Technologies for combined renovation of buildings

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European Commission, Joint Research Centre (JRC)

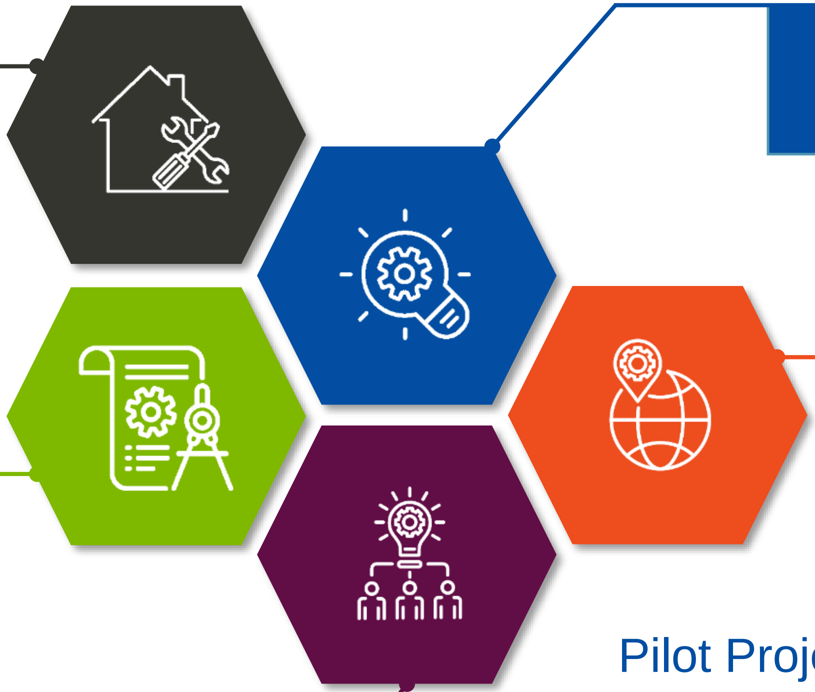
E3 - Safety and Security of Buildings

21/03/2024

European Commission

Integrated retrofitting: Pilot Project REEBUILD

1. Technologies for seismic strengthening and energy upgrading



3. Methodologies for assessing the combined effect of upgrading

4. Regional impact assessment

5. Stakeholders' engagement

Pilot Project scope

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

Action 2 Team

Dionysios Bournas, European Commission, Joint Research Centre – Action leader

Daniel Pohoryles, European Commission, Joint Research Centre

Francesca Da Porto, University of Padua - Overview of technology options for integrated upgrading

Giuseppe Santarsiero, University of Basilicata - Analysis of technologies for combined upgrading

Daniel Oliveira, University of Minho - Technologies for the improvement of cultural heritage buildings

Thanasis Triantafillou, University of Patras - Advanced and novel seismic retrofitting technologies

Bjørn Petter Jelle, Norwegian U. of Science & Technology - Novel thermal insulation materials for energy upgrading

Overview

- Motivation and background
- Combined and integrated retrofitting technologies
    - Literature review
    - Examples
- Analysis of technologies for the combined renovation of buildings
- Conclusions

Motivation and background

- Our cities and buildings are ageing

80 % of EU buildings are 30+ years old

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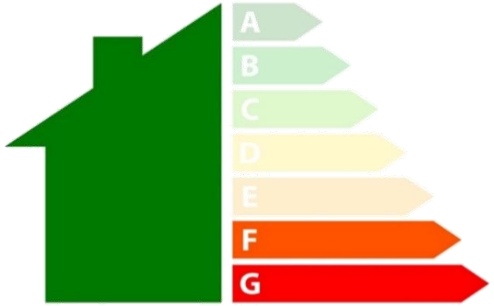
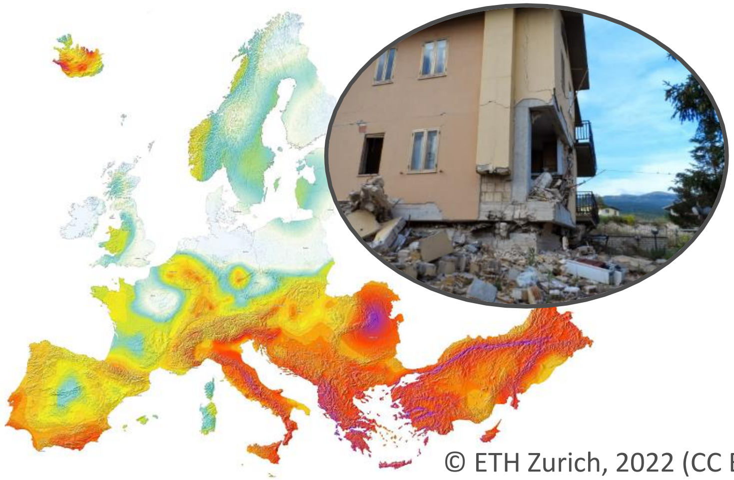
Motivation and background



75% of EU buildings are energy inefficient

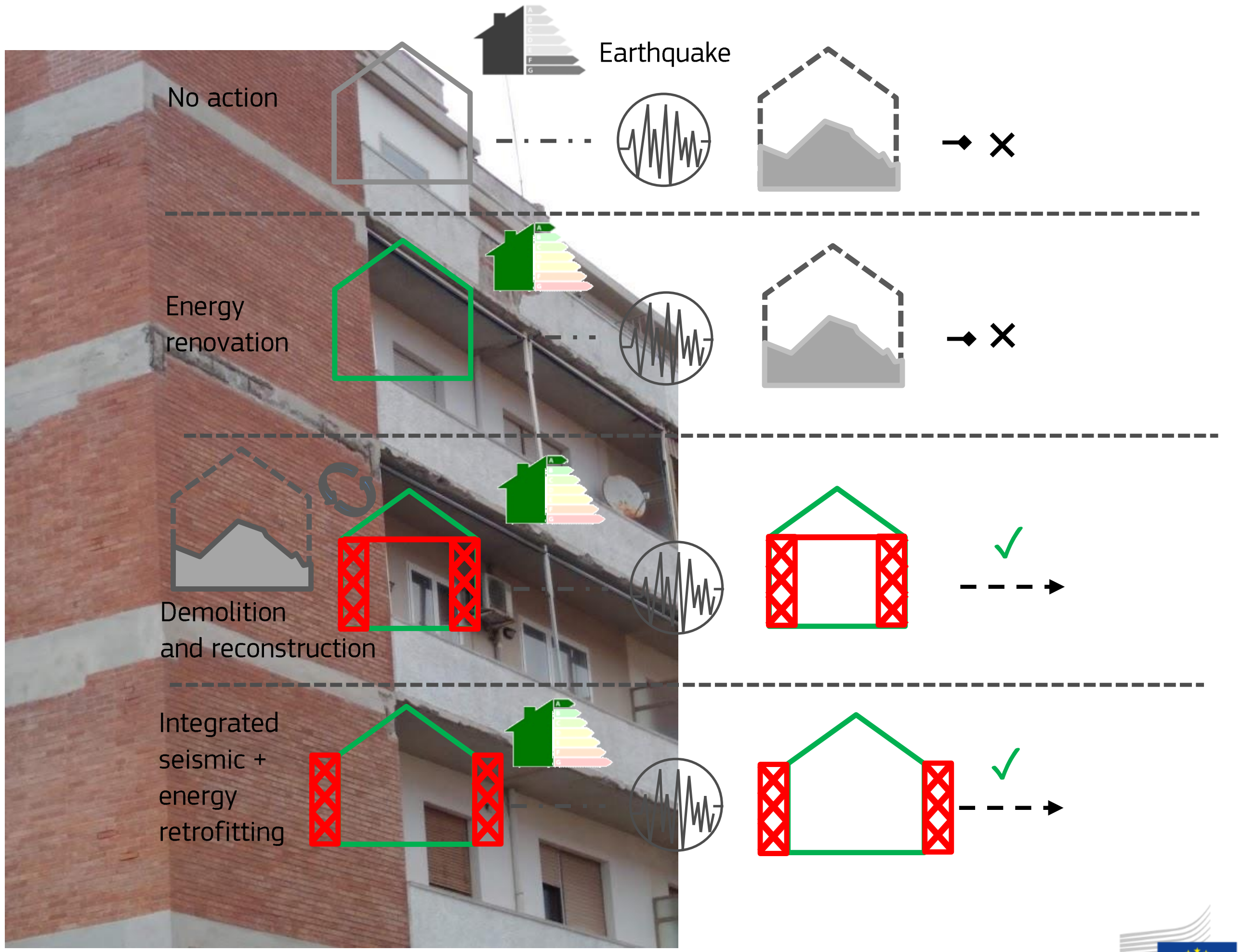
36% of CO_2 emissions

40% of EU energy consumption



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

What can we do?



Combined seismic and energy retrofitting

- Reduce economic & human losses from **seismic** events
- Reduce the impact of re-construction and repairs on the **environment**
- Reduce **labour time** for renovations

Sustainability …

and **resilience**

- Enhance the heating energy **efficiency** of buildings
- Improve the **resilience** of our diverse building stock
- Improve **cost-effectiveness** of building renovations

Combined and integrated renovation technologies

Review of proposed technologies in the scientific literature

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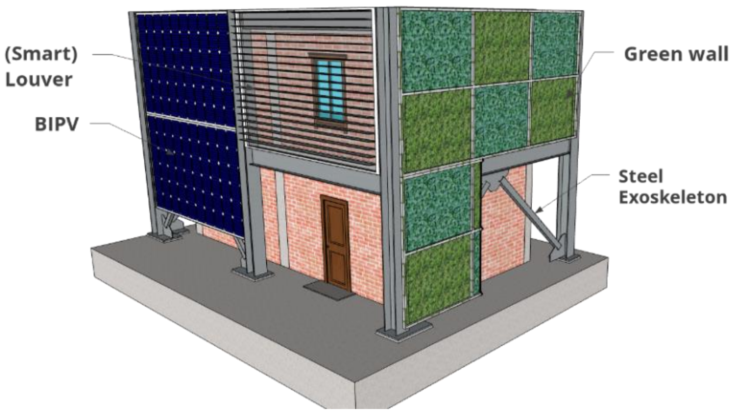
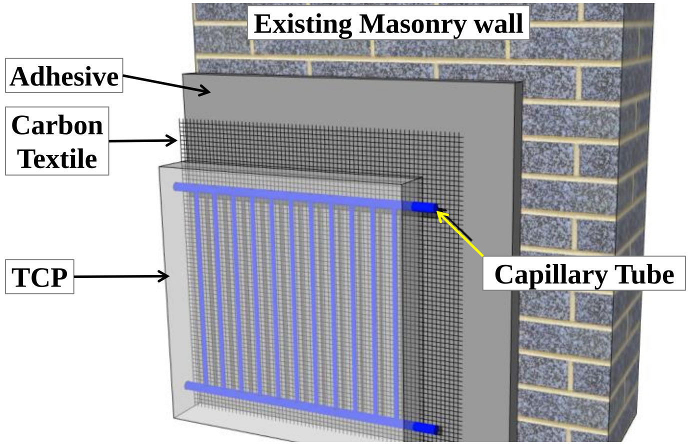
Four avenues for integrated renovation

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



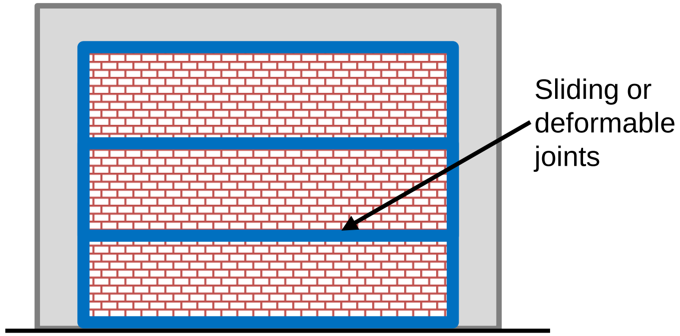
(Pohoryles et al. 2022)

(2) Envelope Interventions: e.g. precast panels integrating capillary tubes for heating and textiles for strengthening



(Baek et al. 2022)

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



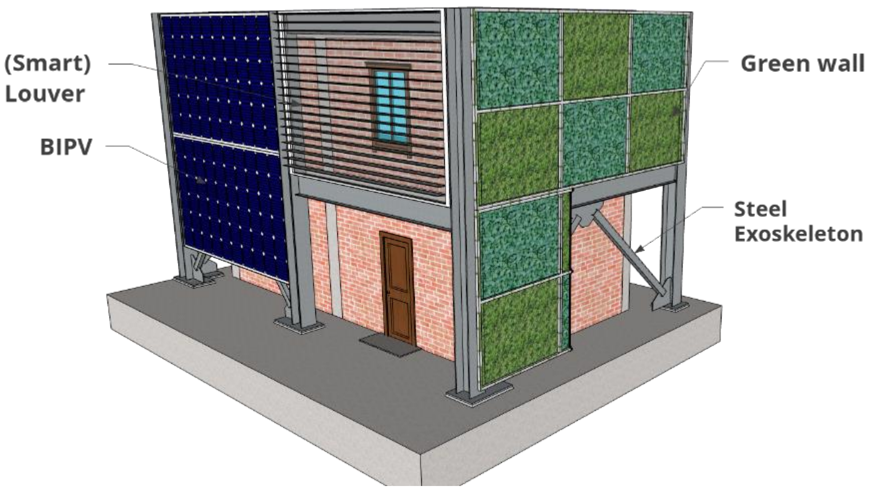
(Pohoryles et al. 2022)

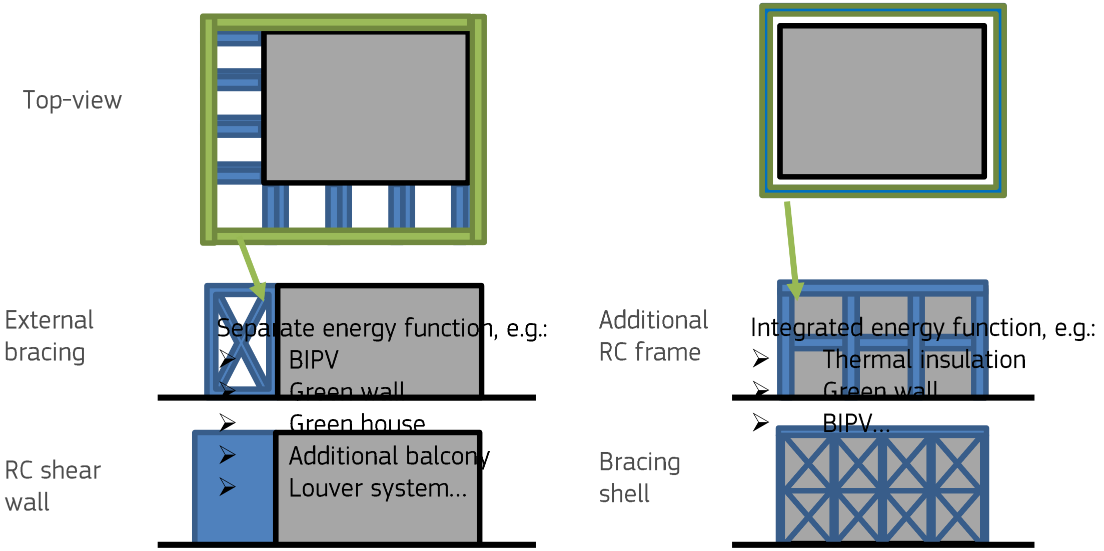
(4) Retrofitting roofs and floors: e.g. stiffening diaphragms and integrating them with an insulation and ventilation layer

(Pohoryles et al. 2022)

1) Integrated exoskeleton solutions

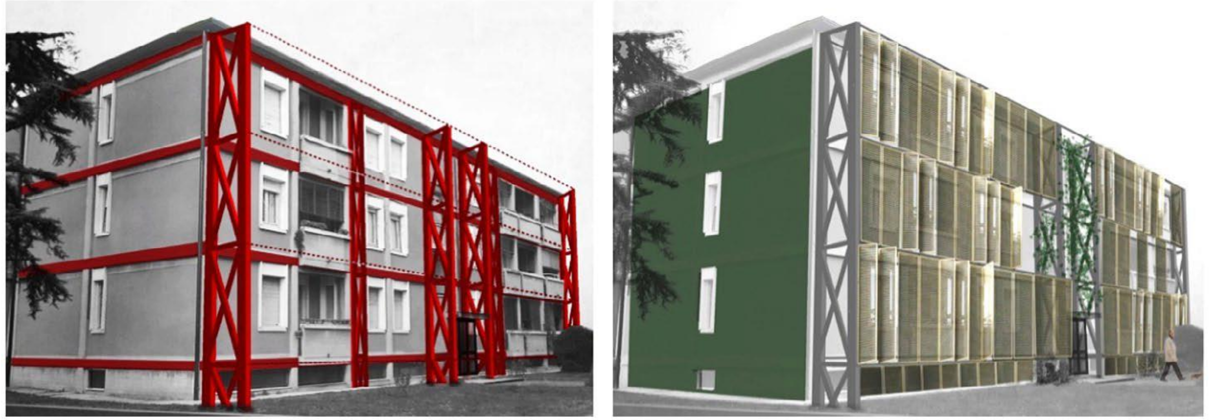
- self-supporting system (i.e. with its own foundations)
- connected to an existing building
- particularly suitable for existing RC buildings with low dissipative capacity.
- can provide additional strength and stiffness to an existing building.



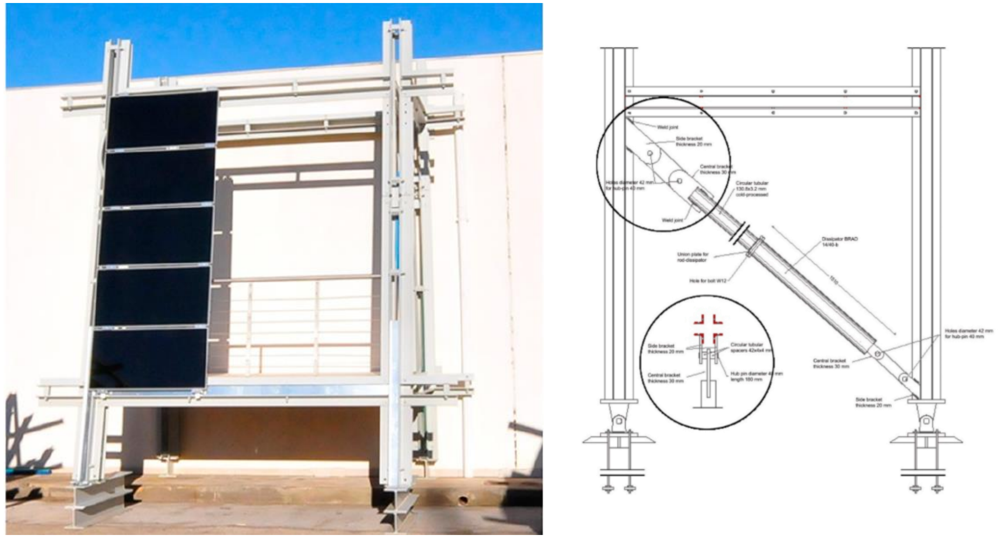


(Pohoryles et al. 2022)

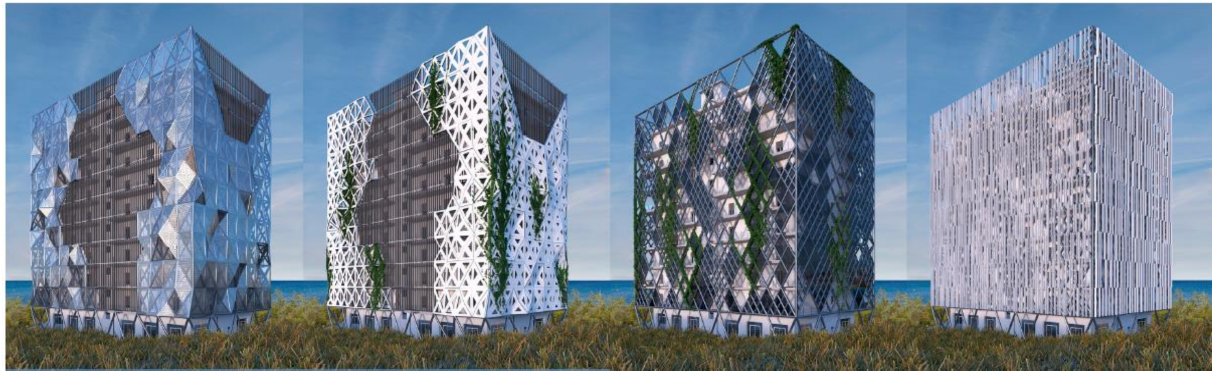
1) Integrated exoskeleton solutions - Examples



Integrated steel-braced shear wall exoskeleton Bellini et al. (2018)



Dissipative frame exoskeleton with integrated photovoltaics
Foti et al. (2020)



Diagrid exoskeletons – e.g. D’Urso and Cicero (2019)

1) Integrated exoskeleton solutions

PROS

- Low business downtime
- Resident relocation not necessary
- Possibility to add new stories and architectural upgrade
- Reversible, demountable and reparable, easy to maintain

CONS

- Highly invasive: complete change of appearance
- Not suitable for heritage buildings
- New foundations are needed
- Difficult in densely built-up areas

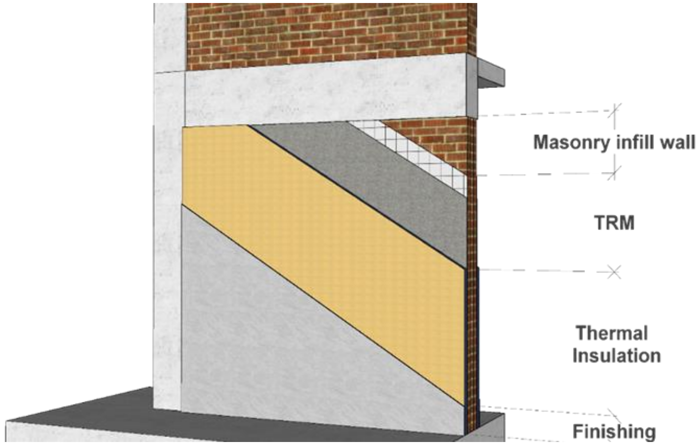
2) Interventions on existing building envelopes

Masonry infill walls

- Contribute to strength and stiffness of RC buildings
- BUT can be the source of severe damage of load-carrying elements, possibly triggering global collapse
- Source of high energy losses through thermal transmittance and air infiltration

2) Interventions on existing building envelopes

Textile reinforced mortars combined with thermal insulation

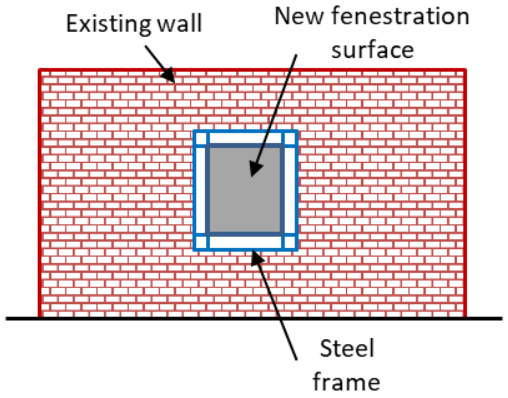


(Pohoryles et al. 2020)

CLT panels

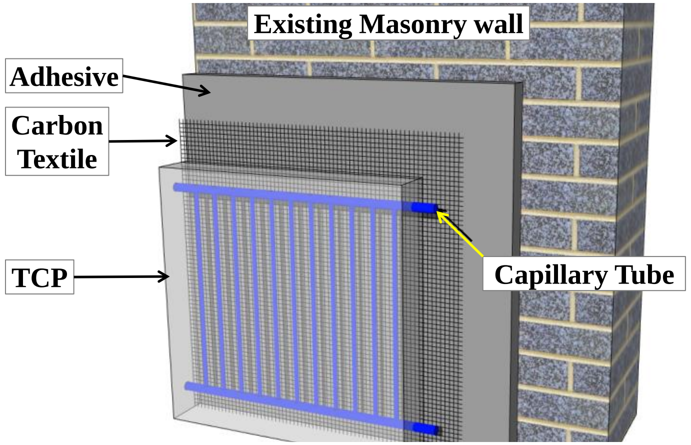
(Pohoryles et al. 2022)

New windows with structural frames



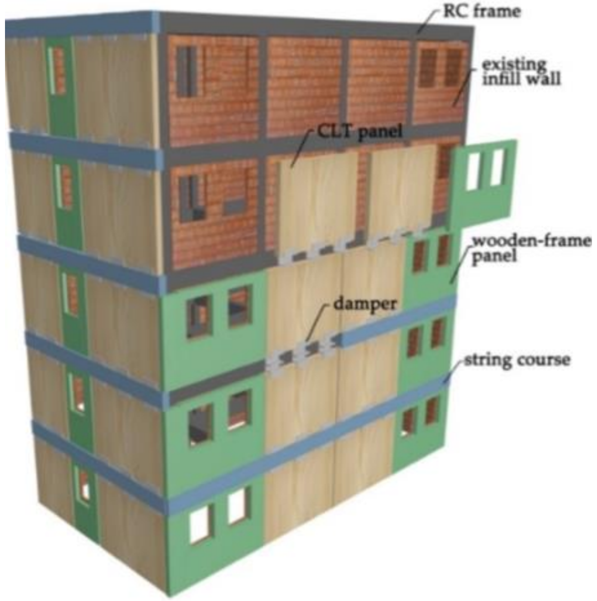
(Pohoryles et al. 2022)

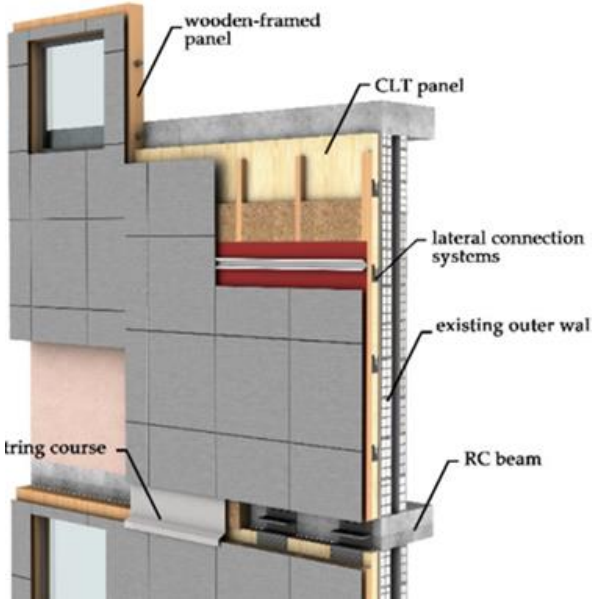
Precast integrated retrofitting panels



(Baek et al. 2022)

2) Interventions on existing building envelopes





Margani et al. (2020)

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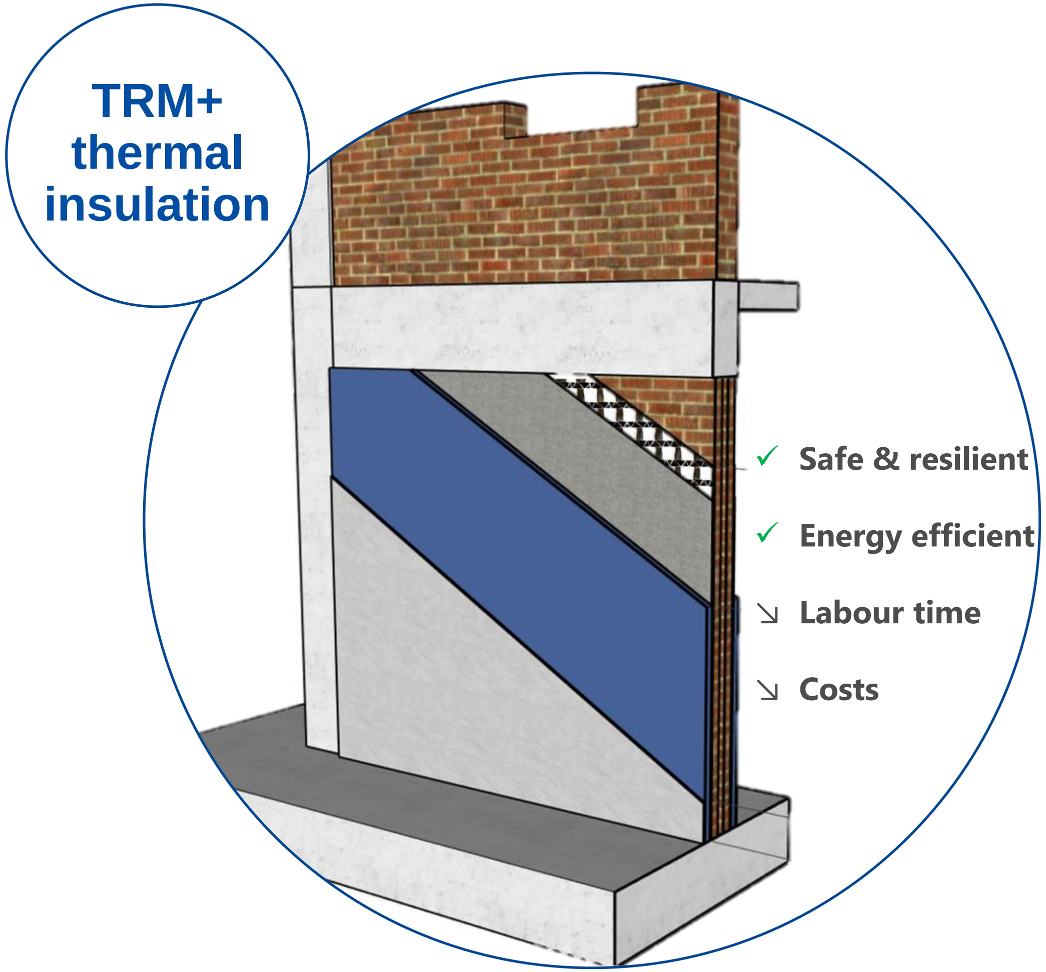
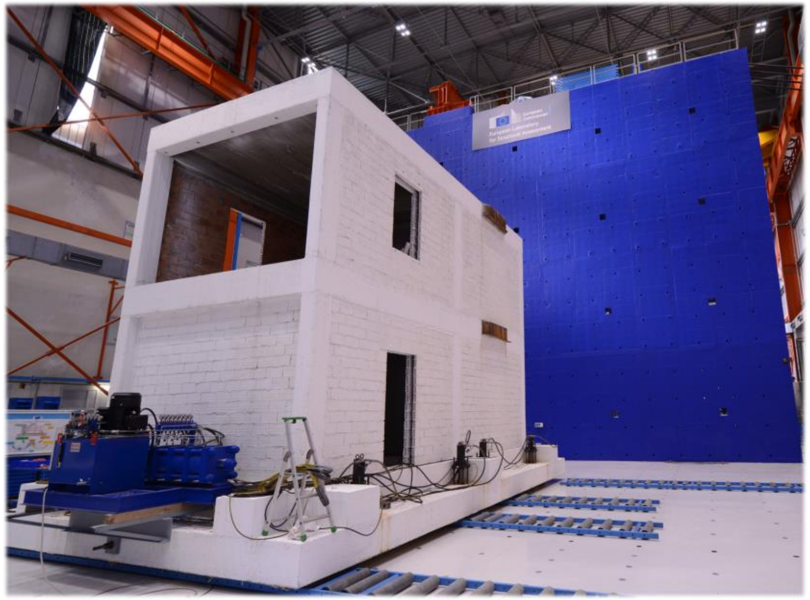
2) Interventions on existing building envelopes



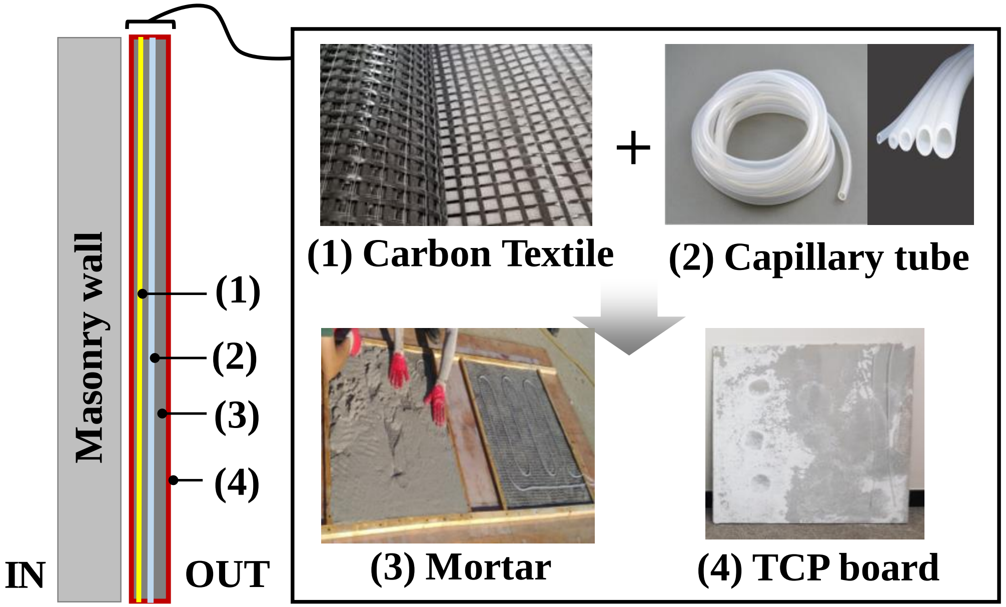
Pohoryles and Bournas (2021)

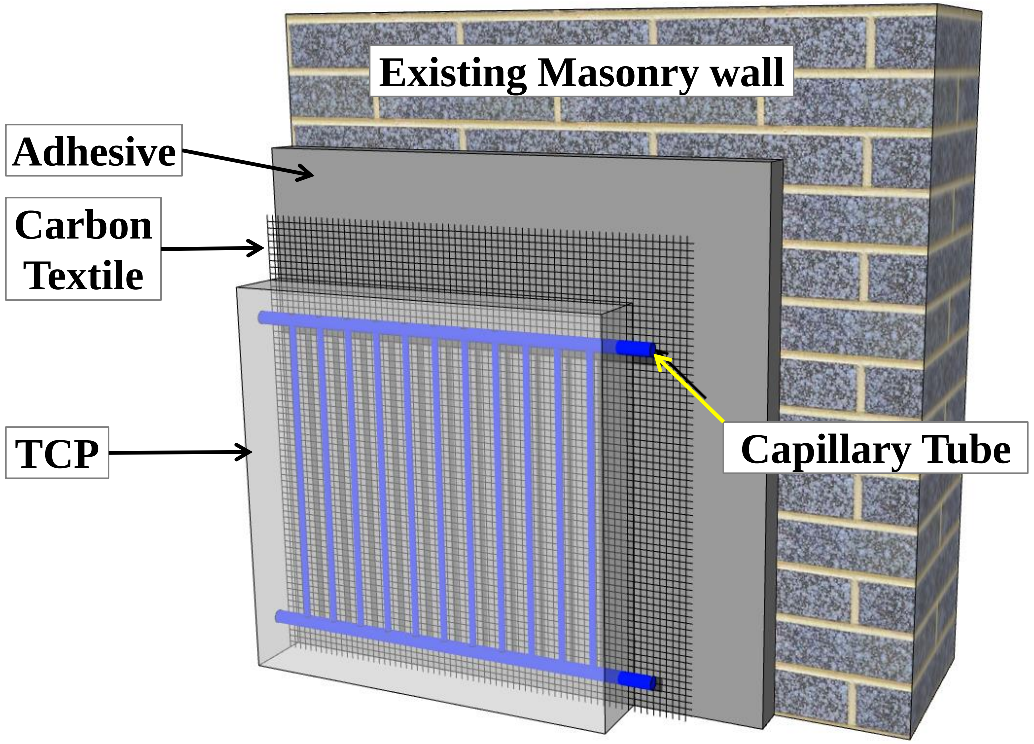
- **iRESIST+** project: Numerical and experimental validation on a typical pre-1970’s infilled RC building
- Pseudo-dynamic tests as five-storey structure at **JRC ELSA** (European Laboratory for Structural Assessment)
- Energy performance tested through blower door tests



2) Interventions on existing building envelopes

Collaboration JRC + KOCED (Korea)





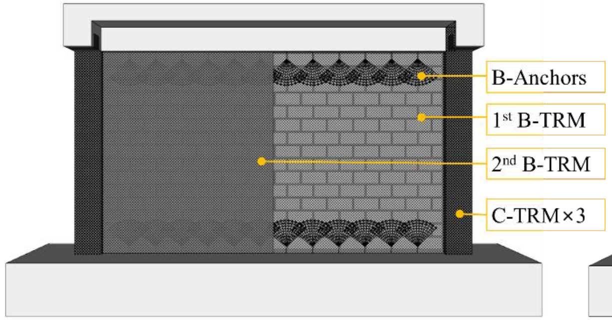
Textile Capillary Tube Panels (TCPs)

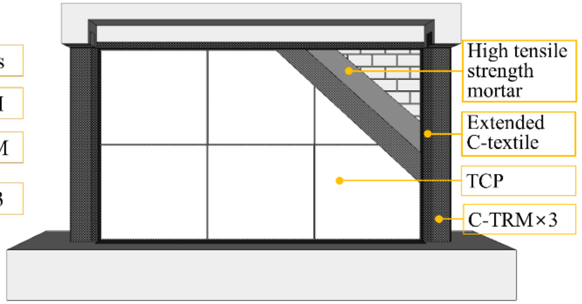
Baek et al (2022)

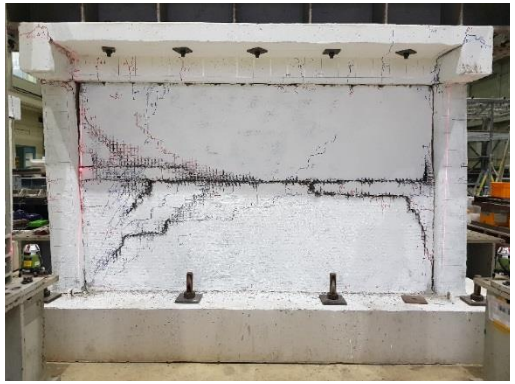
2) Interventions on existing building envelopes

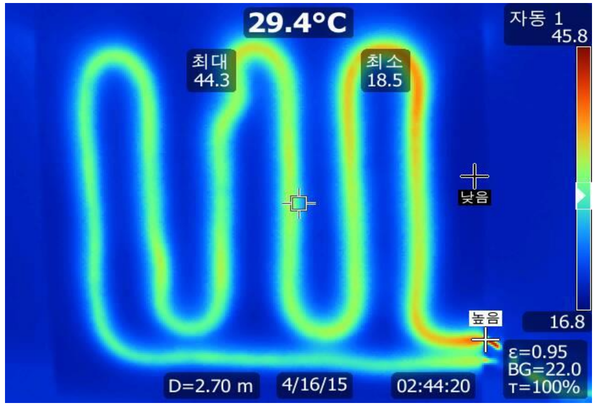
Structural validation: Cyclic and Shaking Table tests

In-situ validation of thermal efficiency









Baek et al (2022)

Baek et al (2024)

KOCED (2022)

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2) Interventions on existing building envelopes

PROS

- Applicable to RC, masonry and steel buildings
- Medium invasiveness (depending on application)
- Residents' relocation not needed and low business downtime *if carried out from outside*
- Fast – if prefabricated/modular elements are used

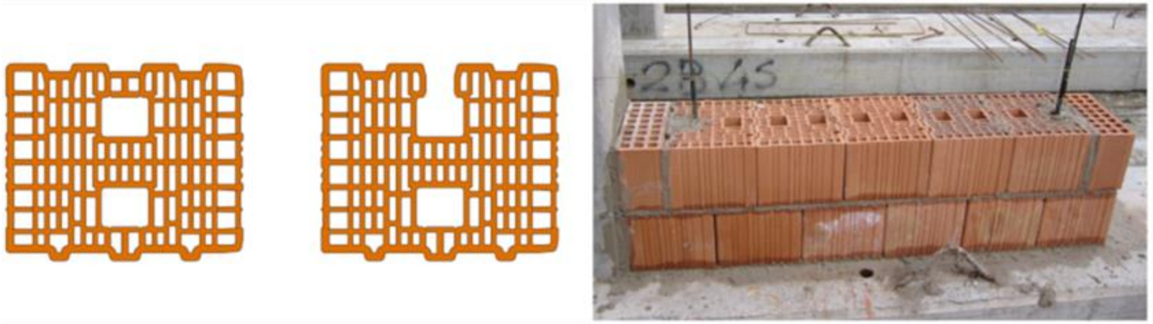
CONS

- Building facade may be deeply modified
- Existing frame members and foundations need to be evaluated (increase in shear forces)
- Much more efficient in case of double-sided application
- Not efficient for low-quality substrate

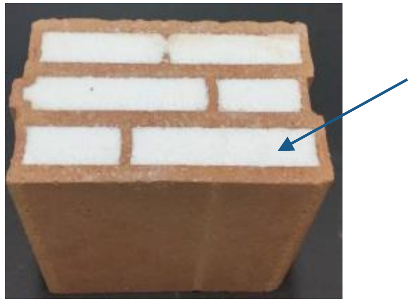
3) Envelope replacement

Strengthening interventions on masonry infills sometimes **not feasible in practice** or **not economically viable** (e.g. due to very poor quality or damage of the existing envelope).

1) increased stiffness and strength of the new infills + better thermal characteristics



Robust masonry bricks (da Porto et al., 2020)

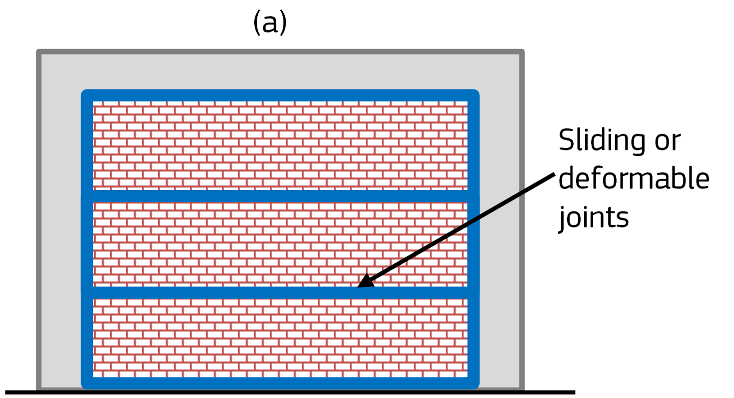


“Aerobricks” (Wernery et al., 2017)

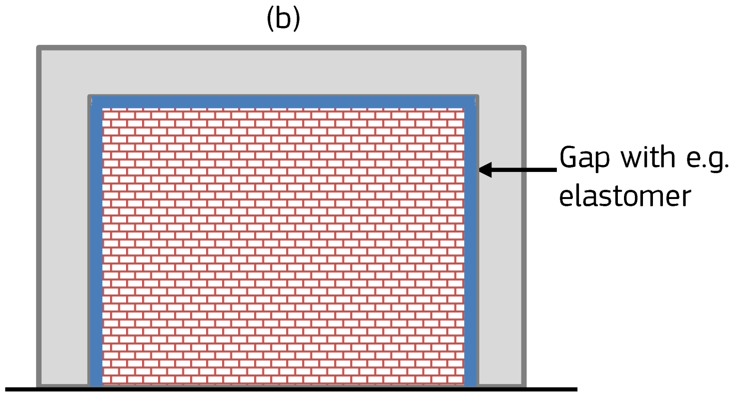
3) Envelope replacement

Strengthening interventions on masonry infills sometimes **not feasible in practice** or **not economically viable** (e.g. due to very poor quality or damage of the existing envelope).

2) increased deformability of the frame by reducing interactions between infill and RC frame + better thermal characteristics



e.g.: Morandi et al. (2018)



e.g.: Tsantilis and Triantafillou (2018)

3) Envelope replacement

PROS

- Applicable to infilled RC and steel buildings
- High improvements in energy and seismic performance possible
- Low costs of materials

CONS

- Highly invasive
- Resident relocation needed
- Medium-high business downtime
- Substantial amount of waste (often not recyclable)
- Not applicable to load-bearing masonry buildings

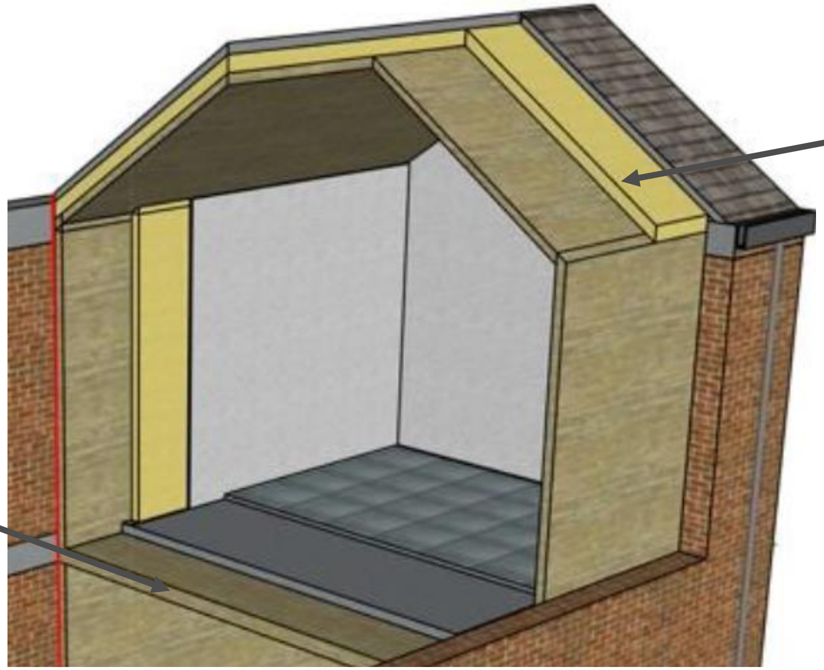
4) Interventions on roofs and floors

Stiffening diaphragms and integrating them with more efficient energy system

e.g. Giuriani et al. (2016)

4) Interventions on roofs and floors

Often combined with other interventions on the envelope, e.g.:



Adapted from Valluzzi et al., 2021

4) Interventions on roofs and floors

PROS

- Substantial improvement of the seismic behaviour of masonry structures
- Can be combined with any other intervention on the envelope

CONS

- Medium to highly invasive (according to the floor level and specific technology)
- Resident relocation needed (in general for one or two floors)

Analysis of technologies for the combined renovation of buildings

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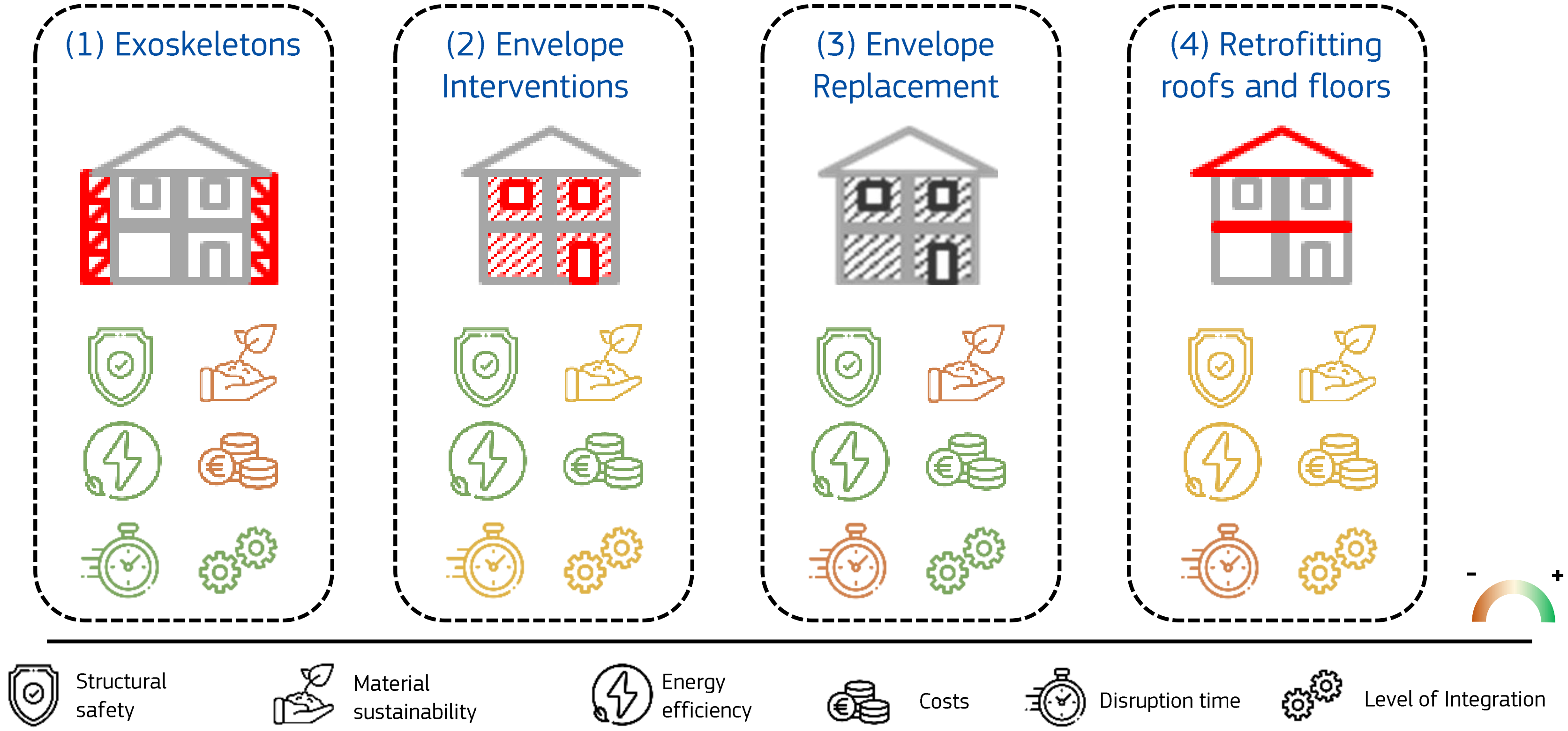
Multi-criteria assessment of different combined retrofitting options

- Effectiveness, costs, level of invasiveness and downtime, environmental impact and level of integration
- Comparison is however only **indicative** and is by no means proposed as a decision-making tool for selecting retrofitting options
    - Each building has its own characteristics, defects, material properties, etc.;
    - Large variability of seismic hazard, as well as heating/cooling energy demand in Europe

→ not possible to make a definite “ranking” of technologies

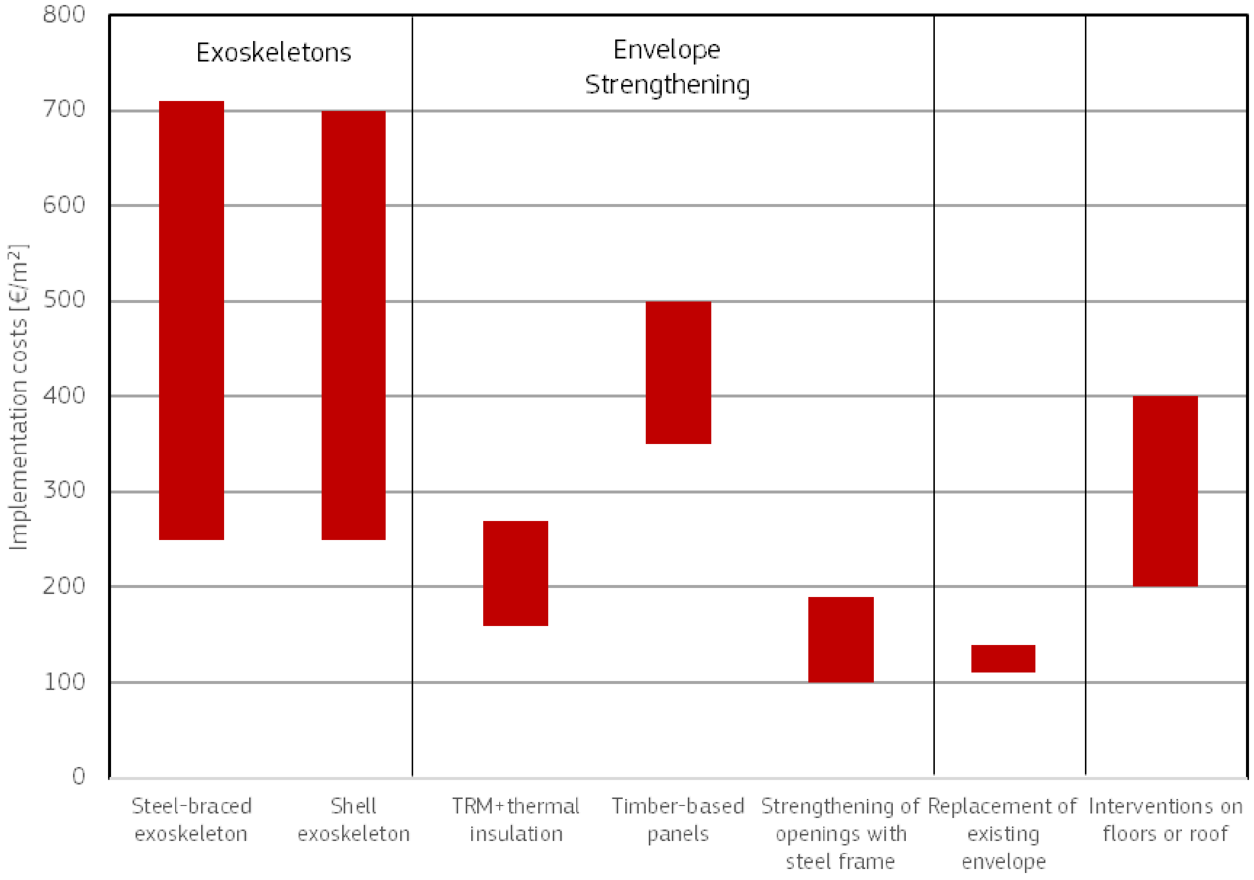
Multi-criteria assessment of different combined retrofitting options



Pohoryles et al. (2022)

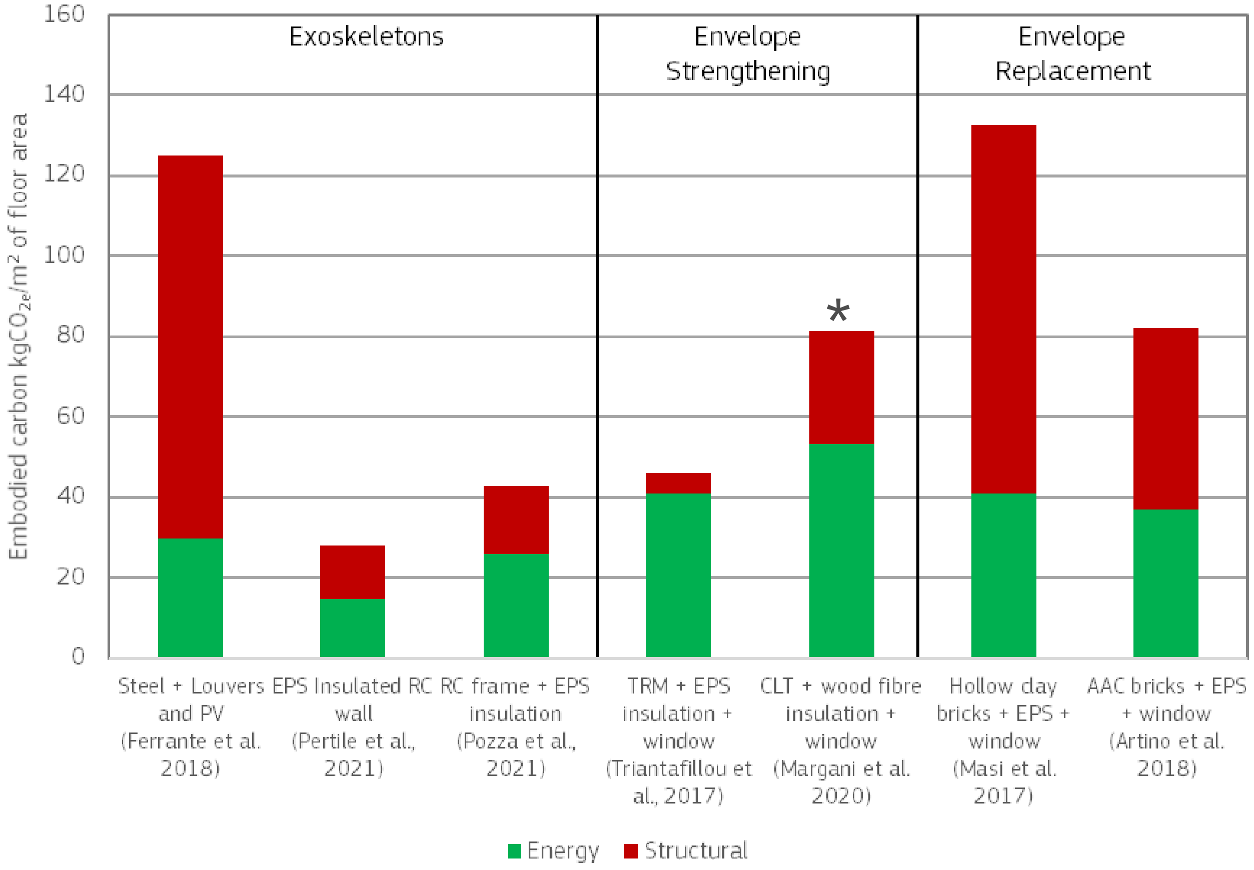
Evaluation of retrofit costs

- Preliminary and simplistic
- Actual costs **will vary substantially** for different geometric and structural configurations, seismic and climatic zones
- Attributed to the same three-storey RC structure and normalised per m² of floor area.
- for <u>illustration purposes only</u>



Environmental impact

- Cradle-to-gate of embodied carbon of **materials only**
- Based on the quantities suggested in the individual publications
- Attributed to the same three-storey RC structure and normalised per m^2 of floor area
- for <u>illustration purposes only</u>



* carbon capture/storage not considered

Analysis of technologies for combined upgrading of existing buildings

	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

Pohoryles et al. (2022)

Conclusions

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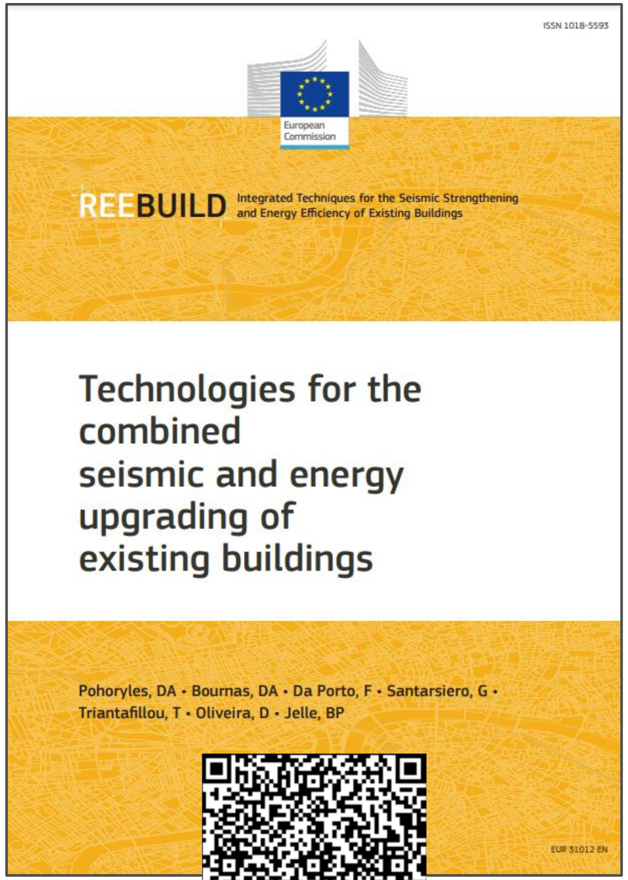
Conclusions

- **Four main types of interventions** identified: (1) exoskeletons; (2) interventions on the existing envelope, (3) replacement of the existing envelope; and (4) interventions on horizontal elements.

- **Varying level of maturity.** Further development and experimental research is still required as many of the assessed technologies are still in a conceptual stage, while few have already been tested and validated experimentally.

- **Retrofitting is never a unique solution.** Needs to be tailored to fit the building needs (e.g. different deficiencies, materials, differences in protected status)

Relevant Pilot Project reports


ISSN 1018-5593

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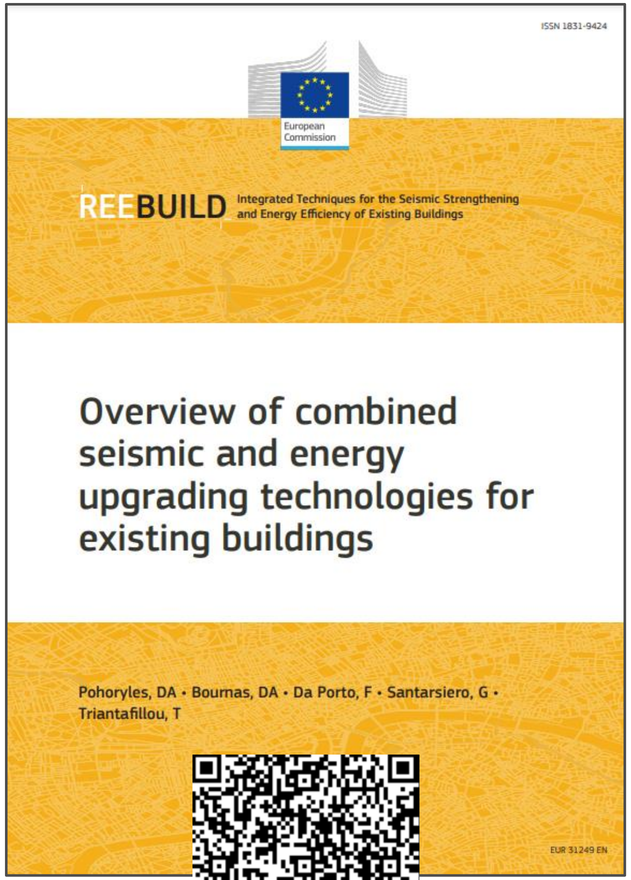
REEBUILD Integrated Techniques for the Seismic Strengthening and Energy Efficiency of Existing Buildings

Technologies for the combined seismic and energy upgrading of existing buildings

Pohoryles, DA • Bournas, DA • Da Porto, F • Santarsiero, G • Triantafillou, T • Oliveira, D • Jelle, BP

EUR 31012 EN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REEBUILD Integrated Techniques for the Seismic Strengthening and Energy Efficiency of Existing Buildings

Overview of combined seismic and energy upgrading technologies for existing buildings

Pohoryles, DA • Bournas, DA • Da Porto, F • Santarsiero, G • Triantafillou, T

EUR 31249 EN


ISSN 1831-9424

European Commission

REEBUILD Integrated Techniques for the Seismic Strengthening and Energy Efficiency of Existing Buildings

Novel technologies for the seismic upgrading of existing European buildings

Triantafillou, TC • Bournas, DA • Gkournelos, PD

EUR 30669 EN

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Thank you

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