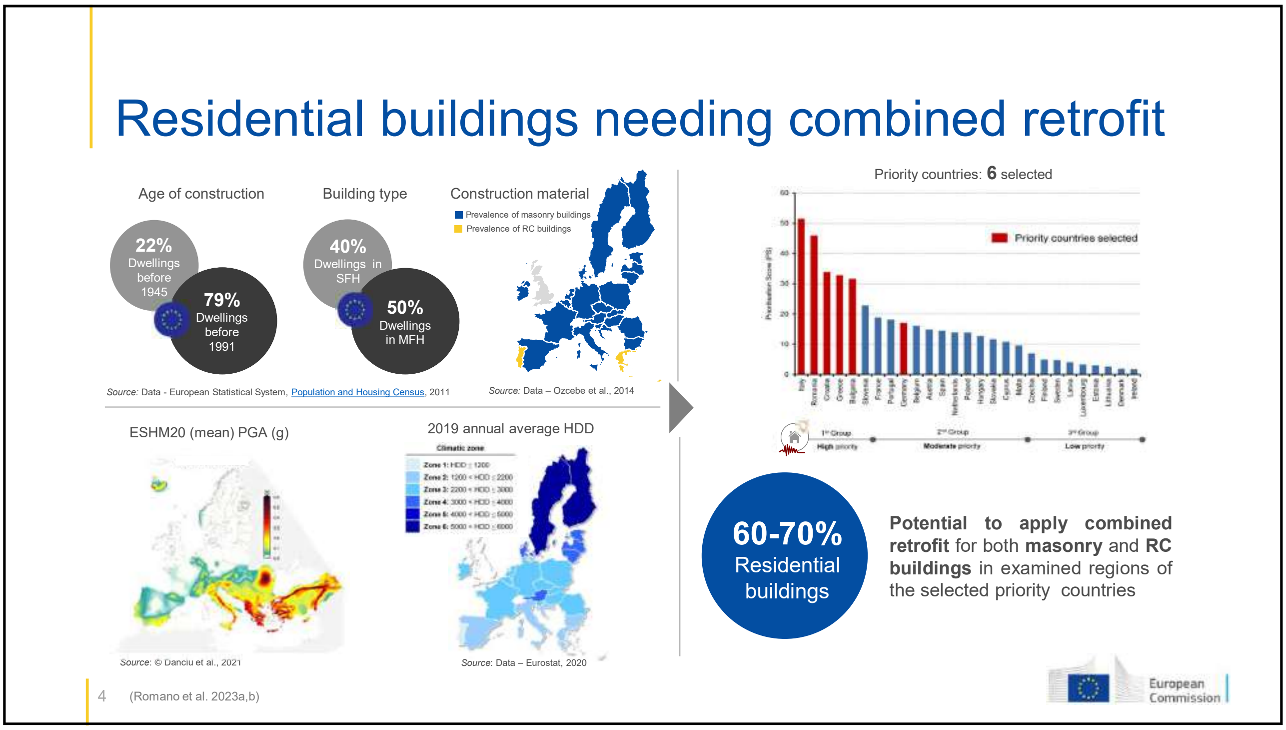

Building stock
44 %
of EU Solidarity Fund assistance in 2002-2019
earthquake addressed in 17 national risk assessments
75 %
of total energy consumption
40 %
of energy-related greenhouse gas emissions
36 %
buildings are not energy efficient
New Industrial Strategy for Europe
New Circular Economy Action Plan
EU Disaster Resilience Goals
Action Plan on Sendai Framework
Sustainable Development Goal 11
Industrial strategy
Risk reduction
Green transition
Cultural heritage
Green Deal / Renovation wave
New European Bauhaus
Energy Performance of Buildings
European Framework for Action on Cultural Heritage
European Agenda for Culture
3


Residential buildings needing combined retrofit
Age of construction
22% Dwellings before 1945
79% Dwellings before 1991
Building type
40% Dwellings in SFH
50% Dwellings in MFH
Construction material
Prevalence of masonry buildings
Prevalence of RC buildings
Source: Data - European Statistical System, Population and Housing Census, 2011
Source: Data – Ozcebe et al., 2014
ESHM20 (mean) PGA (g)
Source: © Danciu et al., 2021
2019 annual average HDD
Source: Data – Eurostat, 2020
Priority countries: 6 selected
Priority countries selected
60-70% Residential buildings
Potential to apply combined retrofit for both masonry and RC buildings in examined regions of the selected priority countries
4
(Romano et al. 2023a,b)
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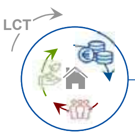
Seismic retrofit technologies

Qualitative evaluation

17 Life Cycle Thinking (LCT) criteria

Holistic/integrated renovation compatibility, occupants' disruption, recycle/re-use potential, economic investment, life cycle cost, repairable/demountable technologies, etc.



Steel bracing system

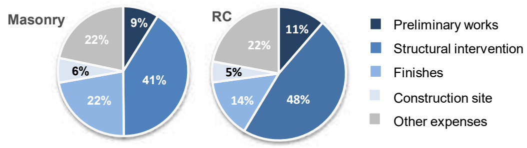
External shell exoskeleton

- ✓ Fully compatible with holistic renovation
- ✓ Minimum disruption
- ✓ High potential to recycle/re-use
- ✓ Extensive use of demountable components
- ✓ Low life cycle cost

Quantitative classification

Cost analysis of 26 seismic retrofit projects in Italy

Retrofit activities average cost ratio



Highest average unit-cost range of selected Seismic Retrofit Technologies (SRTs)

Building	SRT	Average unit-cost range
Masonry	Steel braced shear wall	530–910 €/m²
	RC shear wall	510–880 €/m²
	Strengthening of vaults	350–415 €/m²
RC	Seismic isolation	2500-3000 €/m²

5 (Romano et al. 2023b)

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Energy retrofit technologies

20 passive energy efficiency technologies (EETs)

Envelope component

Wall	Floor & roof	Window	Door
Insulation systems Ventilated façade Green wall	Insulation systems Cool roof Green roof	Replacement Films Weather stripping	Replacement Weather stripping

EETs ranking

Rank		Envelope component	EET	Further details
High	1	Wall	**Insulation of wall air chamber**	Very low unitary cost Low waste generated
	2	Roof	Internal insulation	
	3	Wall	Internal insulation by cladding	
	4	Roof	External insulation of flat roofs	
Moderate	5	Door/window	Weather stripping	/
	6	Door/window	Replacement	
	7	Floor	Insulation systems	
Low	8	Wall	Cement panels sheathing systems for façade renovation	High unitary cost Low cost-effectiveness
	9	Roof	External insulation of pitched roofs	
	10	Wall	Prefabricated unit for external wall insulation	
	11	Wall	**ETICS**	

(Romano et al. 2023b)

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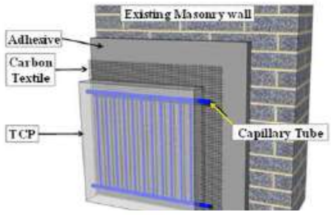
Examples of combined retrofitting applications

Exoskeletons
e.g. supporting additional energy efficiency systems (BIPVs, louvers, green walls, thermal insulation, etc.)

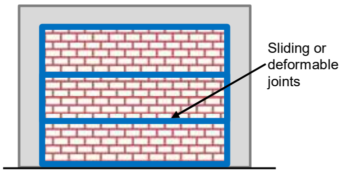
(Pohoryles et al. 2022)



(Baek et al. 2022)

Envelope Interventions
e.g. precast panels integrating capillary tubes for heating and textiles for strengthening

Envelope replacements
e.g. with sliding joints for increased deformability and thermal insulation for energy upgrading

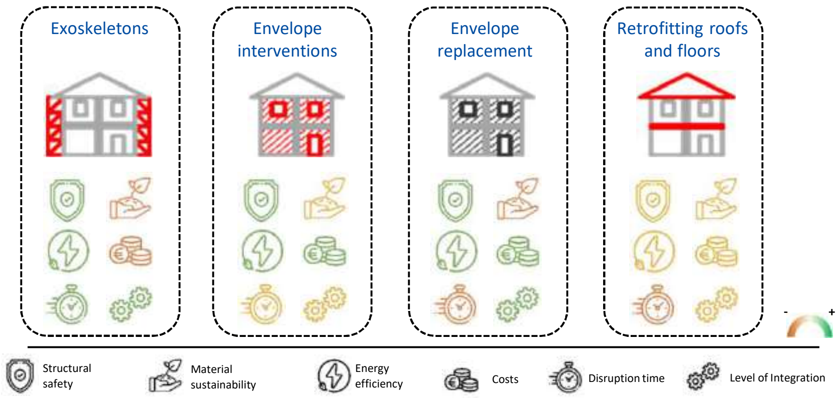


(Pohoryles et al. 2022)

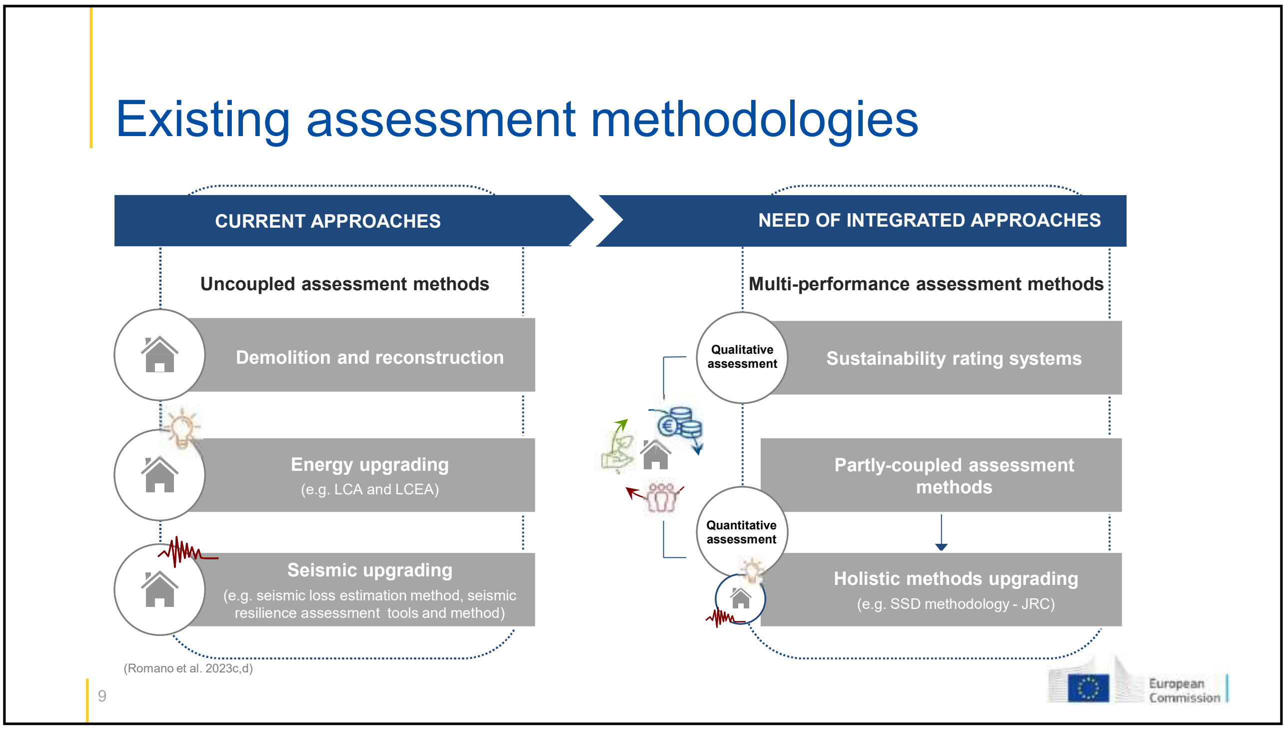

(Pohoryles et al. 2022)

Retrofitting roofs and floors
e.g. stiffening diaphragms and integrating them with an insulation and ventilation layer

Multi-criteria assessment of combined retrofit



(Pohoryles et al. 2022)


Existing assessment methodologies
CURRENT APPROACHES
NEED OF INTEGRATED APPROACHES
Uncoupled assessment methods
Demolition and reconstruction
Energy upgrading
(e.g. LCA and LCEA)
Seismic upgrading
(e.g. seismic loss estimation method, seismic resilience assessment tools and method)
Multi-performance assessment methods
Qualitative assessment
Sustainability rating systems
Partly-coupled assessment methods
Quantitative assessment
Holistic methods upgrading
(e.g. SSD methodology - JRC)
(Romano et al. 2023c,d)
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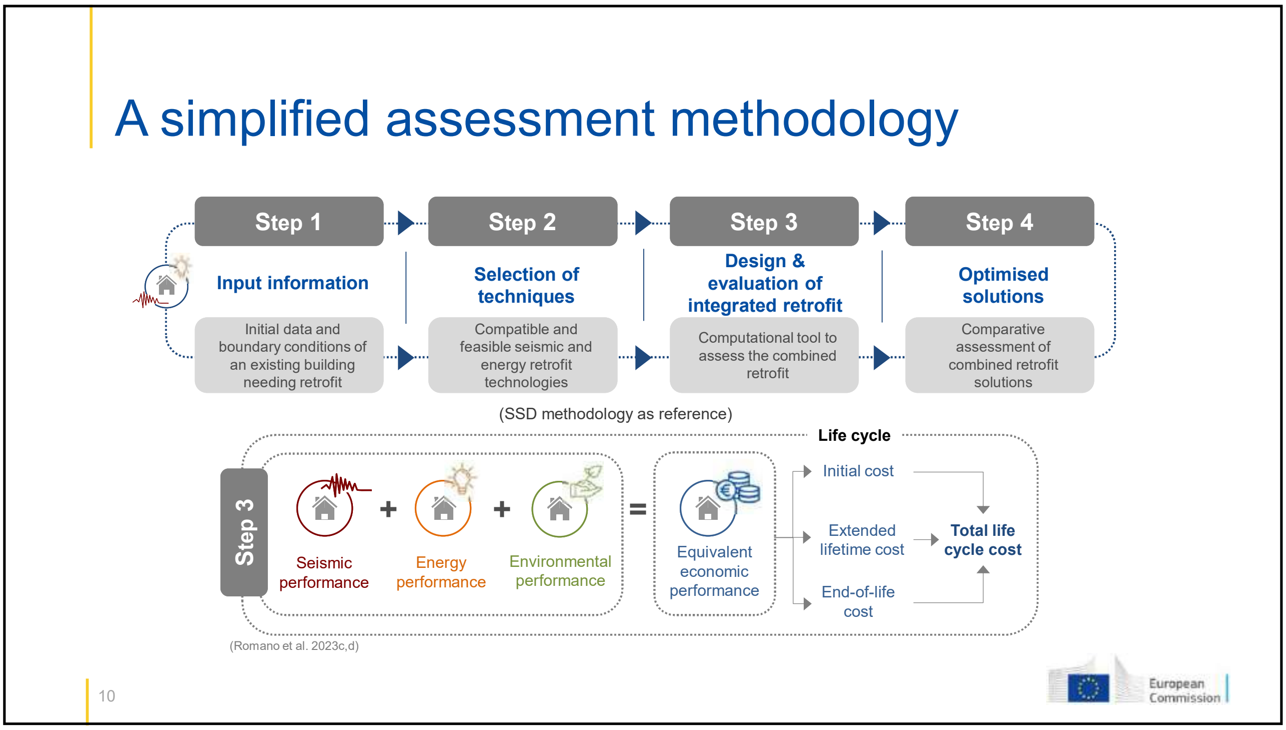
A simplified assessment methodology
Step 1
Input information
Initial data and boundary conditions of an existing building needing retrofit
Step 2
Selection of techniques
Compatible and feasible seismic and energy retrofit technologies
Step 3
Design & evaluation of integrated retrofit
Computational tool to assess the combined retrofit
Step 4
Optimised solutions
Comparative assessment of combined retrofit solutions
(SSD methodology as reference)
Life cycle
Step 3
Seismic performance
+
Energy performance
+
Environmental performance
=
Equivalent economic performance
Initial cost
Extended lifetime cost
End-of-life cost
Total life cycle cost
(Romano et al. 2023c,d)
10
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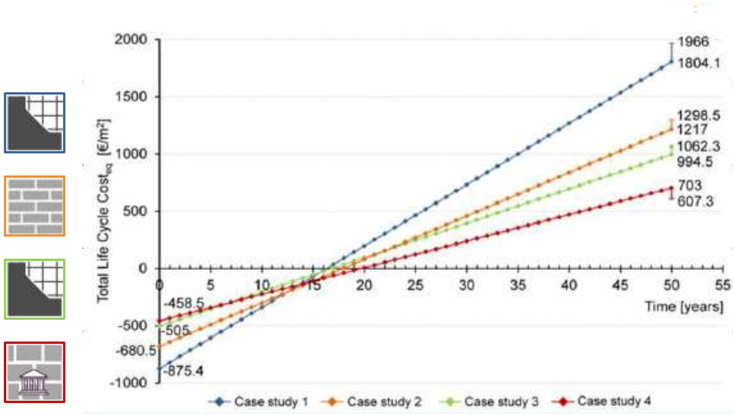
Case studies



Economic savings		Payback time
54 €/m²/year	71 %	16 years
30 €/m²/year	55 %	17 years
38 €/m²/year	61 %	18 years
23 €/m²/year	39 %	20 years

(Romano et al. 2023c,d)

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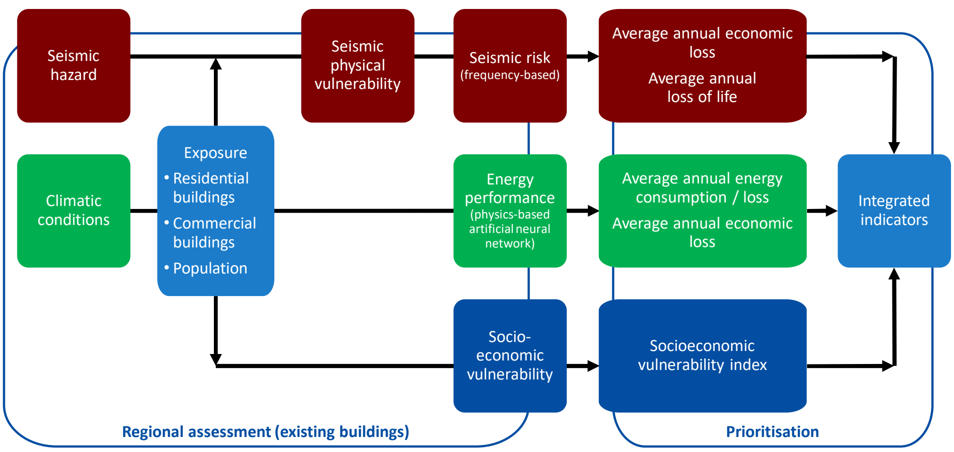
Framework for regional prioritisation



Gkatzogias et al. (2022a)

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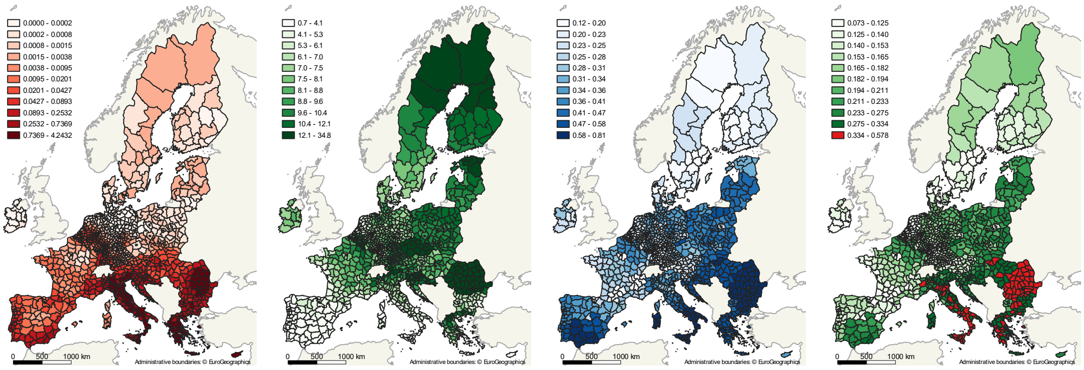
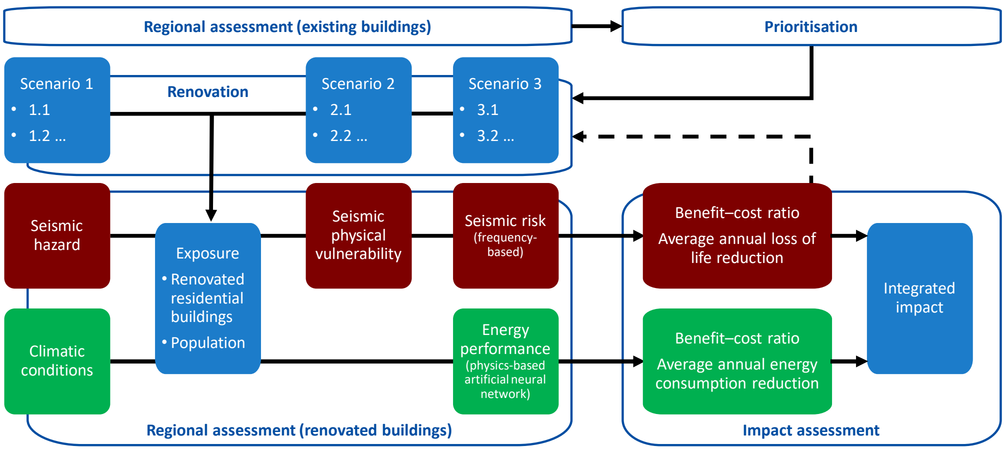
Priority regions



$AAELR_{eq}$ ($\cdot 10^{-3}$) | $AAELR_{en}$ ($\cdot 10^{-3}$) | *SVI* | $I_{eq\text{–}en\text{–}SVI,3}$

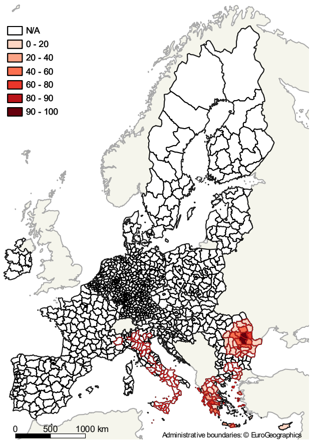
Gkatzogias et al. (2022a,c)

Framework for impact assessment

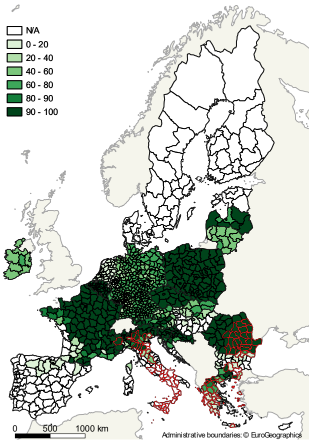


Gkatzogias et al. (2022b)

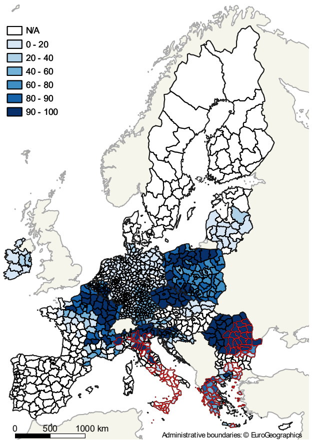
Renovation scenario 3



Seismic renovation
62 of 1151 regions



Energy renovation
922 of 1151 regions



Integrated renovation
734 of 1151 regions

Gkatzogias et al. (2022b,c)

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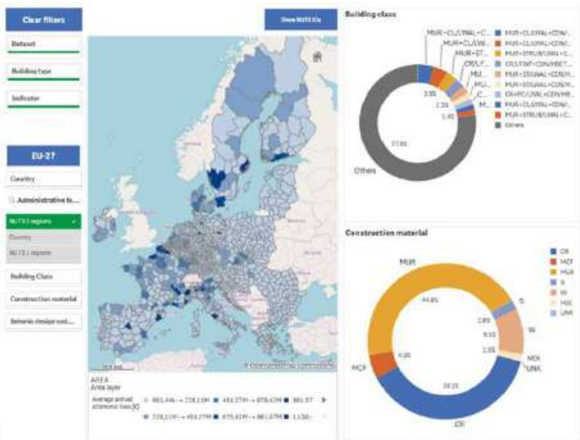
Buildings' renovation makerspace

- **Geo-referenced data** (NUTS3): building stock, population, seismic risk, energy performance, socioeconomic indicators, …
- Interactive **visualisation tools**
- Database of **publications**
- Database of **policy measures**



Gkatzogias et al. (2023)

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Conclusions

- **Masonry** and **RC buildings** would benefit from combined renovation
- **Catalogue of technologies** for seismic, energy and combined renovation
- **Simplified assessment method** for combined renovation benefits
- **Prioritisation** and **impact analysis** are key to inform bespoke renovation plans at a regional, national or European scale
- Integrated renovation is **more beneficial** than separate interventions
- **Further action is needed** to promote future-proof renovation

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Recommendations for policy

Implementation

- Review of technologies to identify appropriate solutions
- User-friendly impact evaluation tools
- Regional prioritisation and impact analysis
- Best practices for regulatory framework, financial instruments, strategies and digital tools

Anticipation

- Research and knowledge needs: technologies, cost, lifetime performance, exposure data, multiple hazards
- Transfer knowledge to standards
- Enrich regulatory framework
- Increase awareness of risks and benefits of renovation
- Training and certification of professionals

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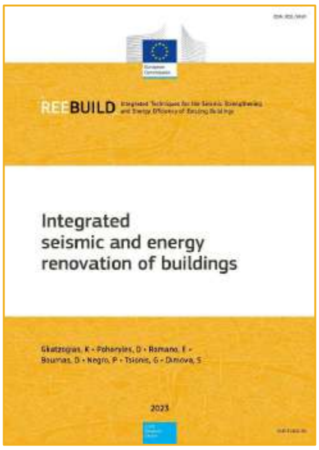
More information



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Science for policy report

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Thank you

The Greek Legislative Framework for pre-earthquake evaluation of buildings and their connection with energy efficiency programs. The existing OASP regulations for the three levels evaluation

Earthquake Planning and Protection Organization (OASP)

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E.P.P.O.
Earthquake Planning & Protection Organization

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Pre-Earthquake Vulnerability Assessment of buildings

The problem of the Pre – Earthquake Assessment of Buildings is complex not only in Greece but also in all countries prone to earthquakes since detailed assessment of the structural capacity of an individual existing building is extremely costly and time consuming.

Selective intervention is therefore the only realistic solution.

The questionis how to locate those buildingswhich - among similar others – have a priority on intervention (in terms of seismic risk).

Pre-earthquake vulnerability assessment of buildings in Greece

In Greece, the Earthquake Protection and Planning Organization (OASP) assigned the preparation of a proposal for a pre-earthquake vulnerability assessment framework for buildings of public use in a Working Group leading to a document submitted in 2000. The proposed framework, strongly influenced by the relevant system of USA (FEMA 154), includes three degrees of assessment .

First degree inspection
Rapid Visual Screening Procedure
A first estimation of bearing capacity of the building (A,B,Γ)

Second degree inspection
Approximate Seismic Evaluation based on simplified calculations and non-destructive methods for insufficient buildings (A) from the first-degree inspection.

Third degree inspection
Detailed assessment of seismic performance of buildings with local or general inefficient seismic performance. According to Greek Intervention Codes: KAN.EPE, KADET or EC8-3.

Pre-Earthquake Vulnerability Assessment of buildings in Greece

OASP is responsible for the implementation and validation of the vulnerability assessment procedure of buildings of public use (hospitals, schools, telelecommunication buildings, power plants etc.)

The vulnerability assessment of public buildings is carried out at **national level.**

Legislative Framework for Pre-Earthquake Evaluation

The existing legislative framework for pre-earthquake evaluation of buildings in our country is the following:

MINISTRY OF PUBLIC WORKS

- ✓ **"Emergency plan design for public buildings in municipalities" GD No 7872/31-12-97**
  Compliance and implementation of all general and specific regulations concerning the safe usage in the public buildings.

- ✓ **"Public buildings inspection for safe and qualitative operation and implementation of the relevant regulations" GD No 1234/39/2-2-99**
  Compliance with the rules of safety in public buildings in order to protect the lives of citizens and working stuff.
  Regular inspections should be conducted.

Legislative Framework for Pre-Earthquake Evaluation

MINISTRY OF PUBLIC WORKS

- ✓ **"Pre-earthquake inspection of public buildings" GD No 2189/29-5-01**

  Operational framework definition of the firstly introduced project PRE-EARTHQUAKE INSPECTION OF PUBLIC BUILDINGS.

- ✓ **" Regulations amendment concerning specific interventions on existing buildings" GG B΄ 350/17-02-2016**

  Pre-earthquake detailed assessment of bearing capacity of existing buildings (3rd degree) is enforced only in cases of interventions (change of use, additions, modifications) which may affect the seismic behavior

Legislative Framework for Pre-Earthquake Evaluation

GENERAL SECRETARIAT OF CIVIL PROTECTION

- ✓ **General Emergency Plan for Earthquakes "Egelados" 2nd edition (18-11-22)**

  1st degree pre-earthquake inspection of public buildings should be conducted by the bodies responsible for the operation and safety of the buildings.

Legislative Framework for Pre-Earthquake Evaluation

Latest Developments

PRESIDENT OF GREEK REPUBLIC

- ✓ **“Regulatory Authority for Energy rename to Regulatory Authority for Waste, Energy and Water…Specific regulations for renewable energy resources and environmental protection” GL No 5037/2023 GG A΄78/28.3.2023**

  Article No 265: Pre-earthquake Inspection of buildings

  1. *The Technical Chamber of Greece (TCG) is assigned to conduct 1st and 2nd degree Pre- earthquake Inspection in public buildings and critical infrastructures of private sector.*
  2. *Earthquake Planning and Protection Organization (EPPO) supervises the implementation of the 1st and 2nd degree Pre-earthquake Inspection Program for public buildings and critical infrastructures of private sector.*

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Legislative Framework for Pre-Earthquake Evaluation

Latest Developments

JOINT MINISTERIAL DECISION

- ✓ **“1st degree pre-earthquake Inspection of buildings according to par.1, article 14, Government Law No 4270/2014 as well as critical infrastructures of private sector” GG B΄ 2943/4-5-2023 (Ministerial Decision)**

  EPPO is responsible for the development, maintenance and operation of the digital database where the results of 1st and 2nd degree Pre- earthquake Inspection will be recorded.

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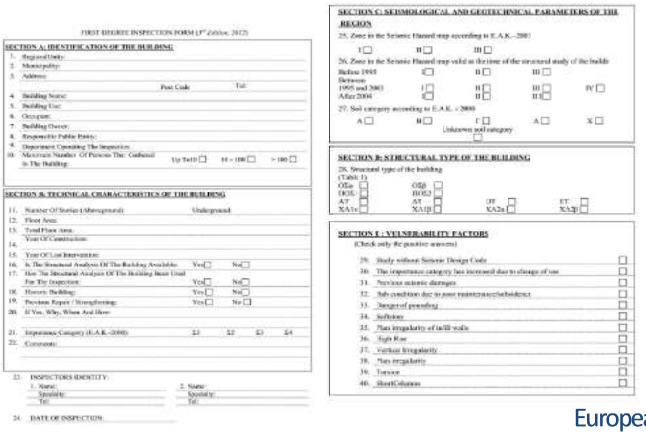
First-Degree Pre-Earthquake Vulnerability Assessment of Buildings

- For each building a Pre-earthquake Vulnerability Assessment Inspection Form is filled. The process is designed to be simplified and standardized in terms of data collection.
- The inspection form includes basic characteristics of each individual structural unit (year of construction, design and construction codes and regulations, damage from previous earthquakes, use, structural system etc.).
- The buildings are classified in 13 categories according to the construction material (concrete, precast concrete, steel, masonry), and the regulatory framework according to which the building is designed for. Vulnerability factors are also collected.


FIRST DEGREE INSPECTION FORM

SECTION A: IDENTIFICATION OF THE BUILDING

1. Regional Unity:
2. Municipality:
3. Address:
   Post Code Tel:
4. Building Name:
5. Building Use:
6. Occupant:
7. Building Owner:
8. Responsible Public Entity:
9. Department Operating The Inspection:
10. Maximum Number Of Persons That Gathered In The Building: Up To 10 ☐ 10 – 100 ☐ > 100 ☐

SECTION B: TECHNICAL CHARACTERISTICS OF THE BUILDING

11. Number Of Stories (Aboveground): Underground:
12. Floor Area:
13. Total Floor Area:
14. Year Of Construction:
15. Year Of Last Intervention:
16. Is The Structural Analysis Of The Building Available: Yes ☐ No ☐
17. Has The Structural Analysis Of The Building Been Used For The Inspection: Yes ☐ No ☐
18. Historic Building: Yes ☐ No ☐
19. Previous Repair / Strengthening: Yes ☐ No ☐
20. If Yes, Why, When And How:
21. Importance Category (E.A.K.-2000): Σ1 Σ2 Σ3 Σ4
22. Comments:

23. INSPECTORS IDENTITY:
1. Name: Specialty: Tel:
2. Name: Specialty: Tel:

24. DATE OF INSPECTION:

SECTION C: SEISMOLOGICAL AND GEOTECHNICAL PARAMETERS OF THE REGION

25. Zone in the Seismic Hazard map according to E.A.K.–2000: I ☐ II ☐ III ☐
26. Zone in the Seismic Hazard map valid at the time of the structural study of the building:
Before 1995 I ☐ II ☐ III ☐
Between 1995 and 2003 I ☐ II ☐ III ☐ IV ☐
After 2004 I ☐ II ☐ III ☐
27. Soil category according to E.A.K.–2000: A ☐ B ☐ Γ ☐ Δ ☐ X ☐
Unknown soil category ☐

SECTION D: STRUCTURAL TYPE OF THE BUILDING

28. Structural type of the building (Table 1)

SECTION E: VULNERABILITY FACTORS
(Check only the positive answers)

29. Study without Seismic Design Code ☐
30. The importance category has increased due to change of use ☐
31. Previous seismic damages ☐
32. Bad condition due to poor maintenance/subsidence ☐
33. Danger of pounding ☐
34. Soft story ☐
35. Plan irregularity of infill walls ☐
36. High Rise ☐
37. Vertical Irregularity ☐
38. Plan irregularity ☐
39. Torsion ☐
40. Short Columns ☐

First-Degree Pre-Earthquake Vulnerability Assessment of Buildings

- The inspection of each building is carried out by the authority that is responsible for the operation and the safety of the building. The inspection forms are entered into a data base by EPPO and are classified according to an assessment procedure with a structural score.
- The outcome of the first-degree assessment is the classification in three categories. Higher scores (category A) correspond to buildings of higher priority for second degree inspection, whereas lower scores (category Γ) correspond to buildings with an expected better seismic performance.
- The results of building scoring, are forwarded by EPPO, in the form of classified documents to the higher levels of administration in order to proceed in further investigation through the second-degree assessment.

Second-Degree Pre-Earthquake Vulnerability Assessment of Buildings

Second-degree pre-earthquake vulnerability assessment of buildings of public use in Greece GG B΄ 3134/21-06-2022

- The Second-degree inspection is more detailed than the First (Rapid Visual), but faster than the Third one. The purpose of this inspection is the hierarchical re-calibration of those buildings which, from the macroscopic First-degree Inspection, received a score below a prescribed limit.
- The Second-degree inspection is an approximate but reliable process of assessing the seismic capacity and the seismic adequacy of existing buildings in relation to the seismic requirement, as defined in the modern regulatory provisions.
- The result of this inspection is an "indicator" called "Priority Index λ" of the building. This indicator indicates (in an approximate way) a degree of inadequacy for individual buildings and consequently the order of priority for the third phase of the whole project (Third-degree Pre-Earthquake Inspection), i.e. the preparation of valuation studies and redesign (reinforcement) of a limited number of buildings according to financial capabilities of the relevant body.

Second-Degree Pre-Earthquake Vulnerability Assessment of Buildings

Second-degree pre-earthquake vulnerability assessment of buildings of public use in Greece GG B΄ 3134/21-06-2022

- The 1st Revision of the methodology for the Second-degree pre-earthquake vulnerability assessment of reinforced concrete buildings of public use was completed by OASP and posted on the Organization's website (www.oasp.gr).
- In the 1st Revision of the methodology for the Second-degree pre-earthquake vulnerability assessment of reinforced concrete buildings (2022) the most important interventions should be considered:
  - ✓ The updating and simplification of the methodology.
  - ✓ The classification of a building in a "seismic category of Second-degree pre-earthquake vulnerability assessment ", in correspondence with the "seismic building classes" provided by the 3rd Revision of the Code of Interventions KAN.EPE. (GG/3197/B/22-6-2022).

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Second-Degree Pre-Earthquake Vulnerability Assessment of Buildings

“Seismic category of Second-degree pre-earthquake vulnerability assessment (K)”

- Seismic category of vulnerability assessment (K) of a building in Second-degree pre-earthquake vulnerability assessment of buildings, is defined the maximum objective of assessment that can ensure a building for performance level B ("Significant Damages" according to KAN.EPE.) by applying the methodology of the Second-degree Pre-Earthquake vulnerability assessment.
- This classification provides the possibility of a more rational prioritization of the buildings that must be examined in the third phase (i.e., complete static and anti-seismic analysis according to KAN.EPE).

Second-Degree Pre-Earthquake Vulnerability Assessment of Buildings

Return Period (years)	Probability of exceedance of seismic action within the conventional lifetime of 50 years	δ	Seismic classification (K)
2475	2%	$1.80 \leq \delta$	**K0**
975	5%	$1.30 \leq \delta < 1.80$	**K1⁺**
475	10%	$1.00 \leq \delta < 1.30$	**K1**
225	20%	$0.75 \leq \delta < 1.00$	**K2⁺**
135	30%	$0.60 \leq \delta < 0.75$	**K2**
70	50%	$0.45 \leq \delta < 0.60$	**K3⁺**
40	70%	$0.35 \leq \delta < 0.45$	**K3**
20	90%	$0.25 \leq \delta < 0.35$	**K4⁺**
<20	>90%	$\delta < 0.25$	**K4**

Table 1. Seismic classification of buildings according to Second-degree pre-earthquake vulnerability assessment of buildings

Third-Degree Pre-Earthquake Vulnerability Assessment of Buildings - CODE OF INTERVENTION (ΚΑΝ.ΕΠΕ)

Code of Interventions (KAN.EPE) 3rd revision Gov. Gazette B΄ 3197/22-6-2022 (Ministerial Decision)

- The 3rd Revision of the Code of Interventions (KAN.EPE.), for buildings of Reinforced Concrete, was completed by the Earthquake Planning and Protection Organization and posted on the website of the Organization (GG/3197/B/22-6-2022)
- Given the necessity:
  - ✓ of a complete, scientifically modern, safe, economical, legally consistent and adapted to Eurocode 8 Code of the critical issue of interventions in existing buildings, which have been designed with older anti-seismic codes.
  - ✓ For completion of Eurocode 8, Part 3 and the update of the Code of Interventions (KAN.EPE.), as published (2nd Revision GG/2984/14-8-2017).
- The completion and revision of individual points of the Code of Interventions (KAN.EPE), was deemed necessary, ten years after its 1st edition and five years after the publication of the 2nd revision, according to the scientific views of Earthquake Planning and Protection Organization (OASP) Working Groups that processed the relevant issues.

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Third-Degree Pre-Earthquake Vulnerability Assessment of Buildings - CODE OF INTERVENTION (ΚΑΝ.ΕΠΕ)

Code of Interventions (KAN.EPE) 3rd revision Gov. Gazette B΄ 3197/22-6-2022 (Ministerial Decision)

- The most important interventions should be considered:
  - ✓ The revision of assessment and redesign objectives in combination with the definition of seismic classification of buildings (Chapter 2)
  - ✓ The values referred to data reliability levels and default conservative material strength values (Chapter 3)
  - ✓ The addition of Appendix 7F for the approximate assessment of the influence of reinforcement corrosion on the mechanical characteristics of structural elements (Chapter 7)
  - ✓ The revision of par. 8.2.1.5, par. 8.3.2.1 and par. 8.5.3. (Chapter 8)

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Third-Degree Pre-Earthquake Vulnerability Assessment of Buildings - CODE OF INTERVENTION (KAN.ΕΠΕ)

Code of Interventions (KAN.EPE) 3rd revision Gov. Gazette B΄ 3197/22-6-2022 (Ministerial Decision)

Return Period (years)	Probability of exceedance of seismic action within the conventional life cycle of 50 years	$\alpha_g / \alpha_{g,ref}$
2475	2%	1.80
975	5%	1.30
475	**10%**	**1.00**
225	20%	0.75
135	**30%**	**0.60**
70	50%	0.45
40	70%	0.35
20	90%	0.25
<20	>90%	<0.25

Table2. Indicative correlation of return period and probability of exceedance of seismic action with the corresponding normalized horizontal ground acceleration.

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Third-Degree Pre-Earthquake Vulnerability Assessment of Buildings - CODE OF INTERVENTION (KAN.ΕΠΕ)

Code of Interventions (KAN.EPE) 3rd revision Gov. Gazette B΄ 3197/22-6-2022 (Ministerial Decision)

$\alpha_g / \alpha_{g,ref}$	Structural performance levels			
	A "Immediate Occupancy after the earthquake" (A)	B "Life Safety" (B)	Γ "Collapse Prevention" (C)	Italian Classification
1.80	A0	B0	Γ0	
1.30	$A1^+$	$B1^+$	$Γ1^+$	
1.00	A1	B1	Γ1	A^+
0.75	$A2^+$	$B2^+$	$Γ2^+$	≈A(0.80)
0.60	A2	B2	Γ2	B
0.45	$A3^+$	$B3^+$	$Γ3^+$	C
0.35	A3	B3	Γ3	≈D(0.30)
0.25	$A4^+$	$B4^+$	$Γ4^+$	≈D(0.30)
<0.25	A4	B4	Γ4	≈E(0.15)

Table3. Assessment or redesign objectives of the structure seismic

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Third-Degree Pre-Earthquake Vulnerability Assessment of Buildings - Code of Assessment and Retrofitting of Masonry Structures (ΚΑΔΕΤ)

Code of assessment and retrofitting of masonry structures (ΚΑΔΕΤ) Gov. Gazette B΄ 2493/18-4-2023 (Ministerial Decision)

- The Code of assessment and retrofitting of masonry structures, was completed in 2022 (GG/2493/B/18-4-2023) by an eleven members Working Group-Authoring Committee of the Earthquake Planning and Protection Organization of Greece and is posted on the website of the Organization (https://www.oasp.gr/node/4145).
- The scope of the Code is the enactment of criteria for the assessment of the structural capacity of existing masonry structures. The code regulates the redesign of these structures, after potential interventions (repairs or strengthening), as well as for potential interventions, repairs or strengthening.
- The Regulation applies both to ordinary buildings and to monuments and preserved buildings, together with additional special provisions that may apply.
- The Regulation covers structures with or without damage from any cause.

Third-Degree Pre-Earthquake Vulnerability Assessment of Buildings - Code of Assessment and Retrofitting of Masonry Structures (ΚΑΔΕΤ)

Code of assessment and retrofitting of masonry structures (ΚΑΔΕΤ) Gov. Gazette B΄ 2493/18-4-2023 (Ministerial Decision)

- The documentation of the structure includes information about the geometry, the materials and the construction details. Depending on the amount and the quality of the collected information, three Levels of Data Reliability are defined: “High”, “Sufficient” and “Tolerable”.
- The code defines three potential performance levels of the structure: Level A: Limited Damage, Level B: Severe Damage, Level C: Near Collapse. The structures are categorized in 9 seismic classes for every performance level depending on their seismic capacity.
- The seismic action effects in the structure are evaluated according one of the two proposed analytical approaches. The force-based approach and the displacement-based approach.
- Several retrofitting techniques are proposed for repair or strengthening of the structure and the relevant models for the evaluation of their capacity after the evaluation are included.

Third-Degree Pre-Earthquake Vulnerability Assessment of Buildings - Code of Assessment and Retrofitting of Masonry Structures (ΚΑΔΕΤ)

Code of assessment and retrofitting of masonry structures (ΚΑΔΕΤ) Gov. Gazette B΄ 2493/18-4-2023 (Ministerial Decision)

- The Standard includes the following chapters:
  - ✓Scope – Field of application – Obligations and responsibilities
  - ✓Basic principles, criteria and procedures
  - ✓Investigation and documentation
  - ✓Basic data for assessment and redesign
  - ✓Analysis prior and after the intervention
  - ✓Basic behaviour models
  - ✓Assessment of behaviour of structural elements
  - ✓Repairs or strengthening/ Design of interventions
  - ✓Safety verifications
  - ✓Required contents of the design
  - ✓Construction – Quality assurance - Maintenance

Pre-Earthquake Vulnerability Assessment of Bridges

- Nowadays many bridges across Greece are considered structurally deficient and need to be repaired in order to improve their condition and avoid additional deterioration.
- In 2002, a study was carried out by OASP with the title "Development of methodology for first and second level Pre-earthquake Assessment for certain types of existing bridges and statement of indicative proposals on bridge rehabilitation ". The methodology was based on preexisting Guides developed in USA and New Zealand and calculates the seismic risk assessment and prioritization of bridges.
- An indicator of seismic vulnerability of bridge which indicates whether the bridge must be further examined is estimated by using this method. Since the method was developed 20 years ago, it is obvious that an updated method for the seismic vulnerability assessment of bridges in order to prioritize them for the higher level of Pre-earthquake assessment must be developed.

Energy Upgrade of Buildings

Thera are no policies and actions regarding the energy efficiency upgrade of buildings to enforce the assessment of seismic capacity according to the national codes before energy upgrading and major renovation works.

EUROPEAN PARLIAMENT

- ✓ **DIRECTIVE (EU) 2018/844 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.**

- *In the directive there is buildings seismic risk acknowledgement and the following general recommendations:*

"…for the State to use its long-term renovation strategy to address risks related to intense seismic activity affecting energy efficiency renovations and the lifetime of buildings."

Energy Upgrade of Buildings

MINISTRY OF ENERGY, COMMERCE AND INDUSTRY

- ✓ **"Building Energy Performance – in accordance with the Directive 2010/31/EU of European Parliament and Council and other regulations." Government Law No 4122/2013 Gov. Gazette A΄42/19.2.2013**

Article 7 Existing Buildings

- *The compulsory building permit for the implementation of major renovation works in existing buildings enforces the evaluation of "risks" possibly affecting buildings structural efficiency.*
- *However, there is no specific reference to seismic risk. In addition, there is no evaluation procedure, where a clear obligation for the responsible bodies to ensure safety of the structural integrity of buildings as well as the energy update investment.*
- *This will be ensured only if the State enforces that the seismic capacity assessment, according to the national codes, take precedence over energy upgrade and major renovation works.*

Energy Upgrade of Buildings

✓ **"Public buildings energy upgrade financing program." Gov. Gazette B΄4813/12.9.2022 (Ministerial Decision)**

- *The inspection form of 1st degree pre-earthquake inspection of public buildings (OASP) (even though the prioritization degree of the inspection in no way confirms the structural capacity of a building) is a mandatory supporting document at the first stage of the application that certifies that there is no insufficient seismic behavior of the specific building .*

Thank you

A. Chatzidakis, S. Stefanidou

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The Greek Legislative Framework for pre-earthquake evaluation of buildings and their connection with energy efficiency programs. The existing OASP regulations for the three levels of evaluation

Aris Chatzidakis Deputy president OASP

OASP team of engineers *D. Panagiotopoulou, M. Panoutsopoulou, K. Tarnava, T. Thoma, M. Fotopoulou, G. Zagora*

1. PRE-EARTHQUAKE VULNERABILITY ASSESSMENT OF BUILDINGS

The problem of the Pre – Earthquake Assessment of Buildings is complex not only in Greece but also in all countries prone to earthquakes since detailed assessment of the structural capacity of an individual existing building is extremely costly and time consuming.

Selective intervention is therefore the only realistic solution. When the scope is to assess and upgrade a particular building, it seems that the Codes can give a rather reasonable answer. When the question is to locate those buildings which - among similar others - have a priority on intervention (in terms of seismic risk), the problem is quite complex.

In Greece, the Earthquake Protection and Planning Organization (OASP) assigned the preparation of a proposal for a pre-earthquake vulnerability assessment framework for buildings of public use in a Working Group leading to a document submitted in 2000. The proposed framework, strongly influenced by the relevant system of USA (FEMA 154), includes three degrees of assessment:

- **First degree inspection**, is a Rapid Visual Screening Procedure for a first estimation of the bearing capacity of the building. Buildings found insufficient, need further examination.
- **Second degree inspection,**is an approximate seismic evaluation which is based on

simplified calculations and nondestructive methods for insufficient buildings from the first degree inspection. In case that the structure is found adequately safe it is excluded of further examination. In case it is not of adequate safety, the assessment proceeds to the next stage.

- **Third degree inspection**is a detailed assessment of seismic performance. It is conducted based on the legislative framework (Greek Code for Seismic Intervention ΚΑΝΕΡΕ, ΚΑΝΕΠΕ or EC8 - Part 3).

2. LEGISLATIVE FRAMEWORK FOR PRE-EARTHQUAKE EVALUATION

The existing legislative frameworkfor pre-earthquake evaluation of buildingsin our country is the following:

GENERAL SECRETARIAT OF CIVIL PROTECTION

General Emergency Plan for Earthquakes "Egelados" 2nd edition (18-11-22)

1st degree pre-earthquake inspection of public buildings should be conducted by the bodies responsible for the operation and safety of the buildings.

MINISTRY OF PUBLIC WORKS

- **"Emergency plan design for public buildings in municipalities"**
  Government document No 7872/31-12-97
  It is a necessity for the public buildings the compliance and implementation of all general and specific regulations concerning the safe usage.
  Especially when State is the owner there should be conducted analytical studies for the evaluation of the structural strength of the public building and the necessary measures should be accordingly.

- **"Public buildings inspection for safe and qualitative operation and implementation of the relevant regulations"**
  Government document No 1234/39/2-2-99
  It is imperative need that public buildings comply with the rules of safety in order to protect the lives of citizens and working stuff and to ensure a qualitative working environment.
  Regular inspections should be conducted to ascertain whether the safety rules are followed.

- **"Pre-earthquake inspection of public buildings"**
  Government document No 2189/29-5-01
  Operational framework definition of the firstly introduced project PRE-EARTHQUAKE INSPECTION OF PUBLIC BUILDINGS.
  Notification to the responsible bodies for the operation and safety of public buildings to conduct 1st degree pre-earthquake inspection according to the detailed guidelines of EPPO (Earthquake Planning and Protection Organization).

- **Regulations amendment concerning specific interventions on existing buildings.**

GovernmentGazetteB΄350/17-02-2016
Pre-earthquake detailed assessment of bearing capacity of existing buildings (3rd degree) is enforced only in cases of interventions(change of use, additions, modifications) which may affect the seismic behavior.

PRESIDENT OF GREEK REPUBLIC
Government Law No 5037/2023 Gov. Gazette A΄78/28.3.2023
“Regulatory Authority for Energy rename to Regulatory Authority for Waste, Energy and Water…Specific regulations for renewable energy resources and environmental protection”
According to Article 265 Pre-earthquake inspection of buildings

1. The Technical Chamber of Greece (TCG) is assigned to conduct 1st and 2nd degree Pre-earthquake Inspection in public buildings and critical infrastructures of private sector.
2. Earthquake Planning and Protection Organization (EPPO) supervises the implementation of the 1st and 2nd degree Pre- earthquake Inspection Program for public buildings and critical infrastructures of private sector.

Gov. Gazette B΄2943/4-5-2023 (Ministerial Decision)
“1st degree pre-earthquake Inspection of buildings according to par.1, article 14, Government Law No 4270/2014 as well as critical infrastructures of private sector”

EPPO is responsible for the development, maintenance and operation of the digital database where the results of 1st and 2nd degree Pre- earthquake Inspection will be recorded.

3. FIRST DEGREEPRE-EARTHQUAKE VULNERABILITY ASSESSMENT OF BUILDINGS

The Pre-Earthquake Vulnerability Assessment (first degree) of buildings of public use was initiated in Greece for the first time in spring of 2001. The purpose of the first -degree inspection is a first estimation of the bearing capacity of the building in order to identify priorities at national level for further assessment and interventions if needed based on the data collected and recorded in the First-Degree Pre -Earthquake Inspection form.

The first-degree inspection is carried out at every administrative level of the country in collaboration with the respective Technical and Civil Protection Departments. The inspection of each building is carried out by the service/authority responsible for the operation and safety of the building.

The inspections are performed by two structural engineers (from the technical Department of each authority) to all public owned or leased buildings such as hospitals, schools, public administrative services, telecommunication buildings etc.

The completed inspection forms sent to OASP are entered into an electronic data base and they are classified in three categories A, B, C. The outcome of the assessment is the relative scoring of the seismic capacity of the examined buildings. When score is above a predefined

threshold value the building is deemed safe and further assessment is not necessary (buildings classified C). For scores below the threshold, the building is deemed as not meeting the current requirements and further investigation is needed. The necessity of buildings classified in Category A for further assessment is greater than that of buildings belonging to Category B, and so on.
The results that determine the priority for the second - degree inspection are sent byOASP to the Responsible Authorities.

It is important that the process of the First-Degree Inspection does not inhibit the responsibilities and obligations of the competent bodies to take immediate and urgent measures inorderto protect the public and the employees in the buildings deemed hazardous under current legislation.

4. SECOND DEGREE PRE-EARTHQUAKE VULNERABILITY ASSESSMENT OF BUILDINGS

Second-degree pre-earthquake vulnerability assessment of buildings of public use in GreeceGovernmentGazetteB΄3134/21-06-2022

The Second-degree inspection is more detailed than the First (Rapid Visual), but faster than the Third one. The purpose of this inspection is the hierarchical re-calibration of those buildings which, from the macroscopic First-degree Inspection, received a score below a prescribed limit. The Second-degree inspection is an approximate but reliable process of assessing the seismic capacity and the seismic adequacy of existing buildings in relation to the seismic requirement, as defined in the modern regulatory provisions.
The result of this inspection is an "indicator" called "Priority Index λ" of the building. This indicator indicates (in an approximate way) a degree of inadequacy for individual buildings and consequently the order of priority for the third phase of the whole project (Third-degree Pre-Earthquake Inspection), i.e. the preparation of valuation studies and redesign (reinforcement) of a limited number of buildings according to financial capabilities of the relevant body.
The 1st Revision of the methodology for the Second-degree pre-earthquake vulnerability assessment of reinforced concrete buildings of public use was completed by OASP and posted on the Organization's website (www.oasp.gr).
In the 1st Revision of the methodology for the Second-degree pre-earthquake vulnerability assessment of reinforced concrete buildings (2022) the most important interventions should be considered:
• The updating and simplification of the methodology.
• The classification of a building in a "seismic category of Second-degree pre-earthquake vulnerability assessment ", in correspondence with the "seismic building classes" provided by the 3rd Revision of the Code of Interventions KAN.EPE. (GG/3197/B/22-6-2022).

More specifically, as " seismic category of Second-degree pre-earthquake vulnerability assessment (K) " of a building, is defined the maximum objective of assessment that can ensure a building for performance level B ("Significant Damages" according to KAN.EPE.) by applying the methodology of the Second-degree Pre-Earthquake vulnerability assessment.

Table 1. Seismic classification of buildings

Return Period (years)	Probability of exceedance of seismic action within the conventional lifetime of 50 years	δ	Seismic classification (K)
2475	2%	$1.80 \leq \delta$	**K0**
975	5%	$1.30 \leq \delta < 1.80$	**K1⁺**
475	10%	$1.00 \leq \delta < 1.30$	**K1**
225	20%	$0.75 \leq \delta < 1.00$	**K2⁺**
135	30%	$0.60 \leq \delta < 0.75$	**K2**
70	50%	$0.45 \leq \delta < 0.60$	**K3⁺**
40	70%	$0.35 \leq \delta < 0.45$	**K3**
20	90%	$0.25 \leq \delta < 0.35$	**K4⁺**
<20	>90%	$\delta < 0.25$	**K4**

This classification provides the possibility of a more rational prioritization of the buildings that must be examined in the third phase (i.e., complete static and anti-seismic analysis according to KAN.EPE).

5. THIRD DEGREE PRE-EARTHQUAKE VULNERABILITY ASSESSMENT OF BUILDINGS

5.1. CODE OF INTERVENTION (ΚΑΝΕΠΕ)

Code of Interventions (KAN.EPE) 3rd revision Gov. Gazette B΄ 3197/22-6-2022 (Ministerial Decision)

The 3rd Revision of the Code of Interventions (KAN.EPE.), for buildings of Reinforced Concrete, was completed by the Earthquake Planning and Protection Organization and posted on the website of the Organization (GG/3197/B/22-6-2022)
Given the necessity:

- of a complete, scientifically modern, safe, economical, legally consistent and adapted to Eurocode 8 Code of the critical issue of interventions in existing buildings, which have been designed with older anti-seismic codes.

- For completion of Eurocode 8, Part 3 and the update of the Code of Interventions (KAN.EPE.), as published (2nd Revision GG/2984/14-8-2017).

the completion and revision of individual points of the Code of Interventions (KAN.EPE), was deemed necessary, ten years after its 1st edition and five years after the publication of the 2nd revision, according to the scientific views of Earthquake Planning and Protection Organization (OASP) Working Groups that processed the relevant issues.
The most important interventions should be considered:

- The revision of assessment and redesign objectives in combination with the definition of seismic classification of buildings (Chapter 2)
- The values referred to data reliability levels and default conservative material strength values (Chapter 3)
- The addition of Appendix 7F for the approximate assessment of the influence of reinforcement corrosion on the mechanical characteristics of structural elements (Chapter 7)
- The revision of par. 8.2.1.5, par. 8.3.2.1 and par. 8.5.3. (Chapter 8)

Table2. Indicative correlation of return period and probability of exceedance of seismic actionwith the corresponding normalized horizontal ground acceleration.

Return Period (years)	Probability of exceedance of seismic action within the conventional life cycle of 50 years	$\alpha_g / \alpha_{g,ref}$
2475	2%	1.80
975	5%	1.30
475	**10%**	**1.00**
225	20%	0.75
135	**30%**	**0.60**
70	50%	0.45
40	70%	0.35
20	90%	0.25
<20	>90%	<0.25

Table3. Assessment or redesign objectives of the structure seismic

$\alpha_g / \alpha_{g,ref}$	Structuralperformancelevels			
	A "Immediate Occupancy after the earthquake"(A)	B "LifeSafety" (B)	Γ "Collapse Prevention"(C)	Italian Classification
1.80	**A0**	**B0**	**Γ0**	
1.30	**A1+**	**B1+**	**Γ1+**	
1.00	**A1**	**B1**	**Γ1**	**A+**
0.75	**A2+**	**B2+**	**Γ2+**	**≈A(0.80)**
0.60	**A2**	**B2**	**Γ2**	**B**
0.45	**A3+**	**B3+**	**Γ3+**	**C**
0.35	**A3**	**B3**	**Γ3**	**≈D(0.30)**
0.25	**A4+**	**B4+**	**Γ4+**	**≈D(0.30)**
<0.25	**A4**	**B4**	**Γ4**	**≈E(0.15)**

5.2. CODE OF ASSESSMENT AND RETROFITTING OF MASONRY STRUCTURES (ΚΑΔΕΤ)

Code of assessment and retrofitting of masonry structures (ΚΑΔΕΤ) Gov. Gazette Β΄2493/18-4-2023 (Ministerial Decision)

The Code of assessment and retrofitting of masonry structures, was completed in 2022 (GG/2493/B/18-4-2023) by an eleven members Working Group-Authoring Committee of the Earthquake Planning and Protection Organization of Greece and is posted on the website of the Organization (https://www.oasp.gr/node/4145).

The scope of the Code is the enactment of criteria for the assessment of the structural capacity of existing masonry structures. The code regulates the redesign of these structures, after potential interventions (repairs or strengthening), as well as for potential interventions, repairs or strengthening.

The Regulation applies both to ordinary buildings and to monuments and preserved buildings, together with additional special provisions that may apply.

The Regulation covers structures with or without damage from any cause.

The documentation of the structure includes information about the geometry, the materials and the construction details. Depending on the amount and the quality of the collected information, three Levels of Data Reliability are defined: “High”, “Sufficient” and “Tolerable”.

The code defines three potential performance levels of the structure: Level A: Limited Damage, Level B: Severe Damage, Level C: Near Collapse.The structures are categorized in 9 seismic classes for every performance level depending on their seismic capacity.
The seismic action effects in the structure are evaluated according one of the two proposed analytical approaches. The force-based approach and the displacement-based approach.
Several retrofitting techniques are proposed for repair or strengthening of the structure and the relevant models for the evaluation of their capacity after the evaluation are included.
The Standard includes the following chapters:

- Scope – Field of application – Obligations and responsibilities
- Basic principles, criteria and procedures
- Investigation and documentation
- Basic data for assessment and redesign
- Analysis prior and after the intervention
- Basic behaviour models
- Assessment of behaviour of structural elements
- Repairs or strengthening/ Design of interventions
- Safety verifications
- Required contents of the design
- Construction – Quality assurance - Maintenance

6. PRE-EARTHQUAKE VULNERABILITY ASSESSMENT OF BRIDGES

Nowadays many bridges across Greece are considered structurally deficient and need to be repaired in order to improve their condition and avoid additional deterioration. A systematic methodology for bridge preservation, focusing on preventive maintenance, and spending on bridge rehabilitation is definitely required to be developed.
At Earthquake Planning and Protection Organization (OASP) in 2002 a study was carried out with the title "Development of methodology for first and second level Pre-earthquake Assessment for certain types of existing bridges and statement of indicative proposals on bridge rehabilitation ". The methodology was based on preexisting Guides which were developed in USA and New Zealand. The method was developed by A.S. Karamanos, Th. Panoutsopoulos, S. Stathopoulos and S. Karakatsanidis, and calculates the seismic risk assessment and prioritization of bridges. An indicator of seismic vulnerability of bridge which indicates whether the bridge must be further examined is estimated using this method. Since the method was developed 20 years ago, it is obvious that an updated method to calculate the seismic vulnerability assessment of bridges in orderto prioritize them for the higher level of Pre-earthquake assessment must be developed.

7. ENERGY UPGRADE OF BUILDINGS

Thera are no policies and actions regarding the energy efficiency upgrade of buildings to enforce the assessment of seismic capacity according to the national codes before energy upgrading and major renovation works.

EUROPEAN PARLIAMENT

DIRECTIVE (EU) 2018/844 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

In the directive there is buildings seismic risk acknowledgement and the following general recommendations:

"…for the State to use its long-term renovation strategy to address risks related to intense seismic activity affecting energy efficiency renovations and the lifetime of buildings."

MINISTRY OF ENERGY, COMMERCE AND INDUSTRY

GovernmentLawNo 4122/2013 Gov. GazetteA΄42/19.2.2013

"Building Energy Performance – in accordance with the Directive 2010/31/EU of European Parliament and Council and other regulations."

Article 7 ExistingBuildings
The compulsory building permit for the implementation of major renovation works in existing buildings enforces the evaluation of *"risks"*possibly affecting buildings structural efficiency.
However, thereisnospecificreferencetoseismicrisk. Inadditiontothatthe evaluation procedure isn't determined, where there should be a clear obligation for the responsible bodies to ensure safety of the structural integrity of buildingsas well as the energy update investment.
This will be ensured only if the State enforces that the seismic capacity assessment, according to the national codes, take precedence over energy upgrade and major renovation works. Moreover, if structural studies indicate inefficiency, then appropriate measures should be taken to ensure safety. The necessary actions should upgrade the seismic capacity to the minimum acceptable level.

Gov. Gazette B΄4813/12.9.2022 (Ministerial Decision)

"Public buildings energy upgrade financing program."

The inspection form of 1st degree pre-earthquake inspection of public buildings (EPPO) is a mandatory supporting document in the first stage of the application certifying there is no inadequate seismic behavior.

However, the 1st degree pre-earthquake inspection procedure of public buildings (EPPO) is a rapid visual screening procedure.Actually, it is a simplified method for estimating the seismic capacity of a group of existing buildings, in the scope of setting priorities for the 2nd more detailed evaluation. The prioritization degree of a building doesn’t assert in no way the structural capacity.

OASP Team
D. Panagiotopoulou, M. Panoutsopoulou, K. Tarnava, T. Thoma, M. Fotopoulou, G. Zagora

SUMMER WORKSHOP WG15

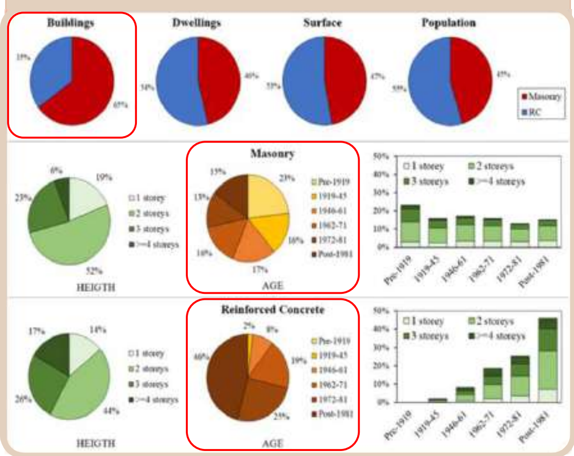
June 22nd, 2023 | TEAMS platform

Reluis Project: the Italian experience on integrated interventions applied to existing buildings

Andrea Prota, Francesca da Porto, Costantino Menna, Chiara Passoni, Alessandra Marini

Existing building stock in Italy

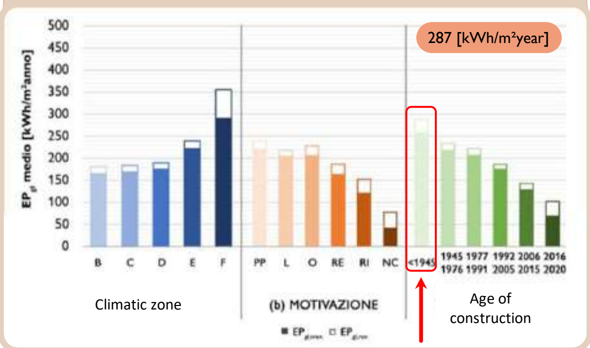
RESIDENTIAL BUILDING DISTRIBUTION (ISTAT)



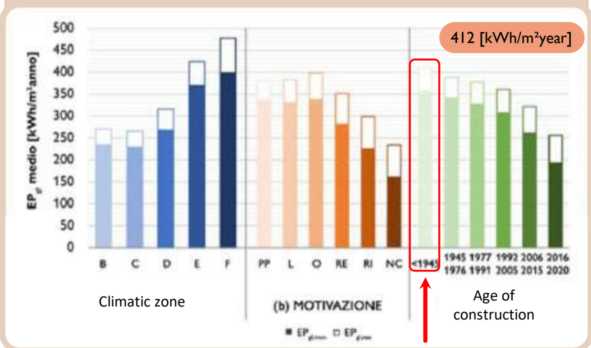
- MAJORITY OF RESIDENTIAL BUILDING (12.5 M vs 1.5 M NON-RESIDENTIAL)
- 54% OF RC BUILDINGS WERE BUILT BEFORE 1981 AND 29% BEFORE 1971
- 85% OF MASONRY BUILDINGS WERE BUILT BEFORE 1981 AND 72% BEFORE 1971
- FOR MASONRY BUILDINGS, THE 94% ARE UP TO 3 FLOORS, SINGLE AND TWO-FAMILY

Energy aspects: primary energy consumption

Global - primary energy consumption – RESIDENTIAL



Global - primary energy consumption - NON RES.



***Soruce**: Agenzia Nazionale Efficienza Energetica - ENEA (2021) "Report annuale sulla certificazione energetica degli edifici"*

3

Seismic aspects: Losses and induced damage

The Italian earthquakes (L'Aquila 2009, Emilia 2012, Centre Italy 2016)

L' Aquila (2009) **Centro Italia (2016)**

Effects of «combined» actions

Many buildings had been recently renovated focusing only on the energy retrofitting

MINISTERO DELL'AMBIENTE E DELLA SICUREZZA ENERGETICA

Super Ecobonus 110% 31 maggio 2023

		Dato Nazionale			
			% lavori realizzati	% edifici	% invest.
N. di edifici		411.873			
Totale investimenti(*)		78.353.945.998,78 €			
Totale investimenti ammessi a detrazione		77.057.998.817,56 €			
Totale investimenti per lavori conclusi ammessi a detrazione		62.300.966.991,84 €	80,8%		
Detrazioni maturate per i lavori conclusi		68.107.435.558,42 €	Onere a carico dello Stato		
di cui	**Condomini**				
	N. di edifici condominiali	64.038		15,5%	
	Totale investimenti(*)	39.686.358.792,76 €			
	Tot. Inv. Condominiali ammessi a detrazione	39.398.240.506,45 €			51,1%
	Tot. Lavori Condominiali realizzati ammessi a detrazione	28.549.667.183,56 €	72,5%		
	Edifici unifamiliari				
	N. di edifici unifamiliari	233.722		56,7%	
	Totale investimenti(*)	27.429.188.917,24 €			
	Tot. Inv. in edifici unifamiliari ammessi a detrazione	26.653.860.004,22 €			34,6%
	Tot. Lavori in edifici unifam. realizzati ammessi a detrazione	23.669.842.876,00 €	88,8%		
	U.I. funzionalmente indipendenti				
	N. di unità immobiliari funzionalmente indipendenti	114.105		27,7%	
	Totale investimenti(*)	11.236.708.771,70 €			
	Tot. Inv. in unità immob. indipend. ammessi a detrazione	11.005.058.774,32 €			14,3%
	Tot. Lavori in unità immob. indipend. realizzati	10.080.731.907,12 €	91,6%		
	Castelli				
	N. di castelli	6		0,0%	
	Totale investimenti(*)	1.689.517,08 €			
	Tot. Inv. in castelli ammessi a detrazione	839.532,17 €			0,0%
	Tot. Lavori in castelli realizzati ammessi a detrazione	725.025,16 €	86,4%		
		Investimento medio(*)			
	Condomini	**619.731,39 €**			
	Edifici unifamiliari	**117.358,18 €**			
	U.I. funzionalmente indipendenti	**98.476,92 €**			
	Castelli	**281.586,18 €**			

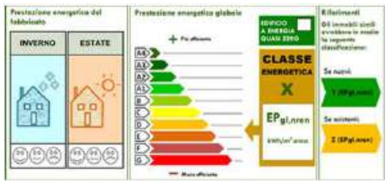
(*) Investimento compreso le somme non ammesse a detrazione

Urgent need for a methodology addressing
the integrated design of retrofit solutions

Italian regulatory framework over the last years

MARCH 2023 | **Directive "Green HOUSES"** Energy efficiency of buildings

Law 90/2013 | **Mandatory - Energy Performance Certificate**



OPCM 3274/03 | **Seismic ordinance** and following standards up to NTC18

- Mandatory seismic verification for strategic and relevant buildings
- Local intervention, improvement (0.6), upgrade (0.8) for strategic and relevant buildings
- +0.10 for improvement of ordinary structures

DM n. 65 07/03/17 | **Seismic risk classification of buildings**

Possibility linked to the use of incentives for the intervention

Reluis Project: WP5 – Integrated interventions

WP5: "**Fast and Integrated Retrofit Interventions**" supported the research activities to develop a proper methodology for the integrated retrofitting of existing buildings by using fast and innovative solutions

7

Reluis Project: WP5 – Techniques

Development of innovative and integrated retrofit techiques with increasing effectivness, level of distruption and costs

FRP wrapping (exterior)

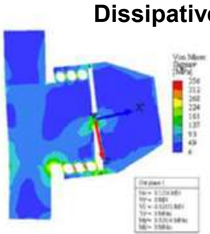
Wood panels

Steel jacketing

Exoscheleton

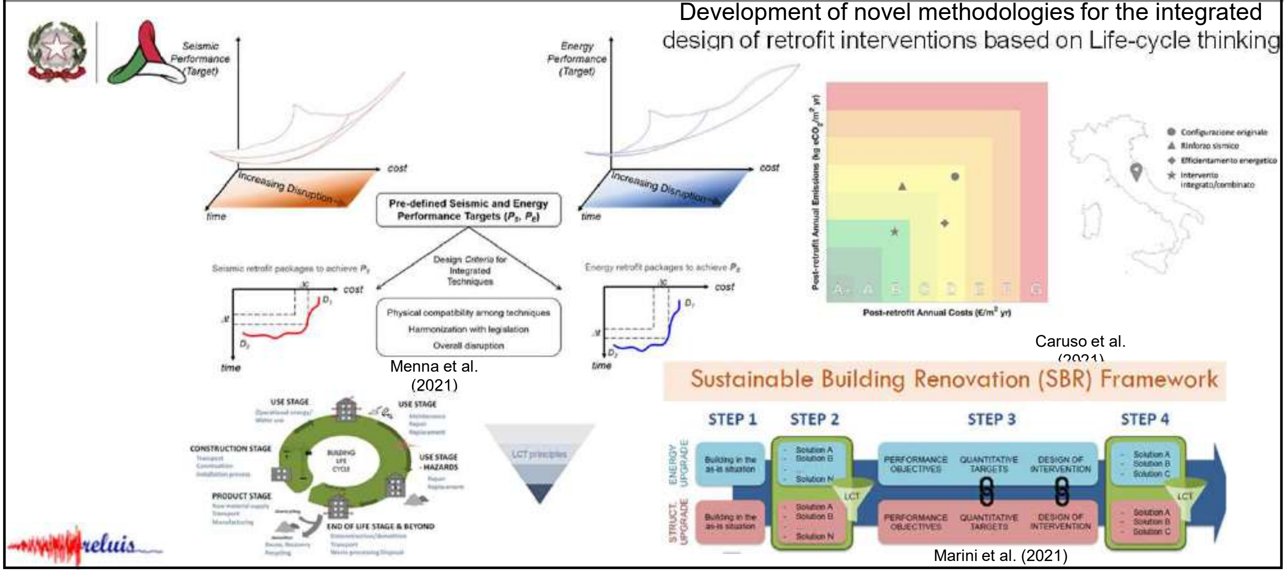
FRCM

Dissipative elements



Reluis Project: WP5 – Methods

Development of novel methodologies for the integrated design of retrofit interventions based on Life-cycle thinking



Reluis Project: WP5 – Case Study

https://www.reluis.it/it/wp5-casi-studio.html

10

MASONRY STRUCTURES: integrated techniques

Use of innovative composite materials

Palazzo Lui, Padova

Casa Olivi, Padova

11

MASONRY STRUCTURES: integrated techniques

Interventions of injection of mixtures based on natural hydraulic lime, repointing and insertion of transverse tie rods in stone masonry

Sourcee: Giaretton e Valluzzi, 2017

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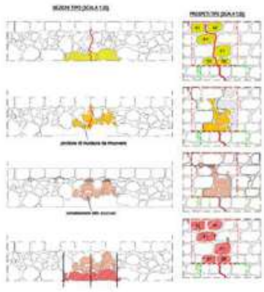
MASONRY STRUCTURES: integrated techniques


Scuola e palestra, Cologna Veneta (VR)



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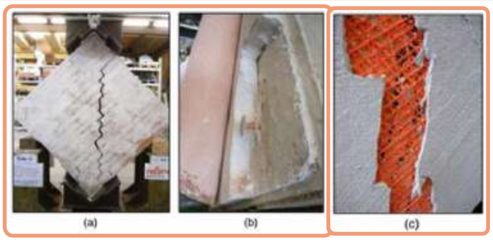
MASONRY STRUCTURES: integrated techniques

Sample type	Identifier	P_{max} (kN)	τ_{max} (MPa)	$\tau_{max}/\tau_{as-built}$
Two-leaf-thick solid clay-brick wall panels (11 samples)				
As-built[a]	UR2-1	121.2	0.32	—
	UR2-2	71.9	0.19	—
	UR2-3	104.6	0.28	—
	Average	99.2	0.26	—
Single-sided	R2s-1	181.1	0.48	—
	R2s-2	142.7	0.37	—
	R2s-3	125.6	0.33	—
	R2s-4	116.7	0.31	—
	R2s-th	173.7	0.46	—
	Average	148.0	0.39	1.5
Double-sided	R2d-1	238.0	0.62	—
	R2d-2	255.9	0.67	—
	R2d-3	270.4	0.71	—
	Average	254.8	0.67	2.6
One-leaf-thick solid clay-brick wall panels (2 samples)				
As-built[a]	UR1-1	34.2	0.19	—
Single-sided	R1s-1	149.6	0.82	4.4
Hollow clay-block wall panels (2 samples)				
As-built[a]	URh-1	304.9	0.69	—
Single-sided	Rhs-1	338.6	0.77	1.1

CNR-DT215-2018

Hydraulic lime plasters reinforced with fiberglass and polypropylene meshes and possibly integrated with insulating external


(a) (b) (c)


(a) (b) (c)

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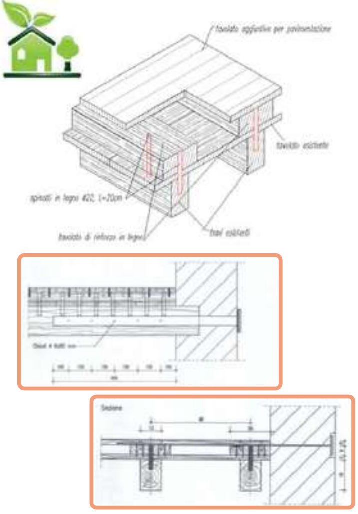
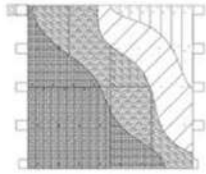
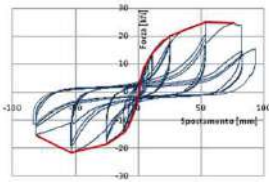
MASONRY STRUCTURES: integrated techniques





+45°SP.LDF.OSB - Simple planking + Panel wood-wool + OSB panel



Fonte: Valluzzi et a., 2005

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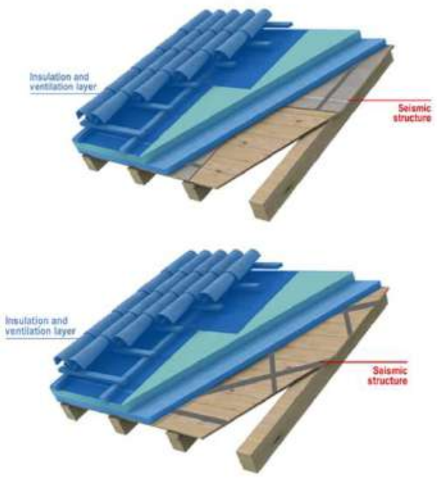
MASONRY STRUCTURES: integrated techniques



Fonte: Giuriani and Marini, 2008

Fonte: Modena, 2010

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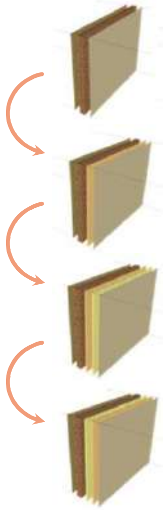
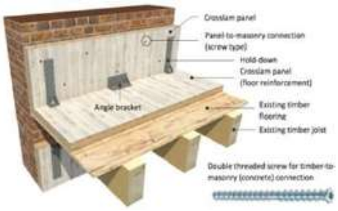
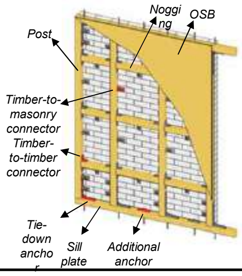
MASONRY STRUCTURES: integrated techniques





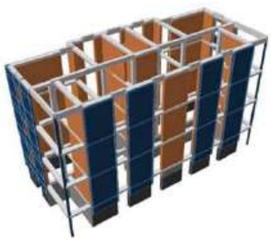
Fonte: Giongo e Piazza, 2022

Use of wooden panels



Fonte: Guerrini e Graziotti, 2022

MASONRY STRUCTURES: integrated techniques

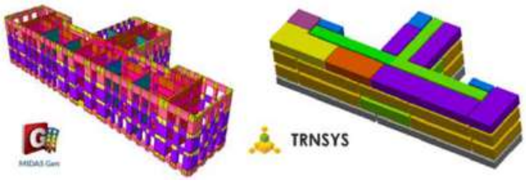


Source: Marini et al., 2021

Incremental approach applied to masonry structures

INCREMENTAL Interventions
Target: seismic / energy performance

Lievel l	Walls
Level 2	Horizontal structures
Level 3	Walls and horizontal structures
Level 4	NZEB building



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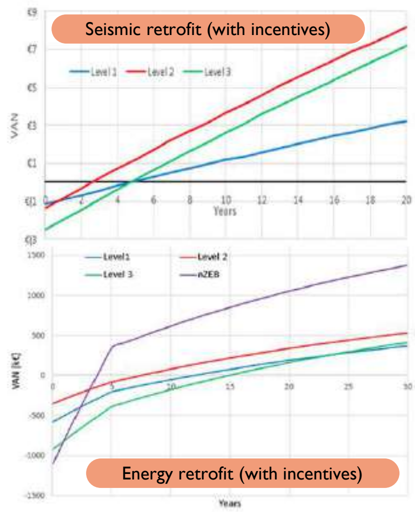
Incremental approach applied to masonry structures

INCREMENTAL Interventions
Target: seismic / energy performance

Level 1 | Level 2 | Level 3 | Level 4

Upgrade ENERGY

Upgrade SEISMIC



Sourcee: Caprino, Carnieletto, De Carli, da Porto (2021)

20

Incremental approach applied to RC structures

CASE STUDY 1: scuola media Parozzani Isola del Gran Sasso (TE)

Sourcee: Menna et al. (2021)

1) ***Local strengthening interventions (Exterior only)***
Seismic performance increase ζ_E=60%
Energy consumption reduction PEC = -20%

2) ***Local strengthening interventions***
(low level of distruption)
Seismic performance increase ζ_E >=60%
Energy consumption reduction PEC = -40%

3) ***Global retrofit (high level of distruption)***
Seismic performance increase ζ_E=100%
Energy consumption reduction PEC <= -60%

Increasing level of disruption

Increasing structural and energetic performances

SLV e SLD
(NTC 2018 + Circ. 2019)
- **Seismic strengthening ζ_E=0,6**
- **Retrofitting ζ_E=0,8**

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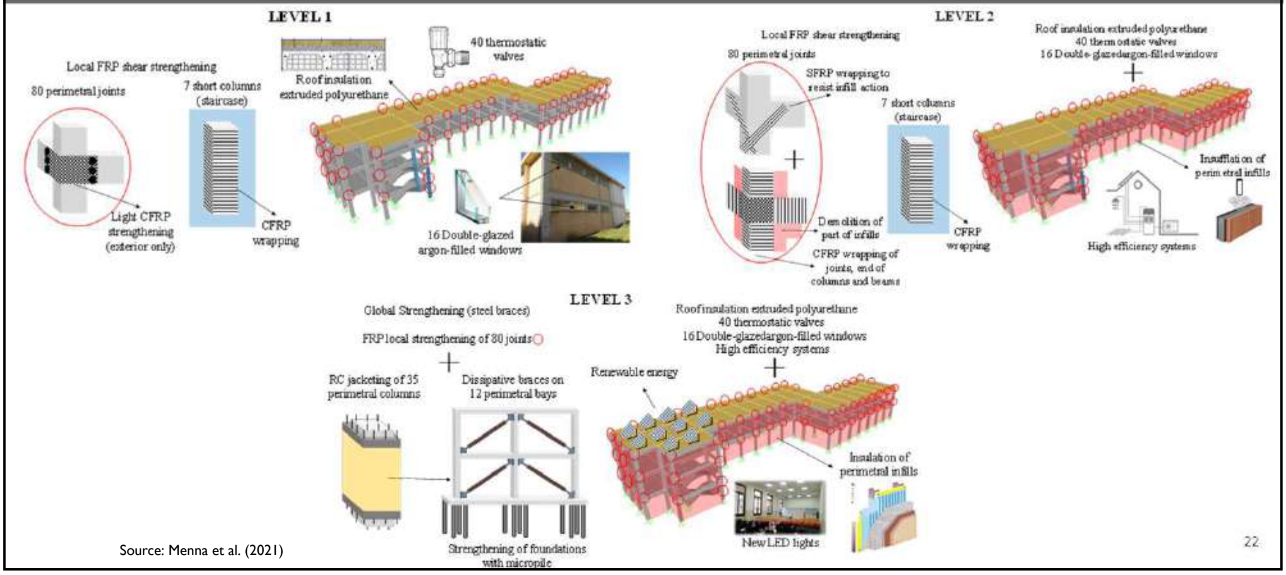
Incremental approach applied to RC structures



Source: Menna et al. (2021)

22

Incremental approach applied to RC structures

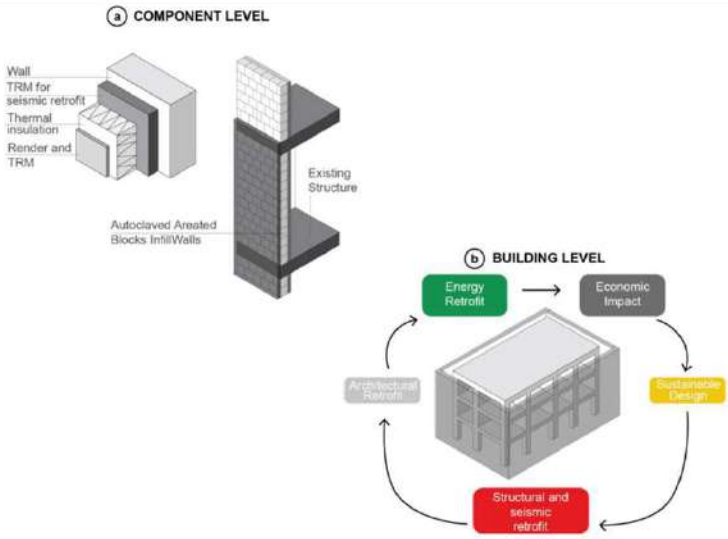
CASE STUDY 1: scuola media Parozzani Isola del Gran Sasso (TE)

Source: Menna et al. (2021)

LEVEL OF DESIGN	Works / CIVIL WORKS	Cost [€]	Surface [m²]	Volume [m³]	€/m²	€/m³
Level I (IS-V=60%, PAM=1.1%) +3 Sesmic classes +2 Energy class	Structural	104,000			70.75	22.13
	Demolition and finishing replacement	21,500			14.63	4.57
	Total structural	125,500	1,470	4,700	85.37	26.70
	Energy efficiency	255,000			173.47	54.26
	TOTAL INTERVENTIONS	**380,500**			**258.84**	**80.96**
Level II (IS-V=60%, PAM=1.1%) +3 Seismic classes +4 Energy classes	Structural	240,500			163.61	51.17
	Demolition and finishing replacement	60,000			40.82	12.77
	Total structural	300,500	1,470	4,700	204.42	63.94
	Energy efficiency	289,000			196.60	61.49
	TOTAL INTERVENTIONS	**589,500**			**401.02**	**125.43**
Level III (IS-V=60%, PAM=0.47%) +5 Seismic classes +7 Energy classes	Structural	359,000			244.21	76.40
	Demolition and finishing replacement	80,000			54.42	17.00
	Total structural	439,000	1,470	4,700	298.64	93.40
	Energy efficiency	513,500			349.32	109.3
	TOTAL INTERVENTIONS	**952,500**			**647.96**	**202.66**
	SAFETY of WORKERS COSTS For all desing levels	25,000	1,470	4,700	17.01	5.32

23

Methods: different approaches

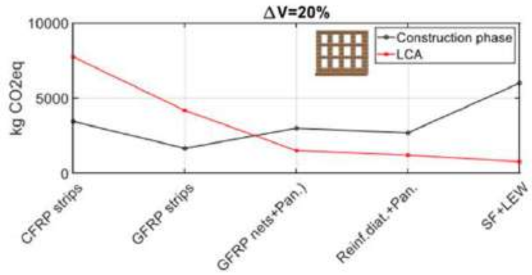


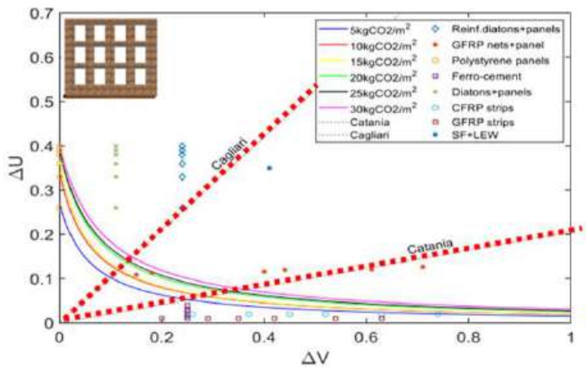
- **1**. Incremental approach: Performance targets Seis-En
- **2**. Definition of iso-performance curves for the techniques
- **3**. Cost optimization: optimal, MCDM
- **4**. Olistic methods or based on LCT

Methods: component level – integrated technique

Definition of curves
ISO-COST and ISO-PERFORMANCE

Source: Giresini et al. (2021)





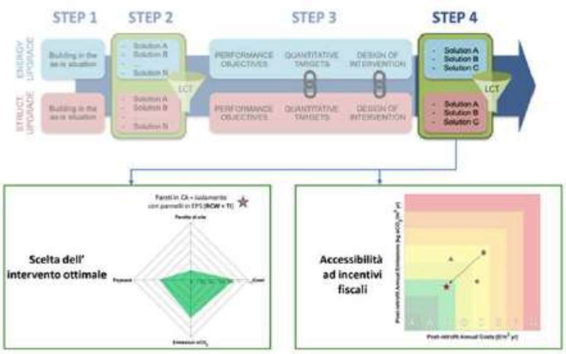
ISO-PERFORMANCE

ISO-COST

25

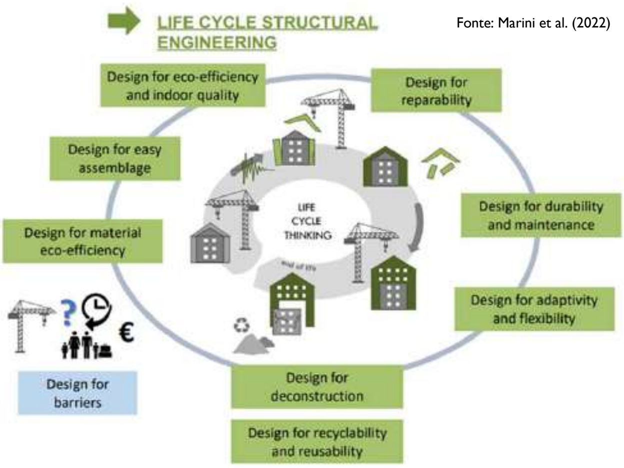
Methods: different approaches

Methods based on
LIFE CYCLE THINKING (LCT)



Source: Caruso et al. (2021)

Fonte: Marini et al. (2022)



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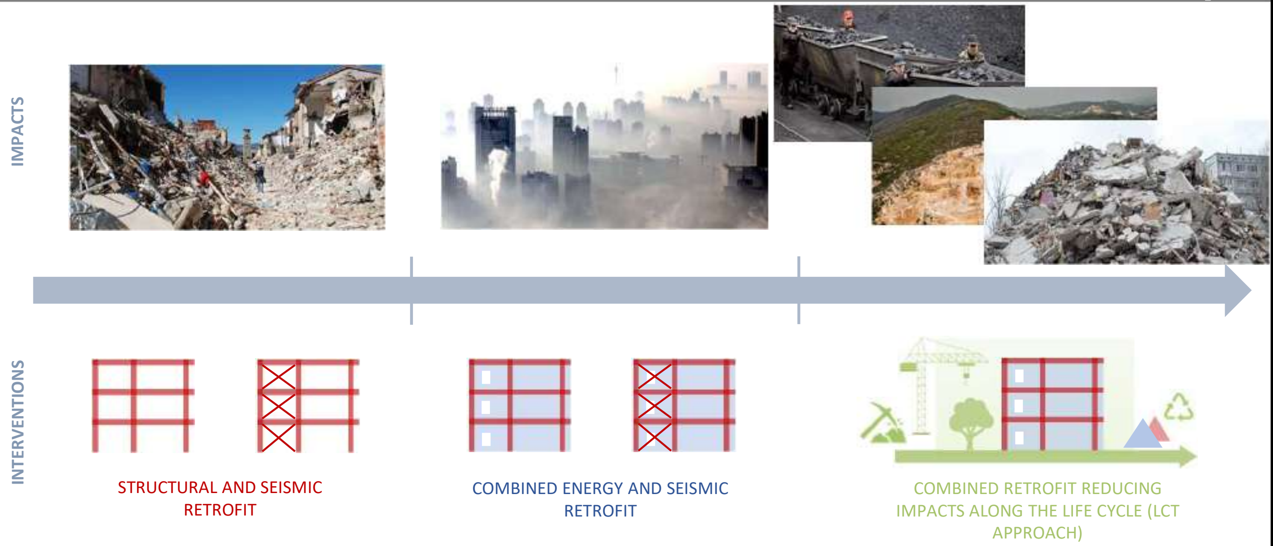
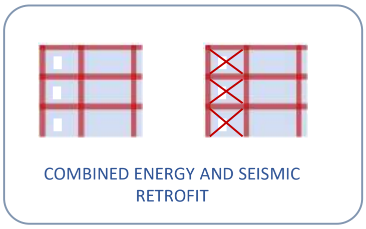
Sustainable and combined retrofit interventions: The evolution of the concept

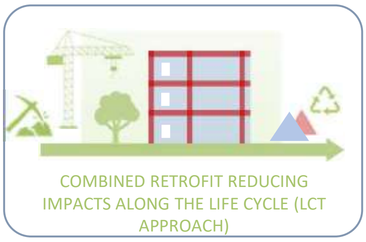


Sustainable and combined retrofit interventions: The evolution of the concept



Need for new design methods allowing:

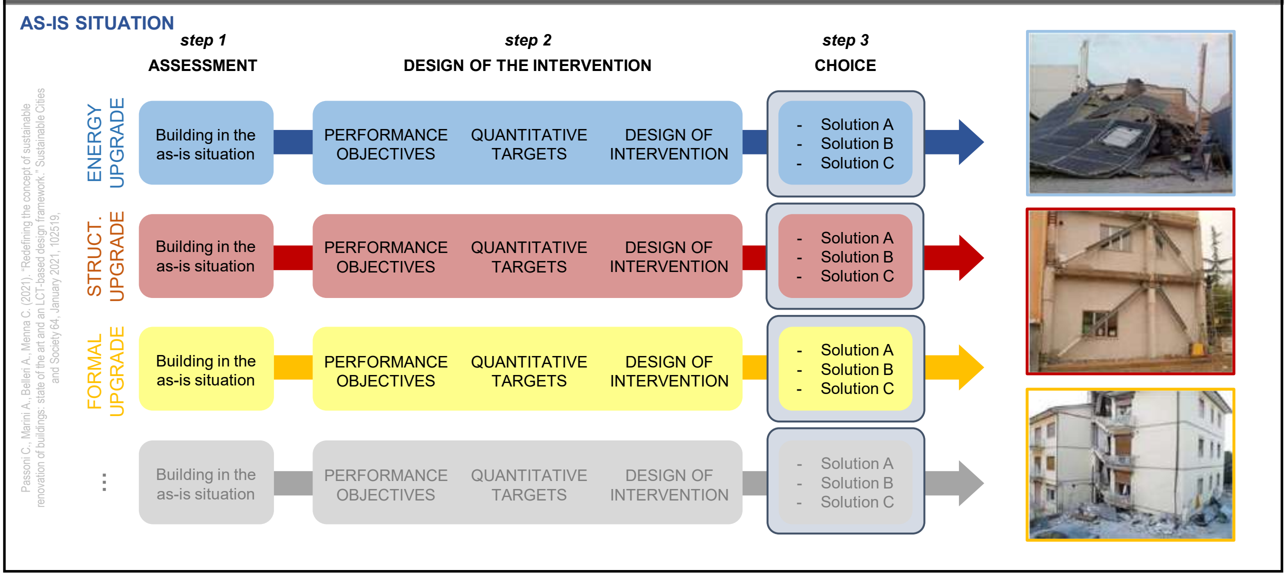
- Integrated assessment of the as-is condition of existing buildings
- Integrated seismic-energy retrofit techniques
- Design targets able to protect both the structural and non-structural (energy) elements



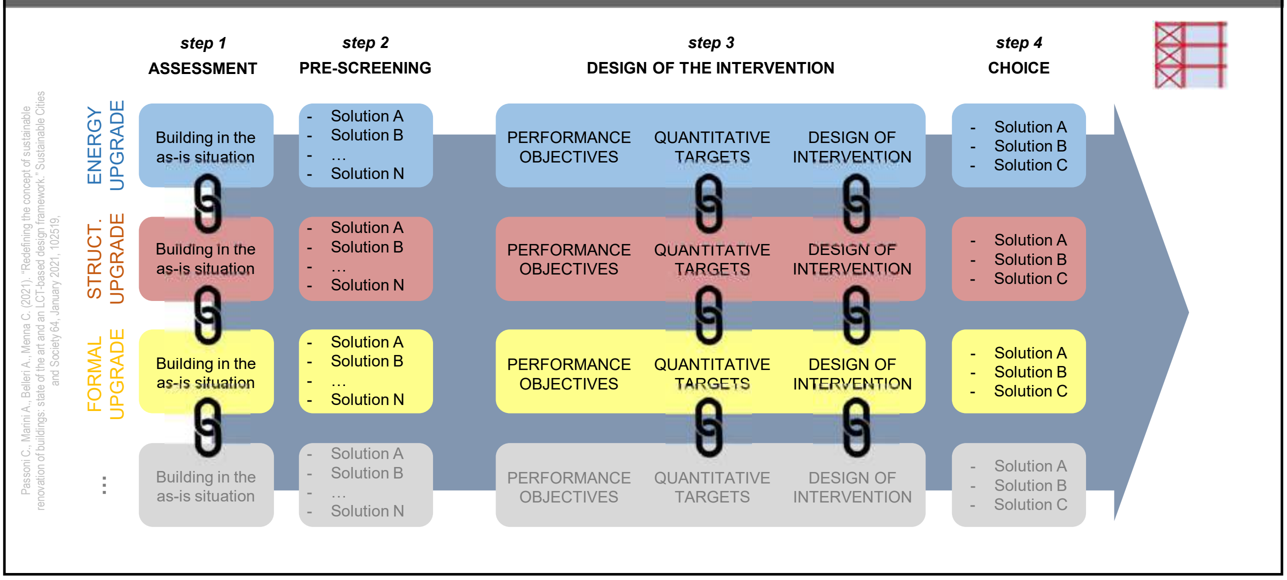
Need for new design methods allowing:

- Integration of LCT principles from an early stage of the design
- Pre-screening of possible retrofit alternatives to avoid the design of unsustainable solutions
- LC analyses (LCA, LCC) for the assessment and choice of retrofit alternatives
- Combined (energy+seismic) classification tools

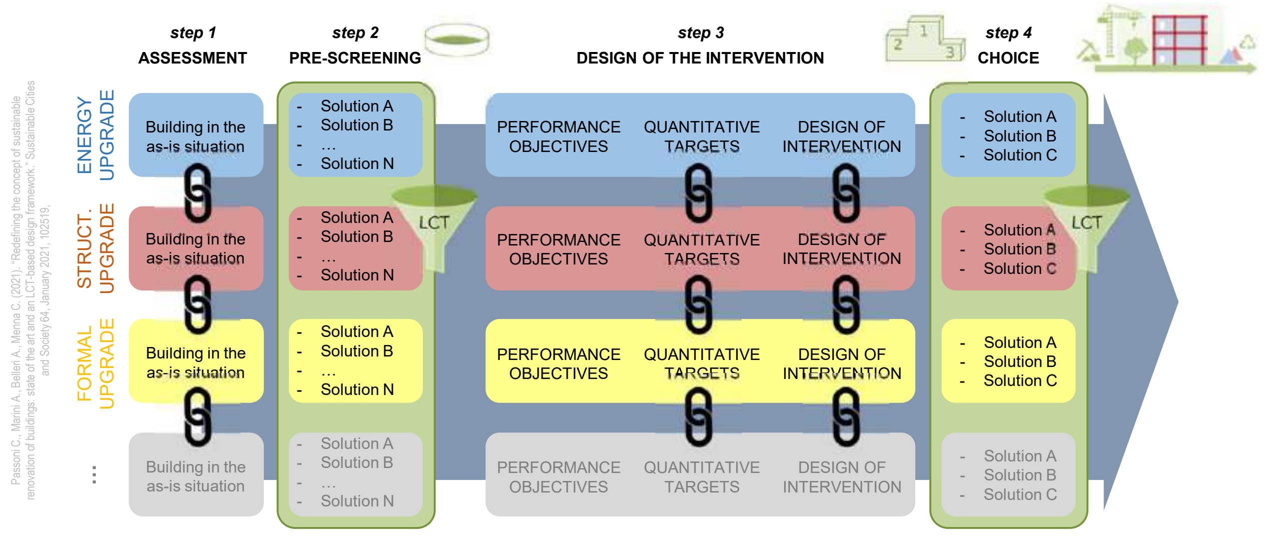
Sustainable and combined retrofit interventions: LCT-based SBR framework



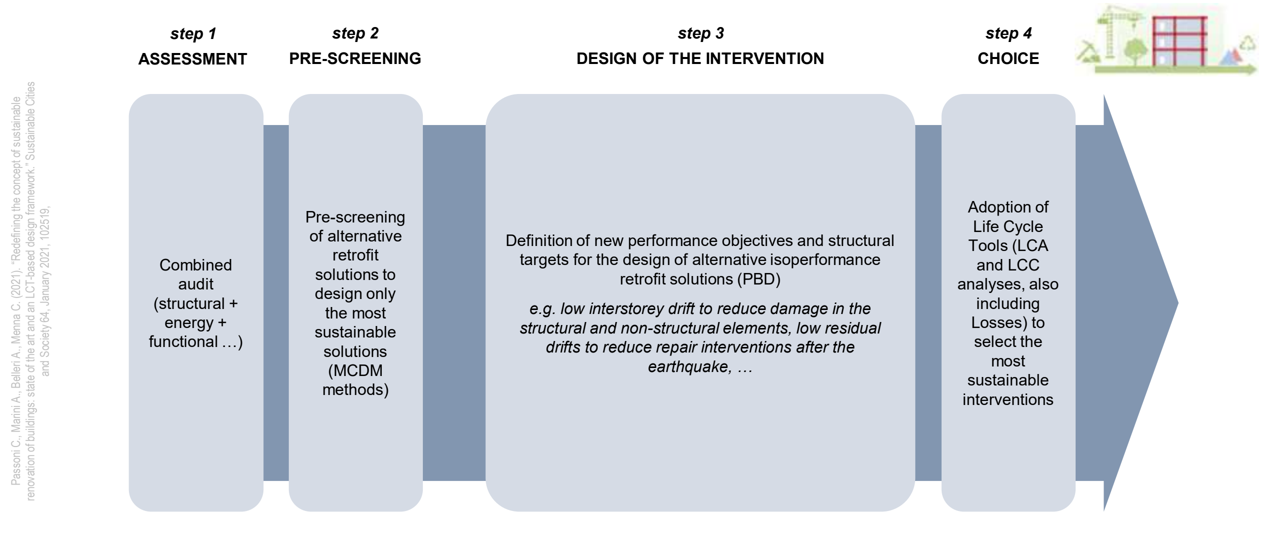
Sustainable and combined retrofit interventions: LCT-based SBR framework



Sustainable and combined retrofit interventions: LCT-based SBR framework



Sustainable and combined retrofit interventions: LCT-based SBR framework



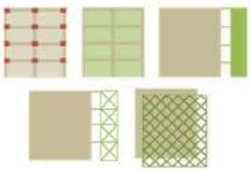
Sustainable and combined retrofit interventions: LCT-based SBR framework

Passoni C., Marini A., Belleri A., Menna C. (2021). "Redefining the concept of sustainable renovation of buildings: state of the art and an LCT-based design framework." Sustainable Cities and Society 64, January 2021, 102519.

Sustainable and combined retrofit interventions: LCT-based SBR framework

Passoni C., Marini A., Belleri A., Menna C. (2021). "Redefining the concept of sustainable renovation of buildings: state of the art and an LCT-based design framework." Sustainable Cities and Society 64, January 2021, 102519.

ALTERNATIVES

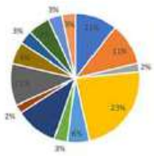


A1	Node strengthening
A2	Strength of selected bays
A3	Seismic isolation
A4	RC shear walls
A5	Steel shear walls
A6	Steel diagrid

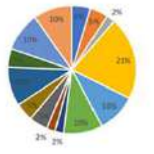
CRITERIA

(considering LCT principles and sustainability triple bottom line)

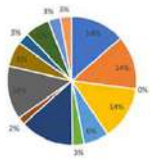
C1	duration of works	SOC
C2	renovation costs	ECO
C3	need for additional space	TEC
C4	need for inhabitant relocation	SOC
C5	fast assembling	ENV
C6	waste generation	ENV
C7	possibility to increase living space	ECO/SOC
C8	adaptability (IR)	ECO
C9	need for maintenance	ECO
C10	repair cost	ECO
C11	impacts connected to repair	ENV
C12	building downtime	SOC
C13	fast disassembling	ENV
C14	recyclability/reusability	ENV



Scenario 1 – residential use; no relocation; limited budget.

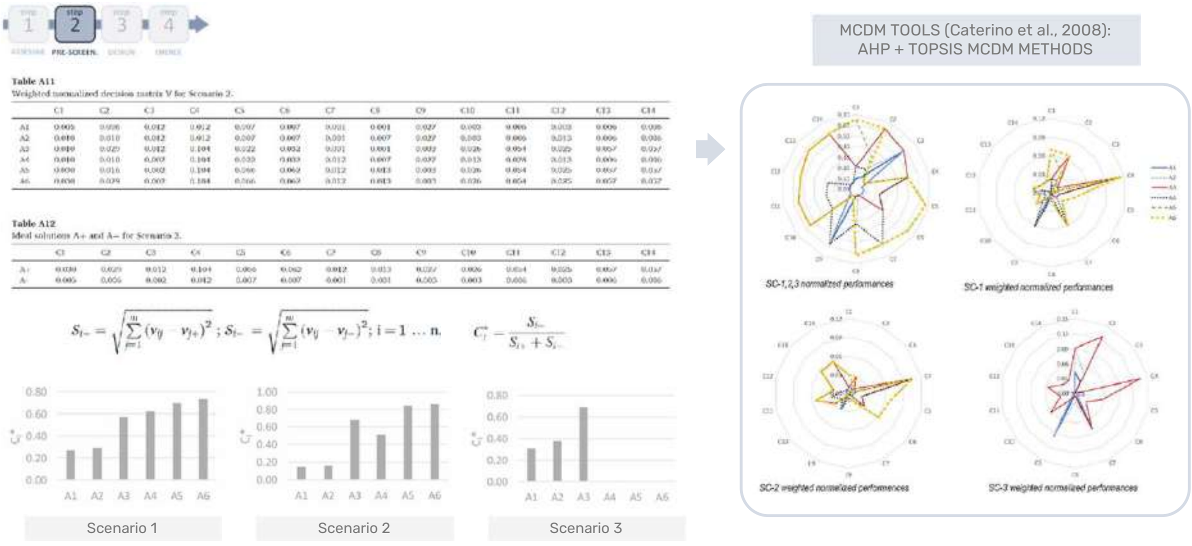


Scenario 2 – residential use; no relocation; no restricted budget; most environmental -friendly retrofit.



Scenario 3 – residential use; low budget; impossibility to increase the building space

Sustainable and combined retrofit interventions: LCT-based SBR framework



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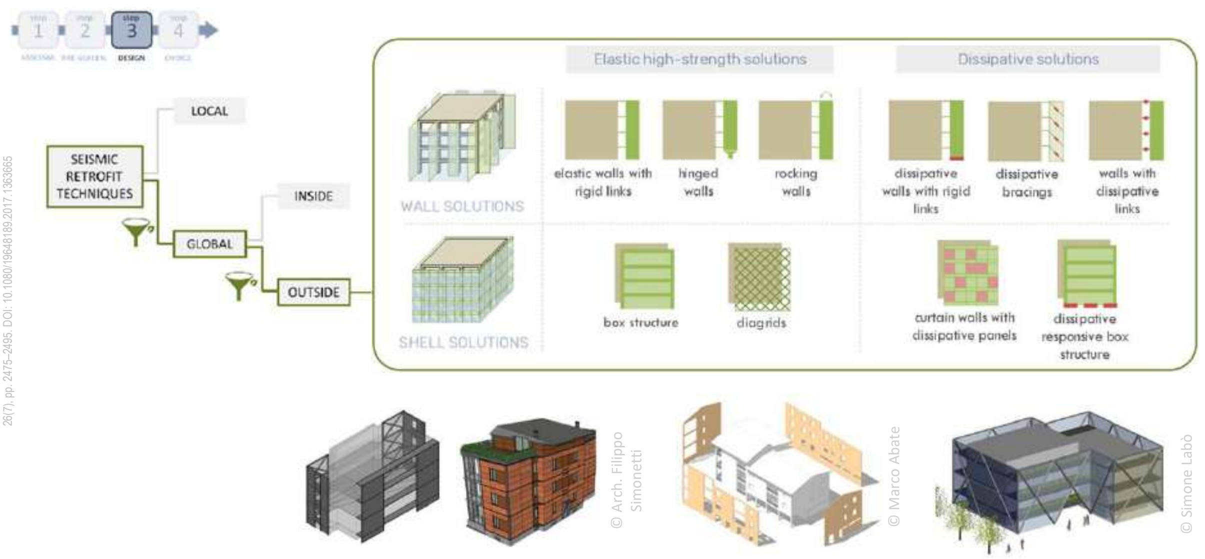
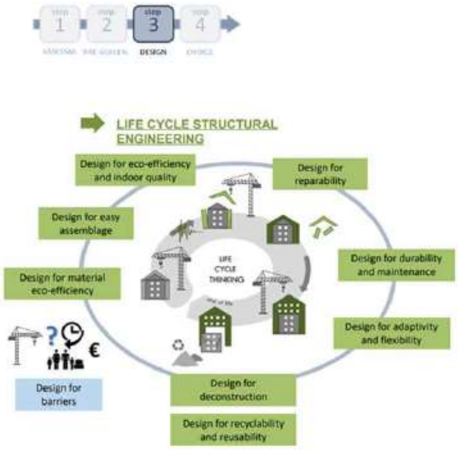
Sustainable and combined retrofit interventions: LCT-based SBR framework

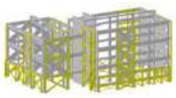


Marini A., Passoni C., Belleri A., Feroldi F., Preti M., Metelli G., Riva P., Giuriani E., Plizzari G. (2017) “Combining seismic retrofit with energy refurbishment for the sustainable renovation of RC buildings: a proof of concept.” European Journal of Environmental and Civil Engineering, 2022, 26(7), pp. 2475–2495. DOI: 10.1080/19648189.2017.1363665

Sustainable and combined retrofit interventions: LCT-based SBR framework



Passoni, C., Caruso, M., Marini, A., Pinho, R., Landolfo, R. (2022) "The role of Life Cycle Structural Engineering in the transition towards a sustainable building renovation: available tools and research needs". Buildings, 12(8), 1107; https://doi.org/10.3390/buildings12081107



Zanni J., Cademartori S., Marini A., Belleri A., Passoni C., Giuriani E., Riva P., Angi B., Brumana G., Marchetti A.L. (2021). "Integrated Deep Renovation of Existing Buildings with Prefabricated Shell Exoskeleton." Sustainability. 2021, 13, 11287. DOI: https://doi.org/10.3390/su132011287

SUMMER WORKSHOP WG15

June 22nd, 2023 | TEAMS platform

THANK YOU FOR YOUR ATTENTION

Andrea Prota, Francesca da Porto, Costantino Menna, Chiara Passoni, Alessandra Marini

Innovative seismic and energy retrofitting of the existing building stock (iRESIST+)

***Dionysios BOURNAS**, Team Leader*

Co-authors: Daniel Pohoryles, Stylianos Kallioras

Joint Research Centre (JRC), European Commission

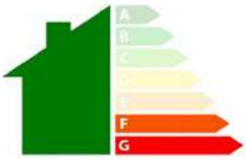
Presentation to the Working Group 15 of the European Association of Earthquake Engineering

June 15, 2023

Motivation and background

- Our cities and buildings are ageing

Motivation and background



75% of EU buildings are energy inefficient

36% of CO_2 emissions

40% of EU energy consumption

Over **170 million Europeans** are potentially exposed to earthquakes

European Commission

Experimental Assessment of Existing Buildings

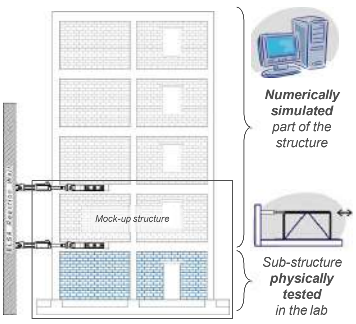
European Commission

Full-scale prototype constructed at the European Laboratory for Structural Assessment (ELSA lab)

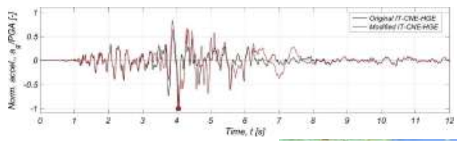
- **Prototype structure representing a typical pre-1970's infilled RC frame in Southern Europe**
- **Tested under pseudo-dynamic loading as five-storey structure**

Seismic Testing at the ELSA Lab

Pseudodynamic and Substructuring

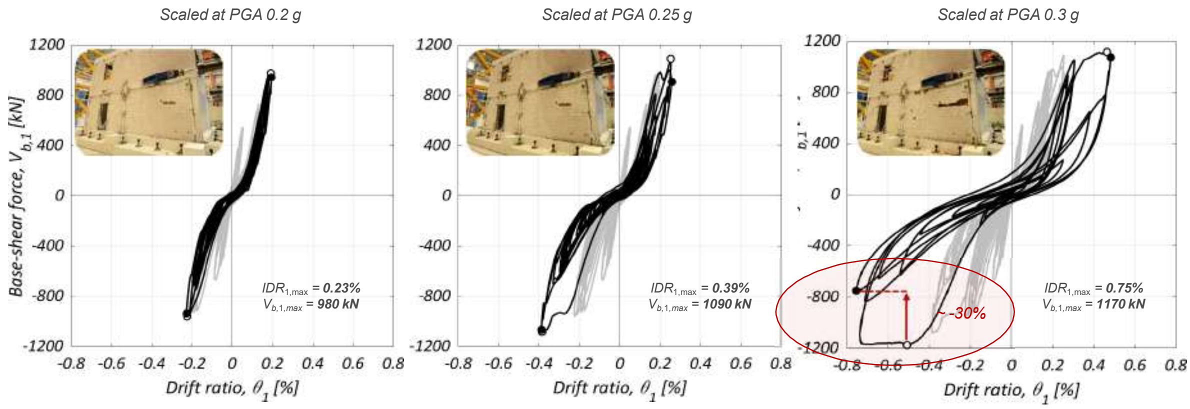


Seismic Input Motion from Central Italy 2016



E-W component of motion registered in ***Castelluccio di Norcia*** *(October 30, 2016 with M_W 5.9)*

Base-shear vs. drift (*1st storey*) hysteretic response

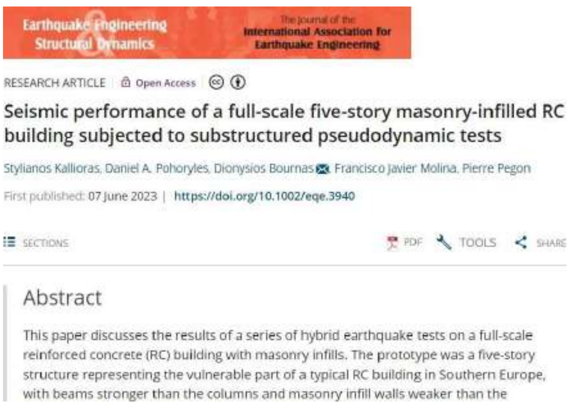


Kallioras, S, Pohoryles, DA, Bournas, D, Molina, F, Pegon, P. Seismic performance of a full-scale five-story masonry-infilled RC building subjected to substructured pseudodynamic tests. *Earthquake Engng Struct Dyn*. 2023; 1- 30. https://doi.org/10.1002/eqe.3940

European Commission

Experimental article on the seismic assessment of the full-scale Building

Kallioras, S, Pohoryles, DA, Bournas, D, Molina, F, Pegon, P. **Seismic performance of a full-scale five-story masonry-infilled RC building subjected to substructured pseudodynamic tests**. *Earthquake Engng Struct Dyn*. 2023; 1- 30. https://doi.org/10.1002/eqe.3940



Earthquake Engineering & Structural Dynamics

The Journal of the International Association for Earthquake Engineering

RESEARCH ARTICLE | Open Access

Seismic performance of a full-scale five-story masonry-infilled RC building subjected to substructured pseudodynamic tests

Stylianos Kallioras, Daniel A. Pohoryles, Dionysios Bournas, Francisco Javier Molina, Pierre Pegon

First published: 07 June 2023 | https://doi.org/10.1002/eqe.3940

SECTIONS PDF TOOLS SHARE

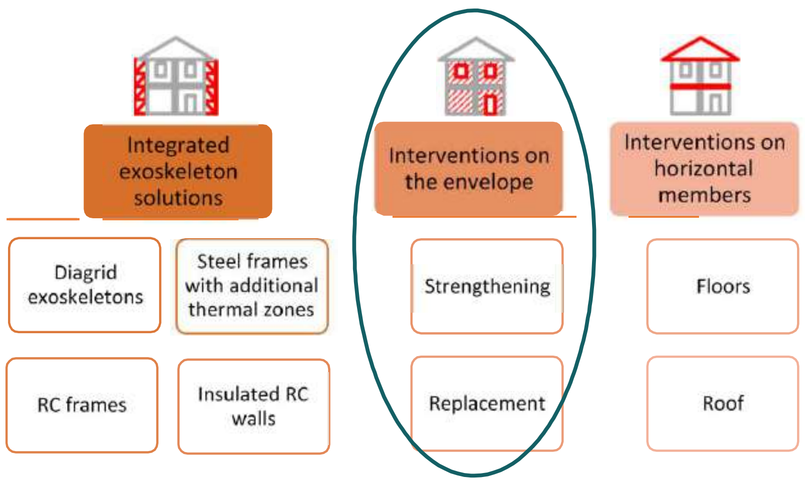
Abstract

This paper discusses the results of a series of hybrid earthquake tests on a full-scale reinforced concrete (RC) building with masonry infills. The prototype was a five-story structure representing the vulnerable part of a typical RC building in Southern Europe, with beams stronger than the columns and masonry infill walls weaker than the

European Commission

Novel Technologies for Integrated Retrofitting

Categorization of integrated renovation technologies[1]



[1]Pohoryles, D.A., Bournas, D.A., Da Porto, F., Caprino, A., Santarsiero, G. and Triantafillou, T. (2022). Integrated Seismic and Energy Retrofitting of Existing Buildings: A State-of-the-Art Review. Journal of Building Engineering, Vol 61, 105274. https://doi.org/10.1016/j.jobe.2022.105274

Analysis of technologies for combined upgrading of existing buildings[1]

	Structural upgrade	Energy upgrade	Costs	Impact on environment	Invasiveness	Level of disruption	Level of Integration
Exoskeleton systems	+++	+++	High	Medium-High	High	Low	Coupled/ Integrated
TRM+thermal insulation	+++	++	Low	Medium	Medium	Low-Medium	Coupled/ Integrated
Strengthening of openings	+	+	Medium	Medium	Medium	Medium	Coupled
Timber-based panels	++	++	Medium	Low-Medium	Medium	Low-Medium	Coupled/ Integrated
Replacing envelope	+++	++	Low	High	High	Medium-High	Integrated
Interventions on floors or roof	+	+	Medium	Medium	Low-Medium	High	Coupled

[1]Pohoryles, D.A., Bournas, D.A., Da Porto, F., Caprino, A., Santarsiero, G. and Triantafillou, T. (2022). Integrated Seismic and Energy Retrofitting of Existing Buildings: A State-of-the-Art Review. Journal of Building Engineering, Vol 61, 105274. https://doi.org/10.1016/j.jobe.2022.105274

European Commission

Review article for deepening on the topic of on integrated retrofitting of existing buildings

Pohoryles, D.A., Bournas, D.A., Da Porto, F., Caprino, A., Santarsiero, G. and Triantafillou, T. (2022). **Integrated Seismic and Energy Retrofitting of Existing Buildings: A State-of-the-Art Review**. Journal of Building Engineering, Vol 61, 105274. https://doi.org/10.1016/j.jobe.2022.105274

Journal of Building Engineering 61 (2022) 105274

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Integrated seismic and energy retrofitting of existing buildings: A state-of-the-art review

D.A. Pohoryles[a], D.A. Bournas[a,*], F. Da Porto[b], A. Caprino[b], G. Santarsiero[c], T. Triantafillou[d]

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ARTICLE INFO

Keywords:
Integrated retrofitting
Seismic and energy retrofitting
Existing buildings
Energy efficiency
Seismic strengthening

ABSTRACT

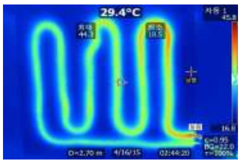
Ageing of the building stock is an issue affecting many regions in the world. This means a large proportion of existing buildings being considered energy inefficient, with associated high energy use for heating and cooling. Through renovation, it is possible to improve their energy-efficiency, hence reducing their significant impact on the total energy household and associated greenhouse gas emissions. In seismic regions, additionally, recent earthquakes have caused significant economic losses, largely due to the vulnerability of older buildings not designed to modern standards. Addressing seismic and energy performance by separate interventions is the common approach currently taken, however to achieve better cost-effectiveness, safety and efficiency, a novel holistic approach to building renovation is an emerging topic in the scientific literature. Proposed solutions range from integrated exoskeleton solutions, over strengthening and insulation solutions for the existing building envelope or their replacement with better materials, to integrated

JRC-KOCED Collaboration: Advanced Materials for Integrated Retrofitting

International Collaboration Project (2019-2021)

Partners: Korea Construction Engineering Development Collaboratory Management Institute (KOCED CMI)

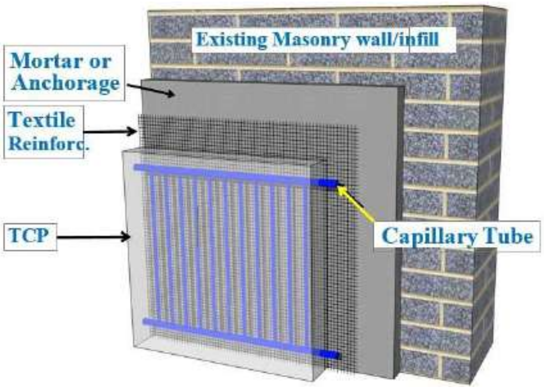
Development of Textile-reinforced mortar & Capillary tube Panel retrofitting technology to simultaneously improve Seismic and Energy Performance of the existing buildings



Source: KOCED (2020)

13

Novel Textile-Capillary Tube Panels (TCPs)



Capillary tube mats embedded in a layer of textile-reinforced mortar

- Lightweight strengthening system
- Prefabricated panels: fast on-site and low-cost application
- Combined seismic and energy retrofit of RC and masonry buildings

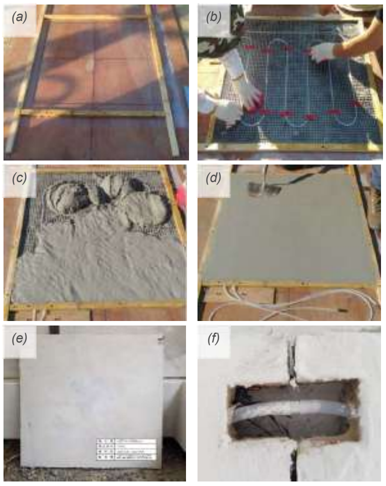
Baek et al., Engineering Structures 265, 2022
https://doi.org/10.1016/j.engstruct.2022.114453

14

TEXTILE CAPILLARY TUBE PANELS (TCPS)

Fabrication of a TCP element

- (a) preparation of a 20-mm-deep mould;
- (b) installation of the composite layer of textile sheet and capillary tube;
- (c) casting the element;
- (d) finishing/smoothening the visible side of the element;
- (e) finished panel (640 wide 620 long);
- (f) detail of connector ensuring water circulation between adjacent TCPs

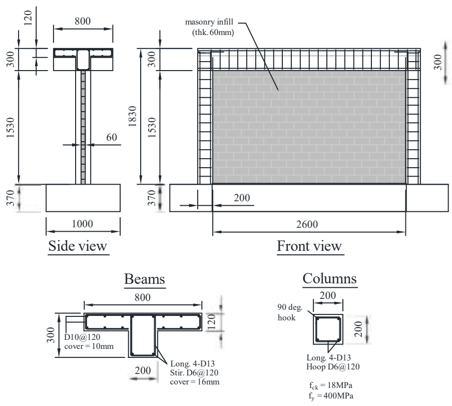


Baek et al., Engineering Structures 265, 2022 https://doi.org/10.1016/j.engstruct.2022.114453

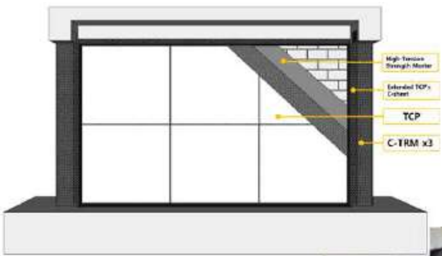
European Commission

Integrating retrofitting of masonry-infilled RC frames

Non Retrofitted specimen



TCP-Retrofitted specimen

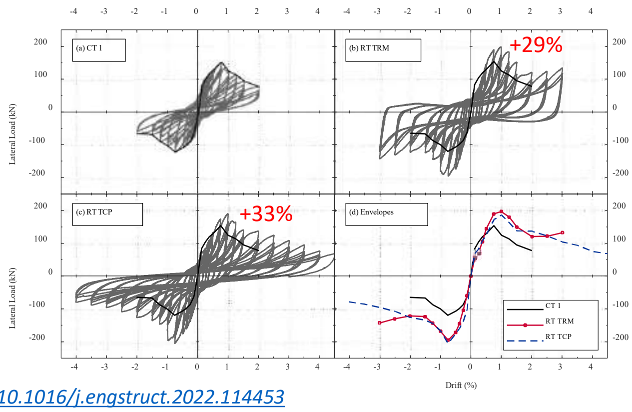


Baek et al., Engineering Structures 265, 2022 https://doi.org/10.1016/j.engstruct.2022.114453

Seismic performance evaluation

Damage at 4% drift ratio

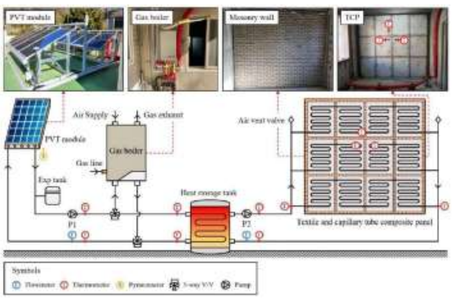
Cyclic Force-Displacement Responses



Baek et al., Engineering Structures 265, 2022 https://doi.org/10.1016/j.engstruct.2022.114453

Thermal performance evaluation

Field Experiment: Thermal Tests on a TCP-Retrofitted Wall



Case study: small residential house in Busan, South Korea *(latitude: 35°22' N; longitude: 129°22' E)*

➢ 2.5×3.0 m² wall retrofitted with a 20 mm thick TCP

➢ Four investigated cases:

Cases	TCP layer position	Fluid inlet temperature	Boiler operation
Case 1	Interior	25°C	Off
Case 2	Exterior	25°C	Off
Case 3	Exterior	50°C	On
Case 4	Interior	50°C	On

Observations:

➢ In all cases, the TCP system **maintained the indoor temperature** (around 20°C)

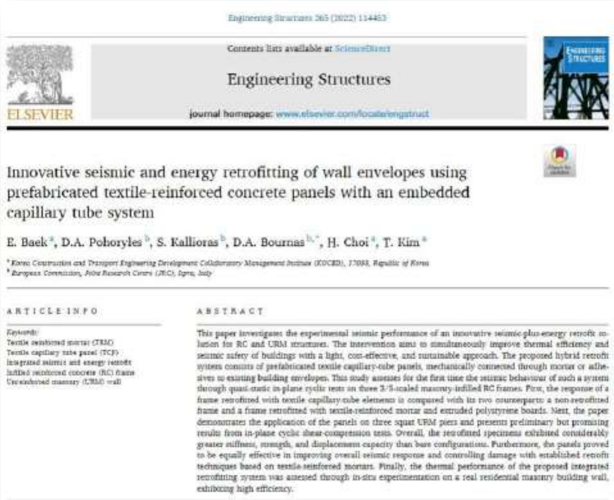
➢ The TCP system performed **slightly better** when installed in the **interior** than exterior wall face

➢ The benefit from operating the system at **higher water temperature** (i.e., 50°C compared to 25°C) is only **marginal**

Baek et al., Engineering Structures 265, 2022 https://doi.org/10.1016/j.engstruct.2022.114453

European Commission

Article presenting on the seismic and energy performance of the prefabricated textile-capilary panels



Engineering Structures 265 (2022) 114453

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journal homepage: www.elsevier.com/locate/engstruct

ELSEVIER

Innovative seismic and energy retrofitting of wall envelopes using prefabricated textile-reinforced concrete panels with an embedded capillary tube system

E. Baek[a], D.A. Pohoryles[b], S. Kallioras[b], D.A. Bournas[b,*], H. Choi[a], T. Kim[a]

[a] Korea Construction and Transport Engineering Development Collaboratory Management Institute (KOCED), 17088, Republic of Korea
[b] European Commission, Joint Research Centre (JRC), Ispra, Italy

ARTICLE INFO

Keywords:
Textile reinforced mortar (TRM)
Textile capillary tube panel (TCP)
Integrated seismic and energy retrofit
Infilled reinforced concrete (RC) frame
Unreinforced masonry (URM) wall

ABSTRACT

This paper investigates the experimental seismic performance of an innovative seismic-plus-energy retrofit solution for RC and URM structures. The intervention aims to simultaneously improve thermal efficiency and seismic safety of buildings with a light, cost-effective, and sustainable approach. The proposed hybrid retrofit system consists of prefabricated textile capillary-tube panels, mechanically connected through mortar or adhesives to existing building envelopes. This study assesses for the first time the seismic behaviour of such a system through quasi-static in-plane cyclic tests on three 2/3-scaled masonry-infilled RC frames. First, the response of a frame retrofitted with textile capillary-tube elements is compared with its two counterparts: a non-retrofitted frame and a frame retrofitted with textile-reinforced mortar and extruded polystyrene boards. Next, the paper demonstrates the application of the panels on three squat URM piers and presents preliminary but promising results from in-plane cyclic shear-compression tests. Overall, the retrofitted specimens exhibited considerably greater stiffness, strength, and displacement capacity than bare configurations. Furthermore, the panels proved to be equally effective in improving overall seismic response and controlling damage with established retrofit techniques based on textile-reinforced mortars. Finally, the thermal performance of the proposed integrated retrofitting system was assessed through in-situ experimentation on a real residential masonry building wall, exhibiting high efficiency.

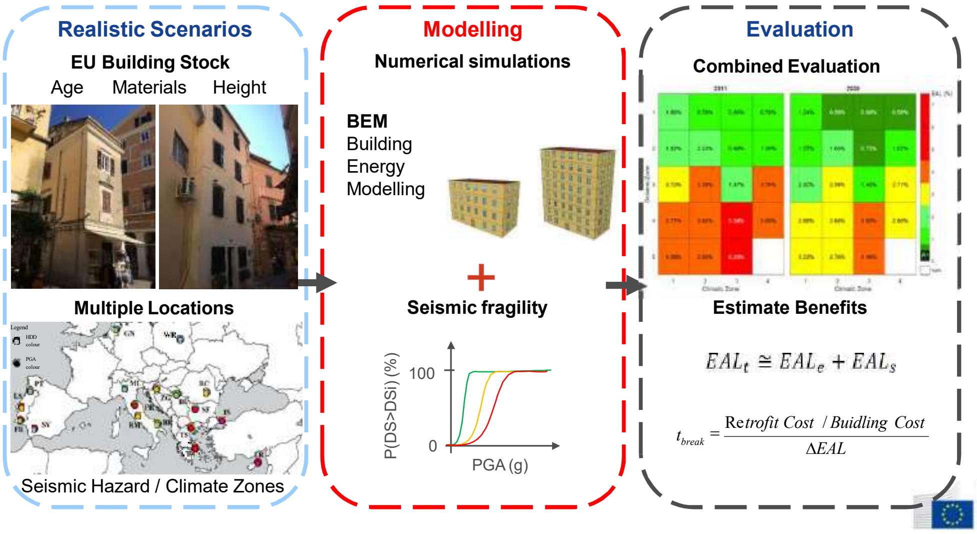
Baek et al., Engineering Structures 265, 2022
https://doi.org/10.1016/j.engstruct.2022.114453

European Commission

Impact evaluation of Combined Retrofitting

European Commission

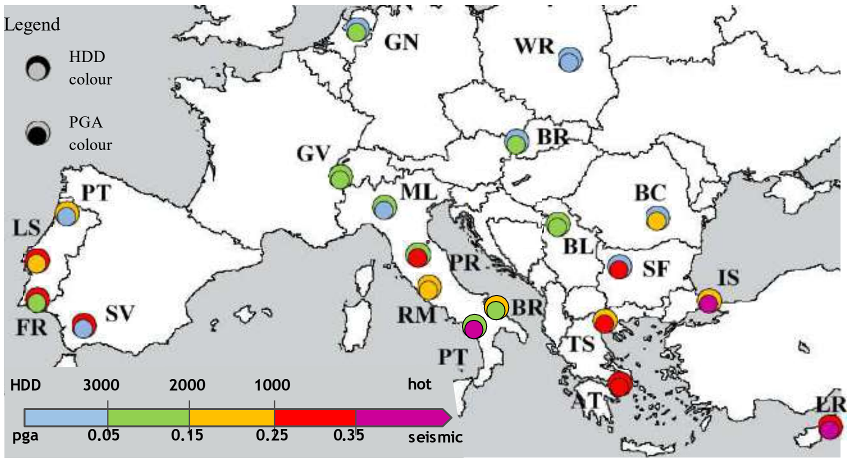
Combined impact evaluation



20 Case study locations

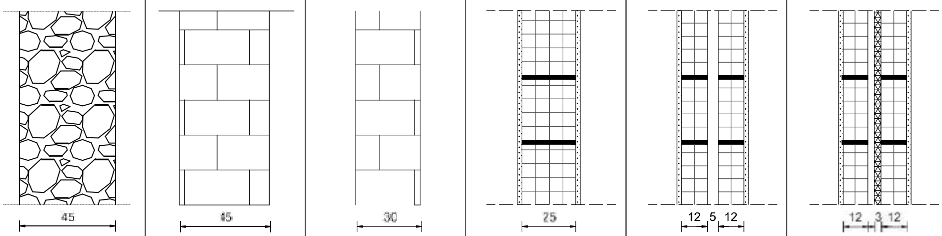
20 cities with:

- **4** different **climatic conditions (HDD)** [1]
- **5** levels of **seismic hazard** (**PGA** 10% - 50yrs) [2]

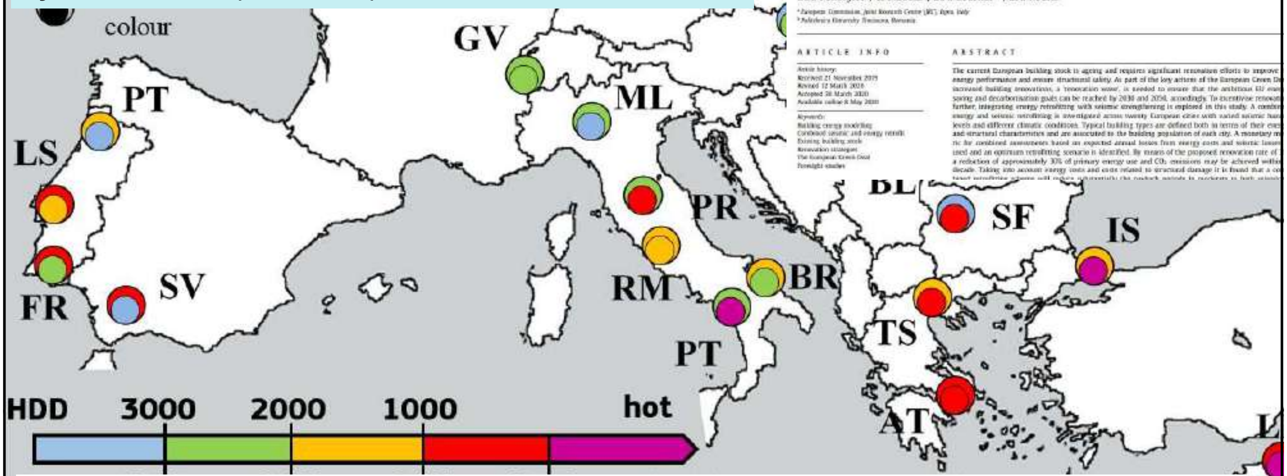


1 ASHRAE method of HDD calculation using IWEC annual weather data
2 2013 European seismic hazard model (Woessner et al. 2015)

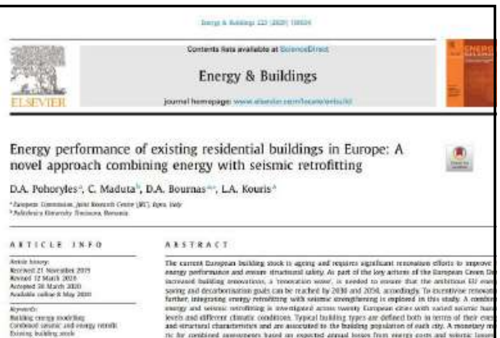
Energy and seismic characteristics

	Pre - 1945	Pre - 1945	1945 - 1959	1960 - 1969	1970 – 1989	Post - 1990
	Stone masonry	Brick masonry	Single leaf wall solid clay bricks	Single leaf wall hollow clay bricks	Cavity wall hollow clay bricks	Cavity wall hollow clay bricks + thermal insulation
Envelope cross - section						
U - value [W/(m²K)]	**2.24**	**1.3**	**2.15**	**1.43**	**1.27**	**0.35 – 0.75**
EU range [TABULA]	0.9 - 2.5	0.9 - 2.5	0.9 - 2.4	0.5 - 2.1	0.4 - 1.6	0.23 – 0.85
Seismic Design Level	**No Design**	**No Design**	**No Design**	**Low Design**	**Medium Design**	**High Design**

European Commission



- Annual **renovation by 3%** leads up to **32% reduction in energy use** and **38% less CO_2 emissions** by year **2030**
- **Combined seismic & energy retrofitting** could **reduce payback periods** from approximately **15 years to 5 years** when compared to separate interventions


Energy & Buildings

ELSEVIER

Energy performance of existing residential buildings in Europe: A novel approach combining energy with seismic retrofitting

D.A. Pohoryles, C. Maduta, D.A. Bournas, L.A. Kouris

ARTICLE INFO

ABSTRACT

Pohoryles, D.A., Maduta, C., Bournas, D.A., Kouris, L.A., 2020. **Energy performance of existing residential buildings in Europe: A novel approach combining energy with seismic retrofitting**. *Energy and Buildings* Vol. 223, 110024.

Conclusions

- Seismic and energy retrofitting is required in seismic areas of the world, affecting a large part of the building stock
- Unretrofitted pre-1970's masonry-infilled RC frames in S.Europe have high seismic vulnerability; In PsD tests on a full-scale building, the masonry infills were unrepairable after a 0.3g PGA test
- Prefabricated Textile-Capillary Tube Panels (TCPs) proved to be very effective in enhancing both the seismic and energy performance of existing buildings
- In Europe, annual renovation rates of 3% (starting in 2020) could lead to reductions in Primary Energy use up to 35% and up to 38% in CO_2 emissions by 2030
- A combined seismic and energy evaluation shows cost benefits even in moderate seismic zones, further incentivizing renovation.

European Commission

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Pohoryles, D.A., Maduta, C., Bournas, D.A., Kouris, L.A., 2020. **Energy performance of existing residential buildings in Europe: A novel approach combining energy with seismic retrofitting**. *Energy and Buildings* Vol. 223, 110024. https://doi.org/10.1016/j.enbuild.2020.110024

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Baek, E., D.A. Pohoryles, S. Kallioras, D.A. Bournas, H. Choi, and T. Kim, 2022. **Innovative Seismic and Energy Retrofitting of Wall Envelopes Using Prefabricated Textile-Reinforced Concrete Panels with an Embedded Capillary Tube System**. Engineering Structures, Vol. 265, August 2022, p. 114453, https://doi:10.1016/j.engstruct.2022.114453

Pohoryles, D.A., Bournas, D.A., Da Porto, F., Caprino, A., Santarsiero, G. and Triantafillou, T. 2022. **Integrated Seismic and Energy Retrofitting of Existing Buildings: A State-of-the-Art Review**. Journal of Building Engineering, Vol 61, 105274. https://doi.org/10.1016/j.jobe.2022.105274

Kallioras, S, Pohoryles, DA, Bournas, D, Molina, F, Pegon, P. (2023). **Seismic performance of a full-scale five-story masonry-infilled RC building subjected to substructured pseudodynamic tests**. Earthquake Engng Struct Dyn.; 1- 30. https://doi.org/10.1002/eqe.3940d

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- '***REEBUILD – A pilot project on the integrated seismic and energy retrofit of European buildings***' sponsored by the European Parliament, **https://buildings-renovation-makerspace.jrc.ec.europa.eu**
- ***NOTICE[EUB] – Novel Timber Composites for Energy and Seismic Upgrading of Buildings) MARIE SKŁODOWSKA-CURIE Individual Fellowship,*** sponsored by the European Commission
- ***SEP+ -Prefabricated TRC panels with integrated capillary tubes for integrated retrofitting of building envelopes,*** International Collaboration Project between JRC and KOCED

We would like to kindly acknowledge the contributions of

- ELSA Laboratory staff (Joint Research Centre, Italy, Ispra)
- KOCED partners (Pusan Technical University, Hybrid Structural Testing Centre)

Thank you

H2020-MSCA-IF
SAFE-FACE Project

Enhancing seismic safety and environmental sustainability of buildings: integrated technologies and multi-criteria performance-based design methods

Resp. Simona Bianchi[1], s.bianchi@tudelft.nl

Co-authors: Jonathan Ciurlanti[2], Mauro Overend[1], Stefano Pampanin[3], Guido Lori[4], Valerie Hayez[5], Giampiero Manara[4]

[1] Delft University of Technology, Delft, The Netherlands
[2] ARUP, Amsterdam, The Netherlands
[3] Sapienza University, Rome, Italy
[4] Permasteelisa S.p.a., Vittorio Veneto, Italy
[5] Dow Silicones, Seneffe, Belgium

Losses in the construction sector

(United Nations Environment Programme 2022)

Urgent need for
Sustainable Development

✓ Environmental sustainability
✓ Energy efficiency targets

Page 2

Losses from earthquakes

Beam-column joint

Structural wall

Flooring system

(Kam et al. 2011, Baird et al. 2011, Baird and Ferner 2017)

Traditional Building

Masonry facades

Ceiling systems

Glass facades

Contents

Partitions

Page 3

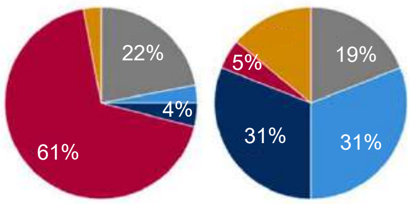
Losses from other extreme events

Flooded street in Valkenburg, Limburg, NL (2021)

Heat wave in July, NL (2021)

Fatalities:
115 602

Economic losses:
EUR 556 848M



- Earthquakes, tsunami, volcanic eruptions
- Storms
- Floods, mass movements
- Heatwaves
- Coldwaves, droughts, forest fires

(EEA data from 1980)

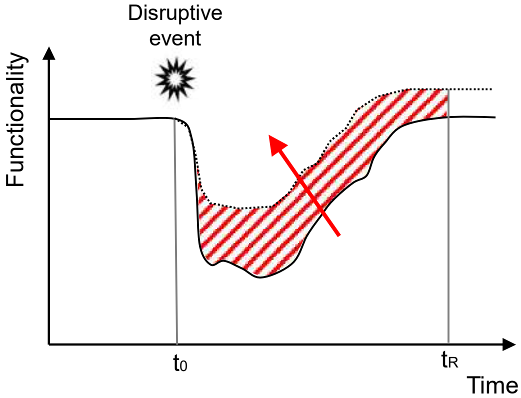
Page 4

Building resilient communities

Environmental sustainability

&

Structural safety



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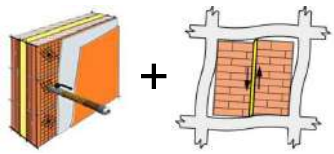
Building resilient communities

Technology

Energy efficiency

Seismic safety

Existing Building

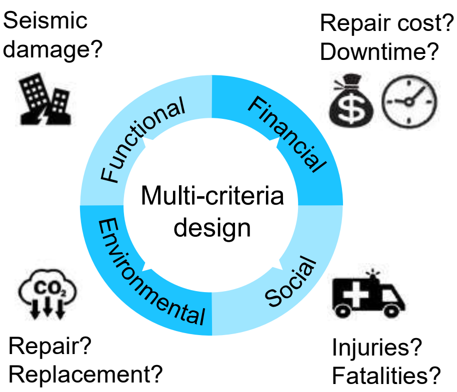


(Di Vece and Pampanin 2019)

New Building

(Baird et al. 2013)

Design methods



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Project overview

SAFE-FACE

O1

Develop earthquake proof & sustainable technologies

Integrate damage-control and energy efficiency techniques/strategies

O2

Multi-criteria design including seismic safety

Develop seismic modules for both practice-oriented and advanced design tools

O3

Fragility-based design to support decision-making

Develop a probabilistic multi performance-based design for technology selection

Project overview

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O1. Earthquake-proof sustainable systems

2018-2019

(Bianchi et al. 2021, Ciurlanti et al. 2021, Pampanin et al. 2023)

2017

(Ciurlanti et al. 2022)

fischer
innovative solutions

JAMOSIL sociedade de construções Lda
GESSI ROCCASTRADA COSTRUIRE CONTEMPORANEO
GLASS POINT
COSTANTINI

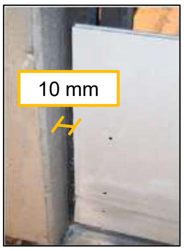
Page 8

O1. Earthquake-proof sustainable systems

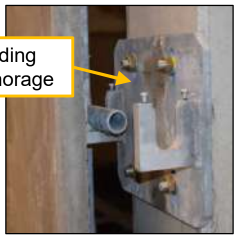
Plug & Play dissipaters

H2020 SERA Project

(Bianchi et al. 2021, Ciurlanti et al. 2021, Pampanin et al. 2023)



Sliding anchorage



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O1. Earthquake-proof sustainable systems

2017

(Ciurlanti et al. 2022a)

2022-2023

(Bianchi et al. 2022a)

2018-2019

(Bianchi et al. 2021, Ciurlanti et al. 2021, Pampanin et al. 2023)

fischer innovative solutions

PERMASTEELISA GROUP

DOW

JAMOSIL sociedade de construções Lda

GESSI ROCCASTRADA

GLASS POINT

COSTANTINI

Page 10

O1. Testing of full-scale glazed facades

PERMASTEELISA GROUP

DOW

- ❑ Influence of **facade detailing** on the seismic behavior
- ❑ Improvement of **testing protocol** for assessing the overall performance
- ❑ Calibration of **numerical modelling**
- ❑ Investigating the post-earthquake serviceability and the façade **modes of failure**

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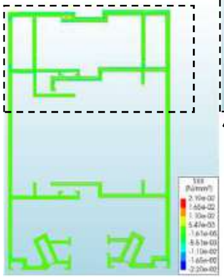
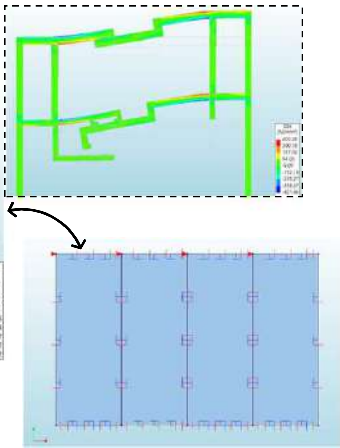
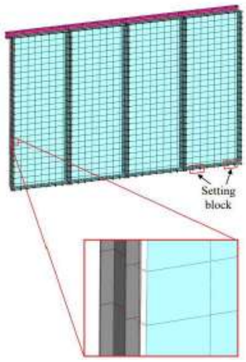
O1. Numerical modelling

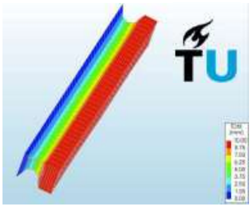

(Enriquez 2023)


(Stavridou 2023)



(Ciurlanti et al. 2023)

ARUP

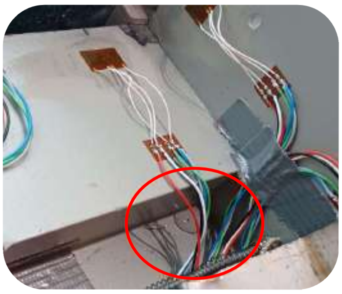

(Enriquez 2023)

DOW

Page 12

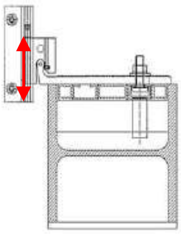
O1. Performance of glazed facades

Water infiltrations at **0.7%** drift level	Failure of silicone at **3.3%** drift level	Dislodgment of façade unit at **5.2%** drift level



- Air infiltration tests
- Water leakage tests
- Wind resistance tests


(Hayez et al. 2023)



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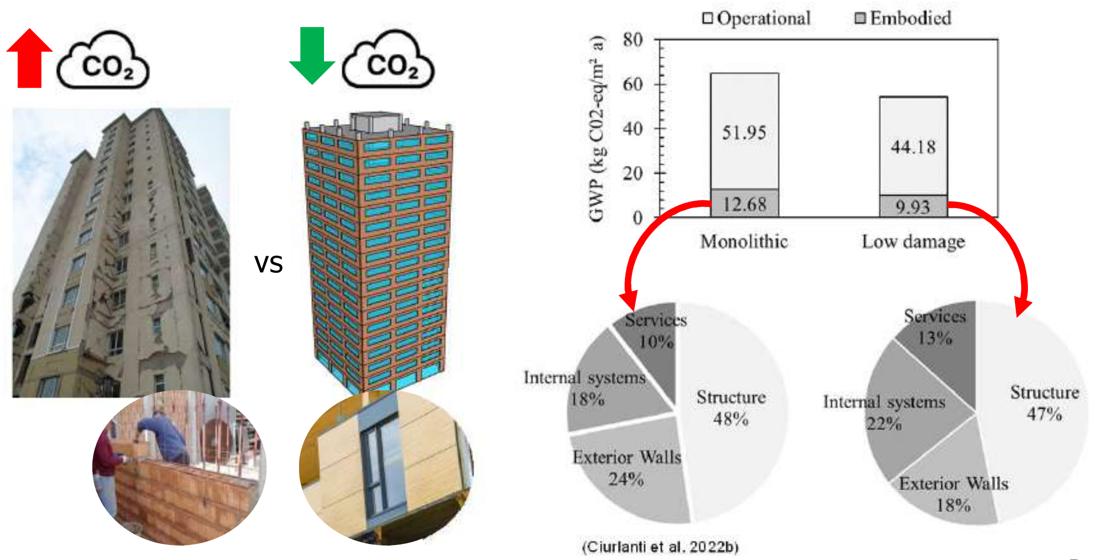
O1. Low-carbon low-damage solutions



(Ciurlanti et al. 2022b)

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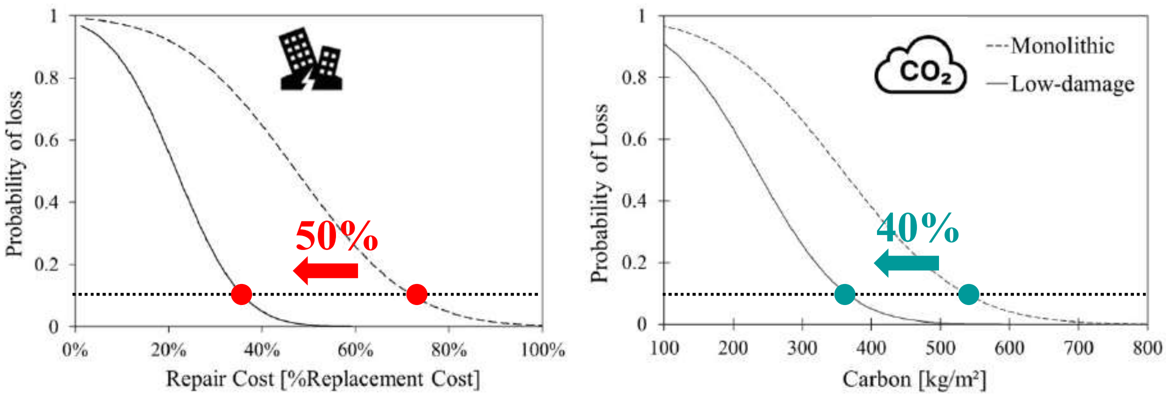
O1. Low-carbon low-damage solutions



(Ciurlanti et al. 2022b)

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Project overview

SAFE-FACE

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Develop earthquake proof & sustainable technologies

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O2

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O3

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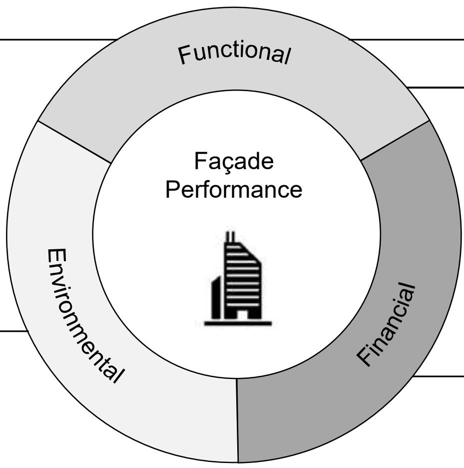
Develop a probabilistic multi performance-based design for technology selection

O2. Multi-criteria decision making

Human Comfort
- ✓ Aesthetics
- ✓ Daylight control
- ✓ Glare control
- ✓ Thermal comfort
- ✓ Air quality
- ✓ Aural comfort
- ✓ Climate adaptability

Sustainability
- ✓ Energy efficiency
- ✓ Use of renewable resources
- ✓ Environmental footprint
- ✓ Reuse and recycling
- ✓ Generated energy
- ✓ Stored energy



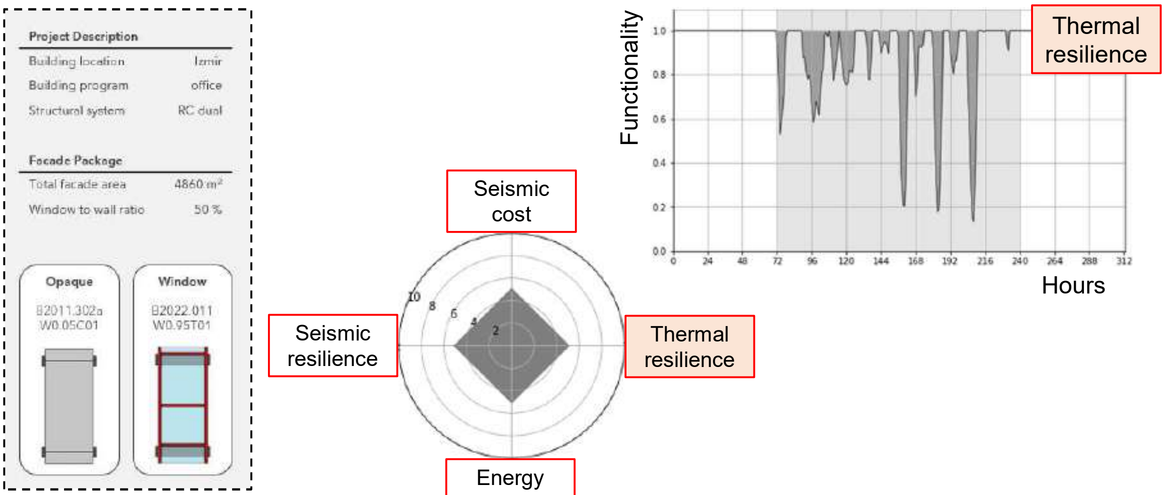
Structural safety
- ✓ Static performance
- ✓ Dynamic performance
- ✓ Fire protection
- ✓ Blast resistance

Durability
- ✓ Expected service life
- ✓ Maintenance and cleaning
- ✓ Condensation resistance
- ✓ Water penetration resistance

Cost effectiveness
- ✓ Initial cost
- ✓ Operation cost
- ✓ Rehabilitation and maintenance cost
- ✓ Disassembly cost

Page 17

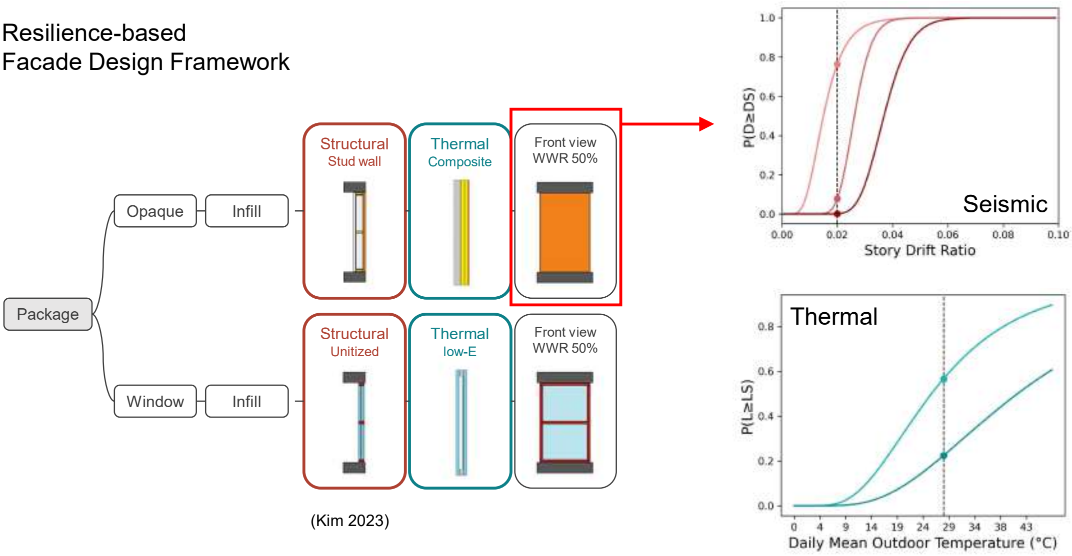
O2. Earthquakes vs. Heat waves



(Kim 2023)

O2. Earthquakes vs. Heat waves

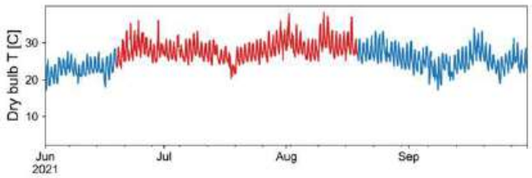
Resilience-based
Facade Design Framework



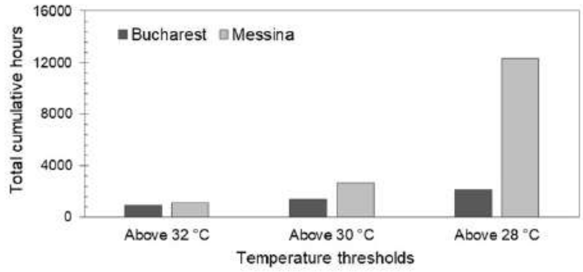
(Kim 2023)

O2. Earthquakes vs. Heat waves

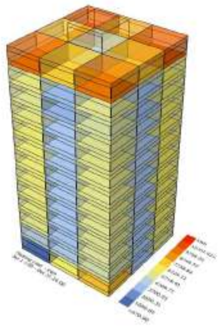
Heat wave in Messina (2021)

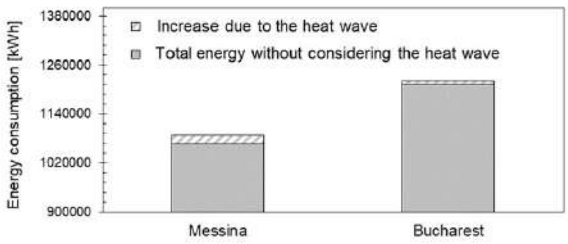


(Bianchi et al. 2023)

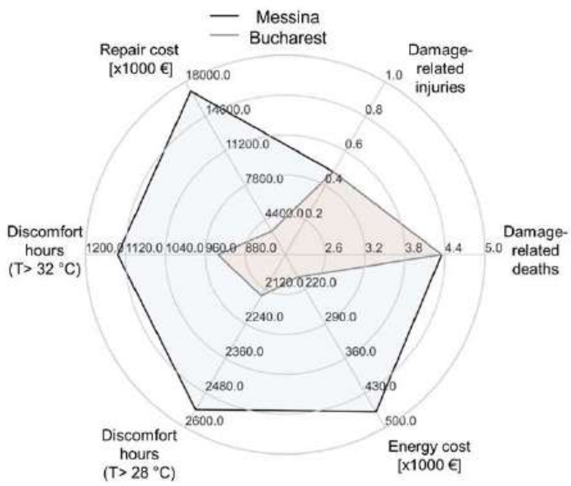


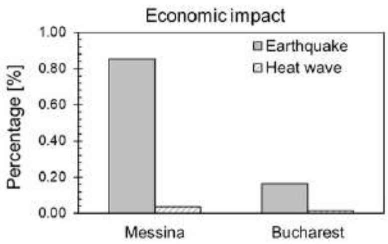
- Operative temperature
- Operational energy

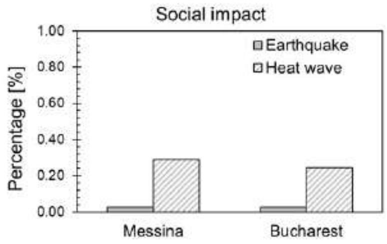




O2. Earthquakes vs. Heat waves







(Bianchi et al. 2023)

Project overview

SAFE-FACE

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O3

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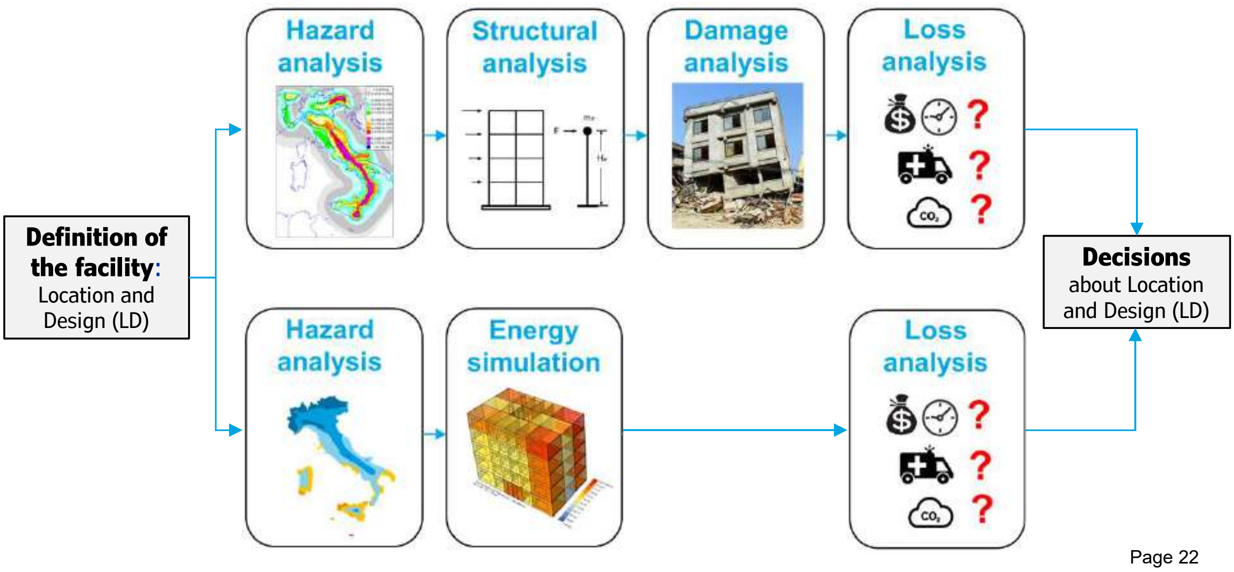
Develop a probabilistic multi performance-based design for technology selection

O3. Integrated risk assessment methods



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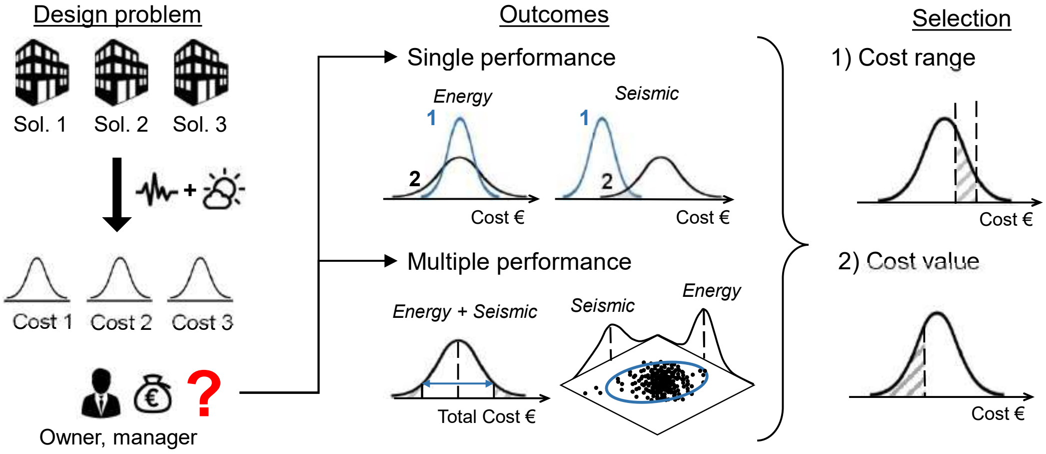
O3. More-informed decision making



(Bianchi et al. 2022b)

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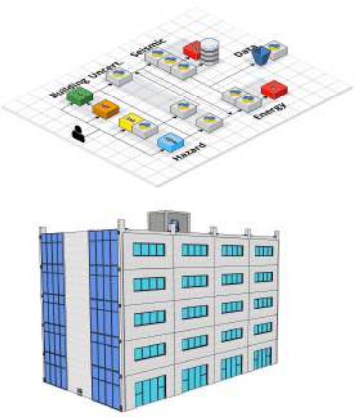
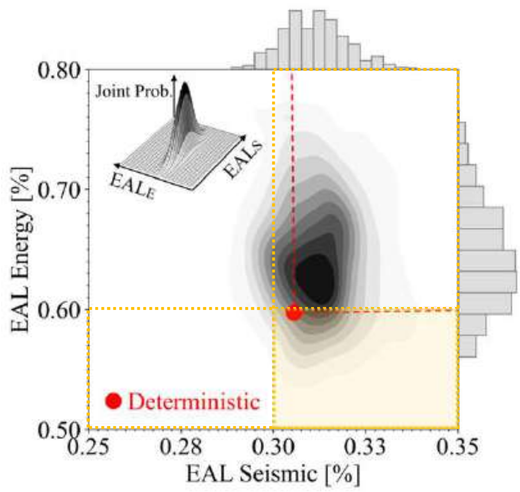
O3. Application to a case study

Deterministic vs.
Probabilistic assessment





(Bianchi et al. 2022b)

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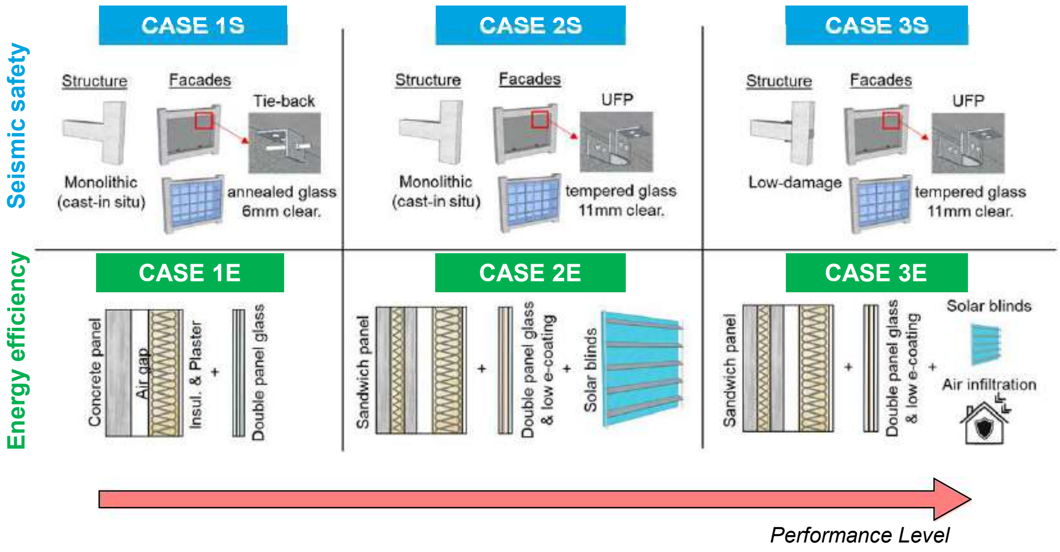
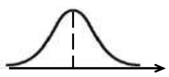
O3. Application to a case study

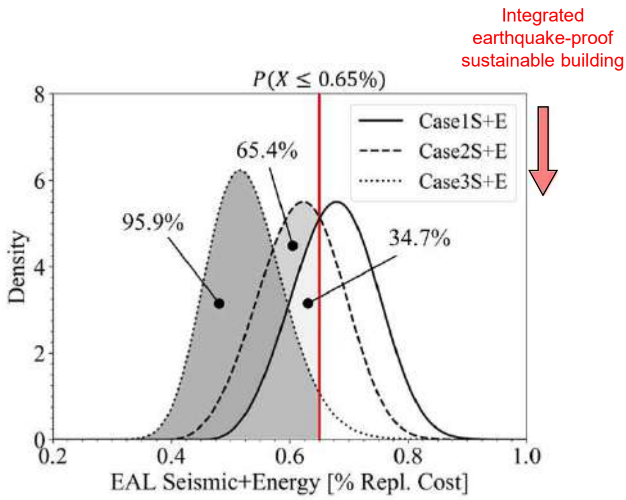


O3. Application to a case study

Expected Annual Losses (EAL)
as % Replacement Cost



Overall seismic
& energy cost €



(Bianchi et al. 2022b)

Conclusions

SAFE-FACE

O1

Develop earthquake proof & sustainable technologies

Integrate damage-control and energy efficiency techniques/strategies

Focus on retrofitting

O2

Multi-criteria design including seismic safety

Develop seismic modules for both practice-oriented and advanced design tools

More advances procedures

O3

Fragility-based design to support decision-making

Develop a probabilistic multi performance-based design for technology selection

Integration of multiple losses

Page 27

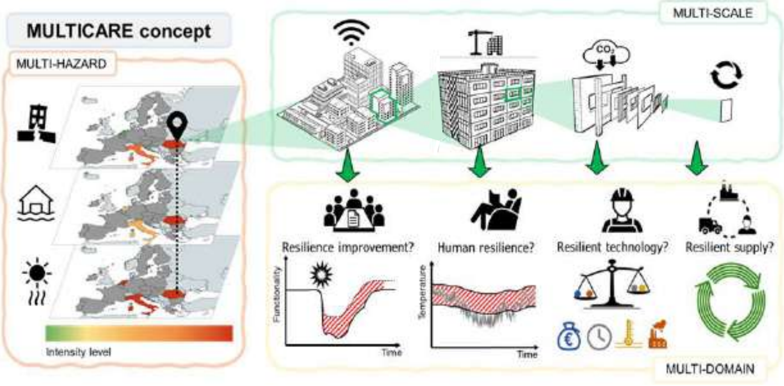
MULTICARE

Multi-hazard low-carbon resilient technologies and multi-scale digital services for a future-proof, sustainable & user-centred built environment

Coordinators:

Dr. Simona Bianchi

Prof. Mauro Overend



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H2020-MSCA-IF
SAFE-FACE Project

Enhancing seismic safety and environmental sustainability of buildings: integrated technologies and multi-criteria performance-based design methods

Resp. Simona Bianchi, s.bianchi@tudelft.nl

Co-authors: Jonathan Ciurlanti, Mauro Overend, Stefano Pampanin, Guido Lori, Valerie Hayez, Giampiero Manara

Thank you!

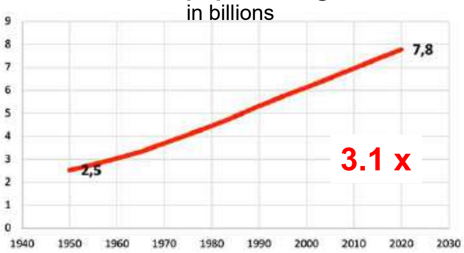
Sustainability and resilience of built environment – *fib* contribution

Petr Hájek
Czech Technical University in Prague
Faculty of Civil Engineering, Department of Architectural Engineering

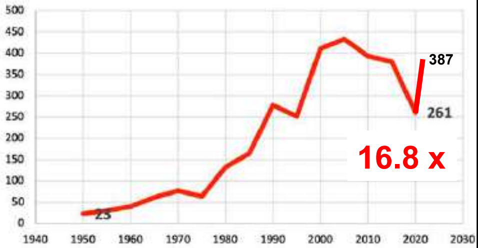
starting points, global targets

World is changing - period 1950 - 2020

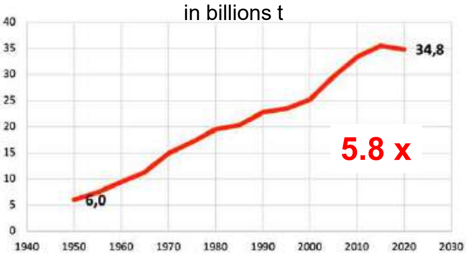
World population growth
in billions



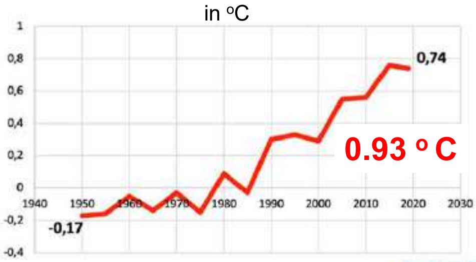
Increasing number of natural disasters



Increasing CO_2 emissions
in billions t



Increasing world average temperature
in °C



data source: Our World in Data

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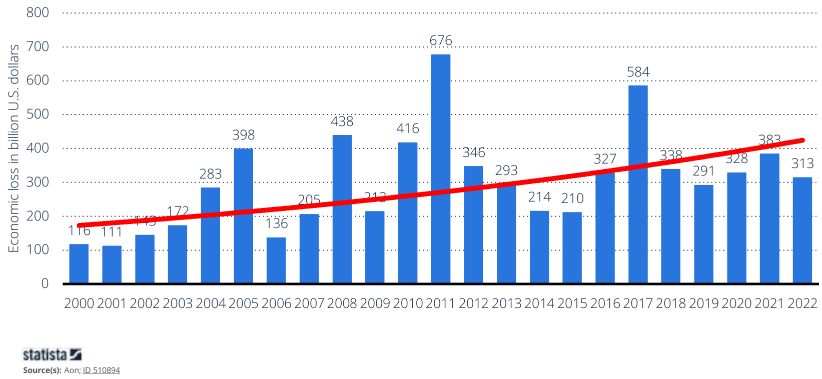
Global economic losses from natural disasters

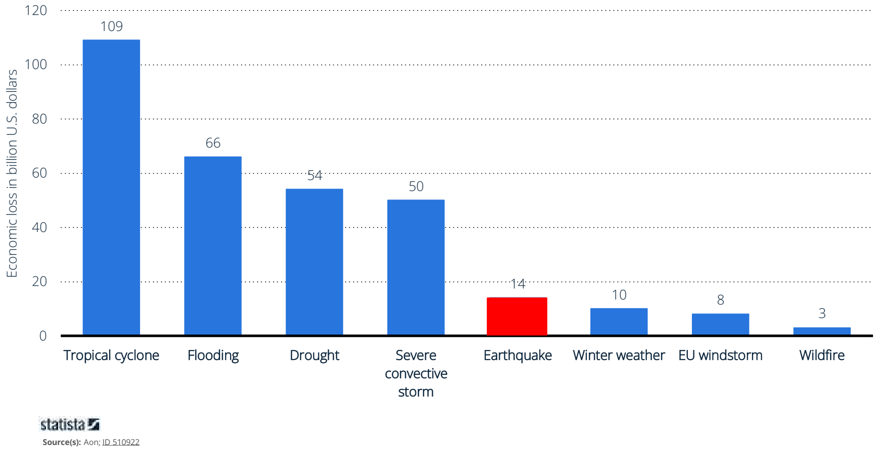
Economic loss from natural disaster events worldwide from **2000 to 2022** (in billion U.S. dollars)



SUMMER WORKSHOP WG15 **Petr Hájek**

Global economic losses from natural disasters

Economic loss from natural disaster events worldwide in **2022**, by peril (in billion U.S. dollars)

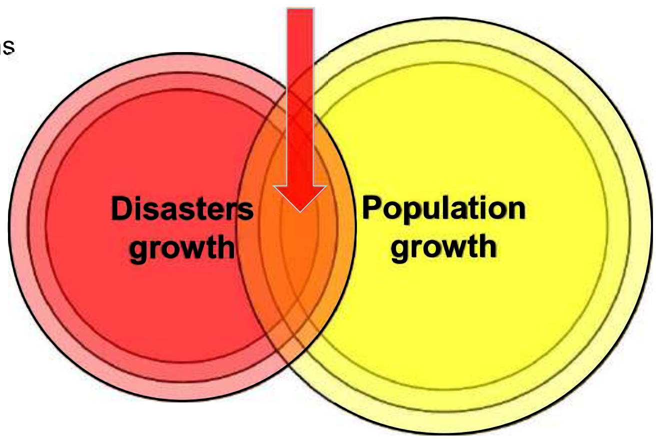


Disasters – life and economic losses

Natural events

Volcanic eruptions
Earthquakes
Tsunamis
Floods
Fires
Storms
Hurricanes
Tornados
Land slides
Heat waves
Cold waves
……….

Increasing impact on humans - life and economic losses



disasters population

Man-made disasters

UN and EU Policy

UN 1987: **Report of the World Commission on Environment and Development: Our Common Future** (Brundtland Report)
defined the principle of sustainable development as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*

UN 2015: Resolution 70/1 (2015): **Transforming our World: the 2030 Agenda for Sustainable Development**
17 **Sustainable Development Goals** (SDGs) with 169 associated targets of three pillars of sustainable development: ***economic, social and environmental.***

EU 2019: announced **European Green Deal** action plan.
The EU aims to be climate neutral in 2050.

EU 2020 announced **A New European Bauhaus**
- driving force to bring the European Green Deal to life in an attractive, innovative and human-centred way.

Buildings, infrastructure & all built environment

- should **ensure quality life** of people
- should **less harm** the environment
- should be **better prepared** for new conditions

they should be

sustainable and ***resilient***

principles of integrated design and assessment of built environment

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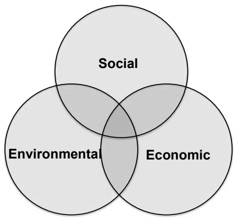
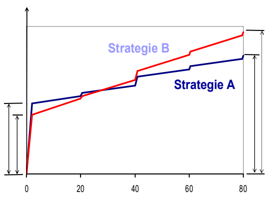
3 basic principles of sustainable design

- **complexity**
  design strategies and assessment methods must include all substantial criteria → multicriteria approach



- **life cycle approach**
  design strategies and assessment methods should include whole life cycle
  → LCA, LCC ...

- **prediction of future performance**
  design strategies and assessment methods should respect probability character of future function in a changing environment



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Regional specifics

- Climatic conditions
- Geomorological conditions incl. **seismic hazard**
- Material and technology bases
- Regulation and Standards
- Economical conditions
- Population density
- Cultural aspects incl. traditions

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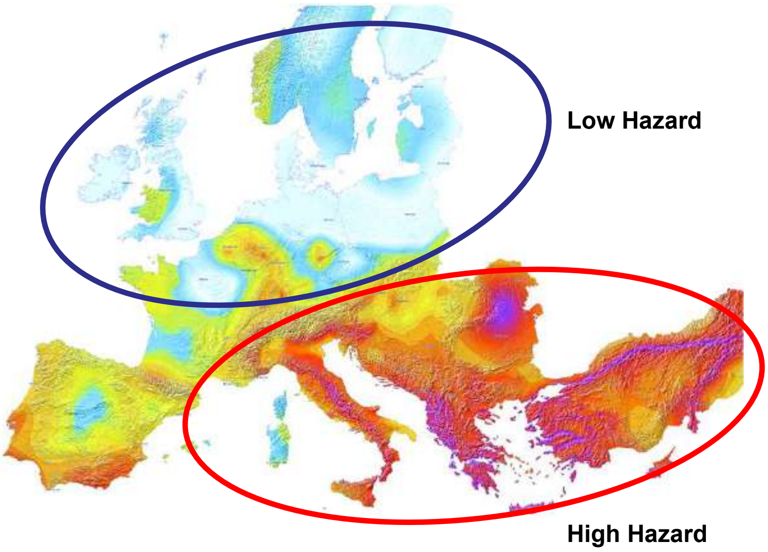
European seismic hazard



Map base: https://www.epos-eu.org/

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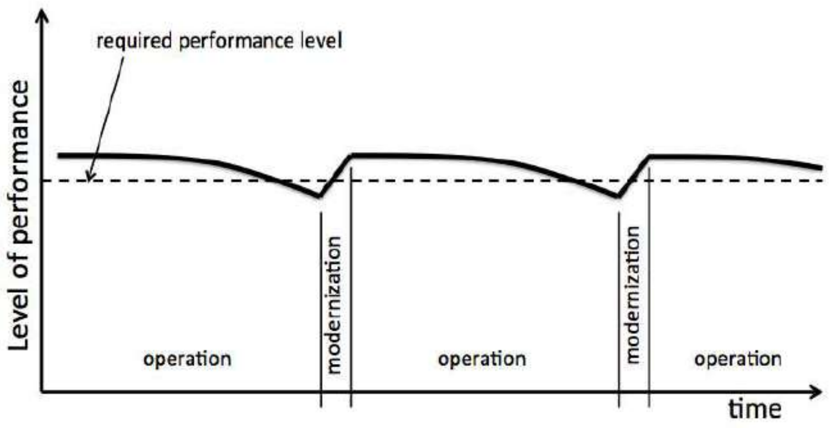
life cycle scenarios of building performance

& disaster events

Life Cycle performance level

Scenario A

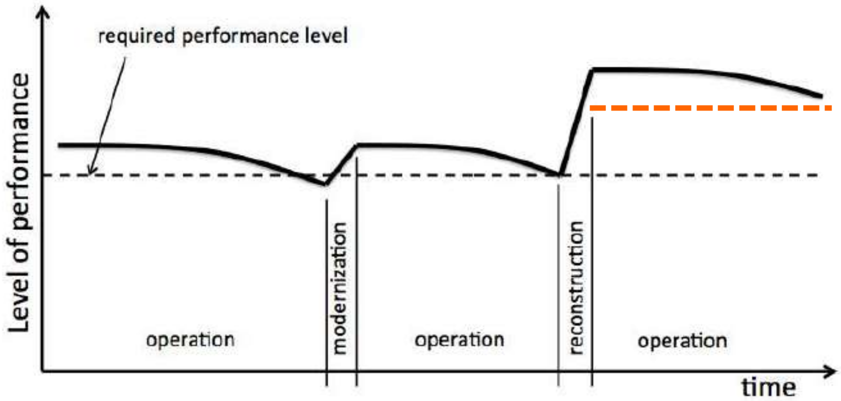
Standard development of performance level within lifetime of the structure.



Life Cycle performance level

Scenario B

Development of performance within lifetime of the structure considering increase of performance level during reconstruction.



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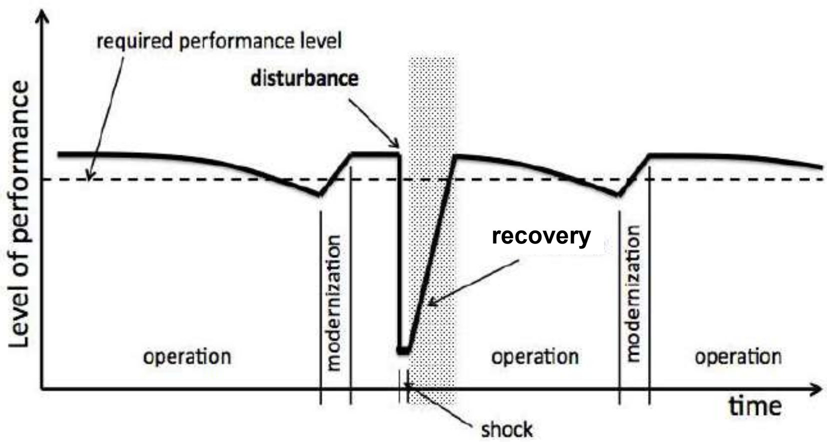
Resilience after disaster

Scenario C

Recovery after disturbance of structure by disaster and shock. The level of performance is recovered to the level before disaster.

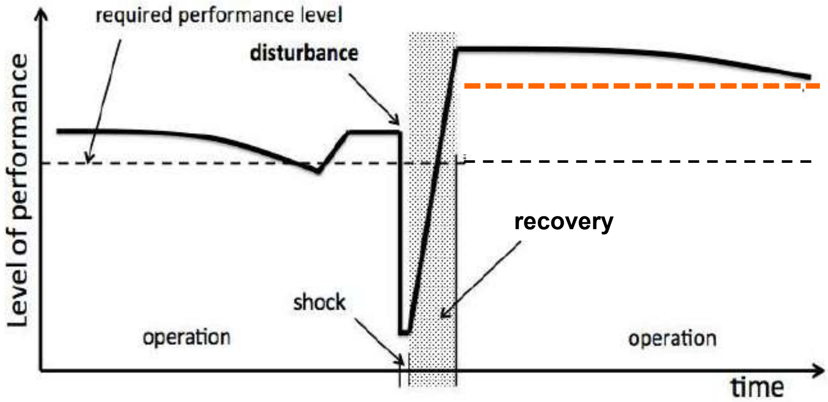


SUM

Resilience – increased performance level

Scenario D

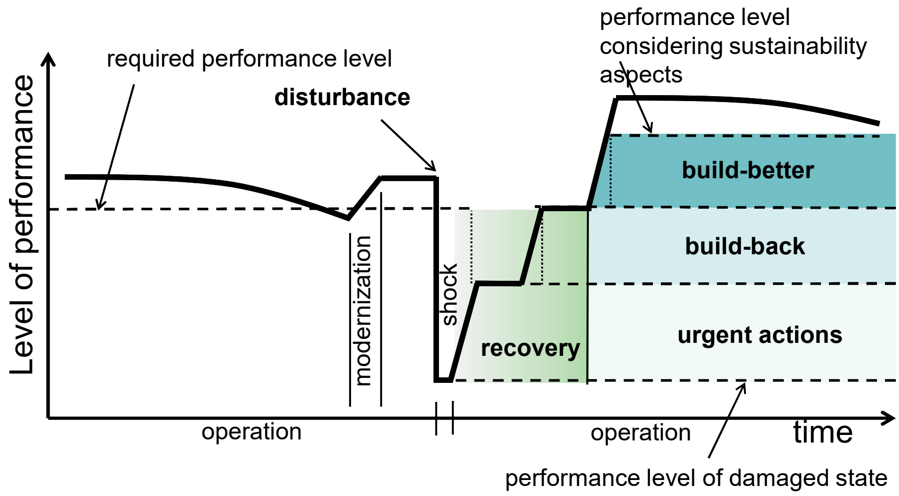
Recovery after disturbance of structure by disaster and shock.
The level of performance is recovered to the higher level.



Build-better concept – sustainability targets

Scenario E

Gradual recovery after disturbance of structure by disaster



sustainability in fib
Model Code 2020

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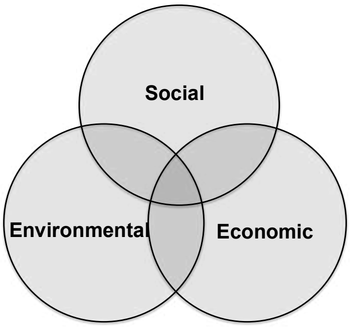
Integrated - Conceptual approach

MC2020, refers not only to traditional demands **safety** and **serviceability**, but takes **sustainability** as a fundamental requirement for high quality design and operation of concrete structures
– considering crucial **social**, **environmental** and **economic aspects**.



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Social performance

Main groups of **social performance** of concrete structures

- Structural performance
- Other aspects of social performance

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Social performance of concrete structures

Structural performance

- Structural safety
- Serviceability
- Durability
- Robustness
- Structural resilience

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Social performance of concrete structures

Other aspects of social performance

- **Health and quality of built environment**
  acoustic comfort, thermal comfort, accessibility, barrier-free access
- **Safety and security of built environment**
  safety of workers and external persons, security of property
- **Aesthetic value and preservation of cultural heritage**
- **Impact to local community**
  hindrance to neighbouring stockholders, disturbances to traffic, communication and other operations, positive impact on local employment

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Environmental performance of concrete structures

Key **environmental aspects**

- Use of **natural resources**
- Use of **energy**
- **Land** use
- Harmful **emissions** to air, water and soil
- **Noise** and **vibration**
- **Waste** generation
- Impact on **biodiversity** (species and ecosystems)

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Economic performance of concrete structures

Key **economic aspects**:

- **Construction** cost
- **Operation** cost
- **Maintenance** cost
- **Refurbishment** cost
- **Demolition** cost
- **Recycling** or **reuse** cost
- Cost of **externalities**
- **Capital** cost
- Support of **local economy**

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Evaluation of sustainability criteria

Sustainability is implemented into MC2020
in accordance with appropriate international standards

- **Social criteria:** standard technical requirements and assessments according to technical standards
- **Environmental criteria: LCA – Life Cycle Assessment** – defined in ISO, CEN, ACI ... (e.g. ISO 14040 and related standards)
- **Economy criteria: LCC – Life Cycle Cost** – standard LCC evaluation defined in ISO, CEN, ACI, … (e.g. ISO 15686-5 and related standards)

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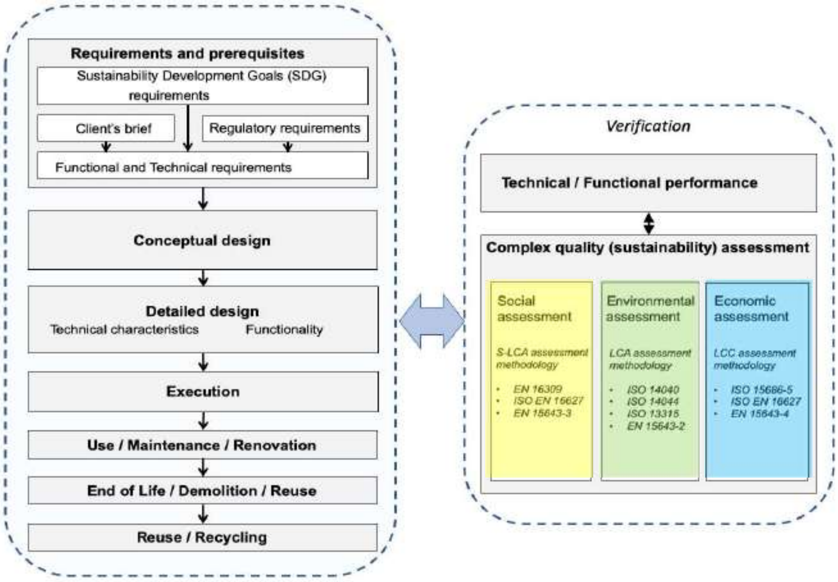
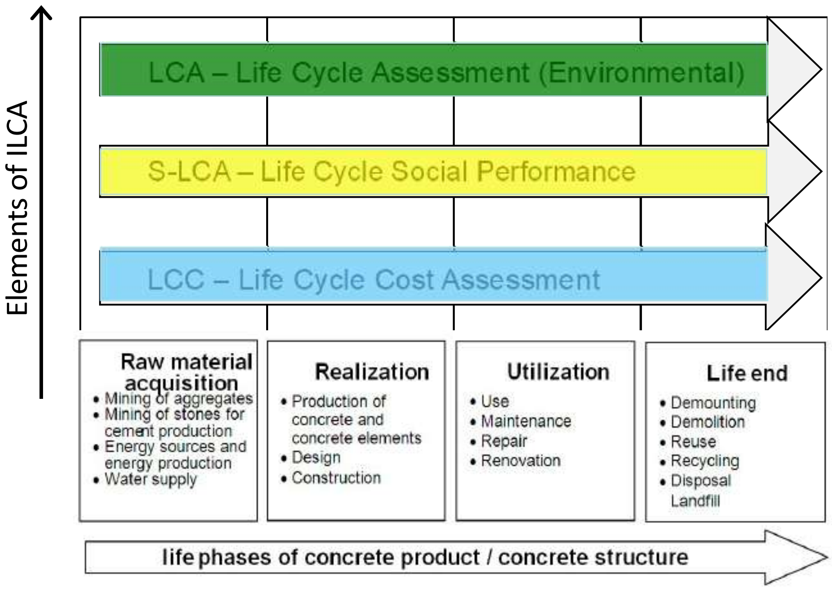
Framework of sustainable design and assessment



Life cycle consideration



Evaluation of environmental impact

$$E_{tot} = \sum E_i$$

LCA

$$E_{tot} = E_{pbm} + E_{pc} + E_{constr} + E_{oper} + E_m + \sum E_{repair} + \sum E_{renov} + E_{demol} + E_{recycl}$$

E_{pbm} environmental impact associated with **production of primary building materials**
E_{pc} environmental impact associated with **production of concrete and concrete elements**
E_{constr} environmental impact associated with **design and construction** of the structure
E_{oper} environmental impact associated with **operation** of the structure;
E_m environmental impact associated with **maintenance**;
E_{repair} environmental impact associated with **repair** of the failure;
E_{renov} environmental impact associated with **renovation**;
E_{demol} environmental impact associated with **demolition**;
E_{recycl} environmental impact associated with **recycling and waste disposal**;

$$E_i = \sum w_j Q_j \qquad \{Q_j\} = (Q_1 \dots Q_m)^T$$

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Evaluation of economic performance

$$C_T = C_{Td} + C_{Ti}$$

LCC

C_{Td} total discounted **direct costs**
C_{Ti} total discounted **indirect costs**

Direct costs

$$C_{Td} = C_o + \sum C_m + C_D$$

C_0 design and construction costs
C_m cost of the preventive maintenance
C_D end-of-service-life costs –Decommissioning costs

Indirect costs

$$C_{Ti} = \sum C_{i,u}$$

$C_{i,u}$ indirect costs incurred at time u

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Sustainability evaluation of entire structure

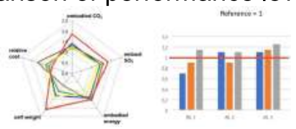
Selection of essential criteria

social	environmental	economical
• .... • .... •	• .... • .... •	• .... • .... • ....

Evaluation of performance levels

social	environmental	economical
• .... • .... •	• .... • .... •	• .... • .... • ....

Comparison of performance levels



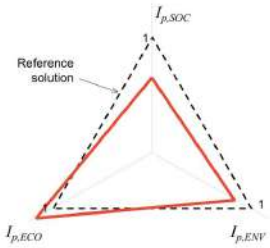
$$I_p = P_d / P_{ref}$$

where

I_p .... performance index

P_d .... design value

P_{ref} .... reference value



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case study

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concept of structural system for SB

Load bearing structure – slender RC frame

- subtle columns from HPC
- optimised RC floor structure

Non-load bearing structures – based on renewable materials

- facade envelope and roof structure: light timber frame heavily insulated by thermal insulation
- partitions: light timber structure

Integration of load bearing structure into building envelope

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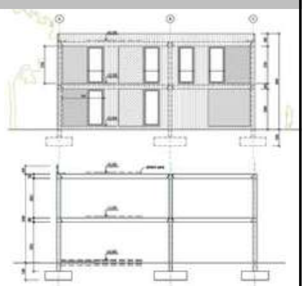
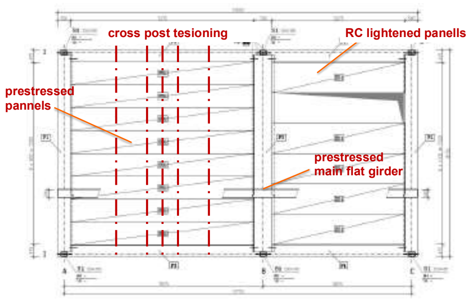
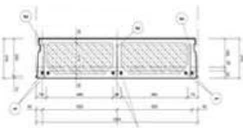
optimisation of load bearing RC frame

- use of HPC 70/85 – subtle precast elements
- optimised shape of columns (C – shape)
- optimised shape and composition of floor panels lightened by recycled materials
- two-way prestressed floor slabs – flat ceiling
- flexibility – spans up to 9 x 9 m
- demountable structure - use of Peikko corbels joints
- precast foundation from recycled concrete

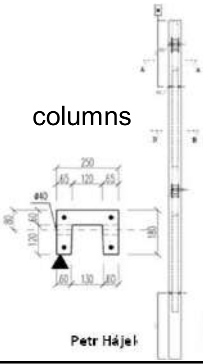




floor panels



columns



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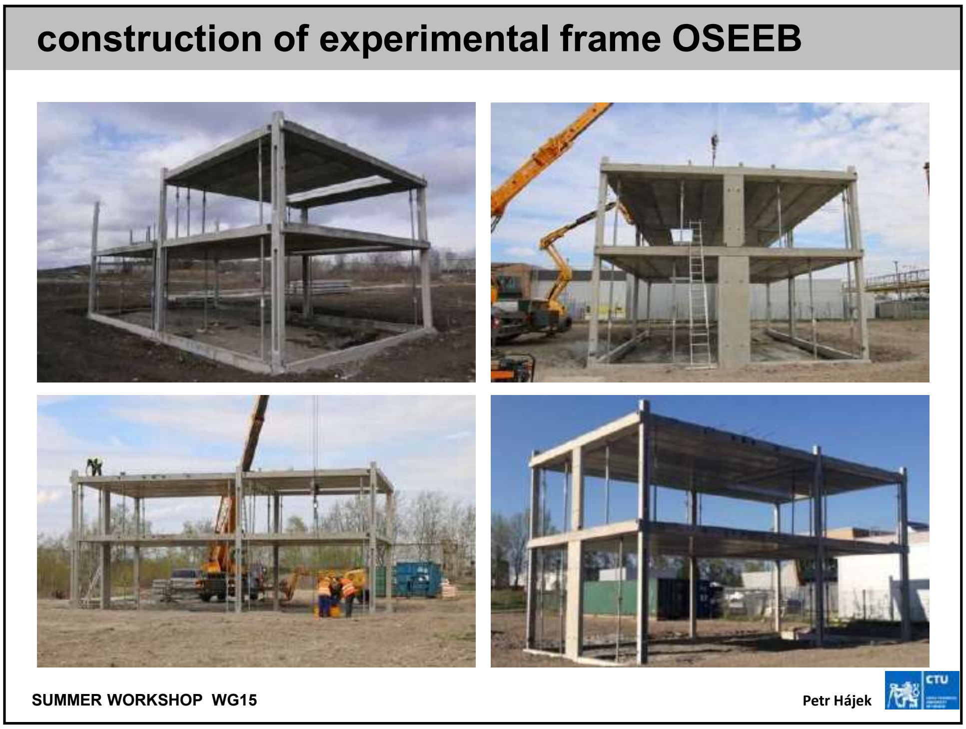
construction of experimental frame OSEEB
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Petr Hájek
CTU


prefabricated timber fasade
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CTU

concept of structural system for SB

advantages from sustainability viewpoint

Environmental

- shape optimized concrete elements – material savings
- use of recycled materials – material savings
- thermal mass of concrete structure – energy savings

Social

- high mechanical resistance and space rigidity
- fire safety
- good acoustic properties of floor structure
- flexibility – large spans up to 9 x 9 m, flat ceiling

Economical

- fast construction - precast structural concept
- durability, easy maintenance a
- design for dismounting + demountable joints

conclusions

1 Conclusion

New environmental, social and economy conditions require **advanced technical solutions** for construction as well as reconstruction and modernization of existing structures.

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2 Conclusion

- Design and assessment of new and existing structures should consider all steps of life cycle = should be based on comprehensive **LCA and LCC** of entire structure considering **regional specifics** including expected future changes

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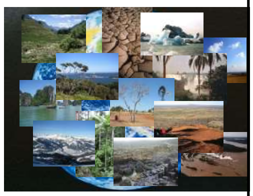
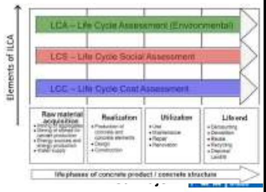
3 Conclusion

It is necessary to look for
complex solutions
covering all critical
sustainable criteria
respecting
regional specifics
and consider
entire life cycle of structure





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Sustainability :

saving of biodiversity
saving of life on the Earth

survival of humans on the Earth

Thank you for your attention

4 Conclusions

Workshop participants presented a number of activities currently underway in different European regions. There is, for example, a research project in the Netherlands examining the performance of glazed facades under seismic activity, or a project in Italy called ReLuis, which aims to develop innovative and integrated retrofit technologies with a greater degree of efficiency, disruption, and cost savings.

A discussion on how to design and refurbish buildings in a manner that is both seismically resilient and sustainable concluded the workshop.

Indeed, the mission of the EAEE WG15 is to help in disseminating the technical content of research activities, primarily by means of the production of independent state of the art journal papers. The core of the proposing team has already been active in this respect, and commits itself to continue with a regular pace, by involving the necessary contributions. Other activities of the WG include activating special sessions in forthcoming conferences or special issues in technical journals and, as in this case, organizing workshops on ongoing European research activities.

The EAEE WG15 Summer Workshop identified the need to develop a position paper on seismic and sustainable refurbishment based on an LCT approach, which can serve as a starting point for future research. While this would enlarge the main mandate of the WG, this position paper will be an important milestone in furthering the understanding of the seismic and sustainable refurbishment issue and should serve as a state-of-the-art for further research, activities and collaborations, benefiting the entire academic and professional community.

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List of abbreviations and definitions

EAEE	European Association of Earthquake Engineering
GBRSs	Green Building Rating Systems
LC	Life Cycle
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCT	Life Cycle Thinking
RC	Reinforced Concrete
WG	Working Group

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