Technologies for separate seismic and energy renovation of buildings

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

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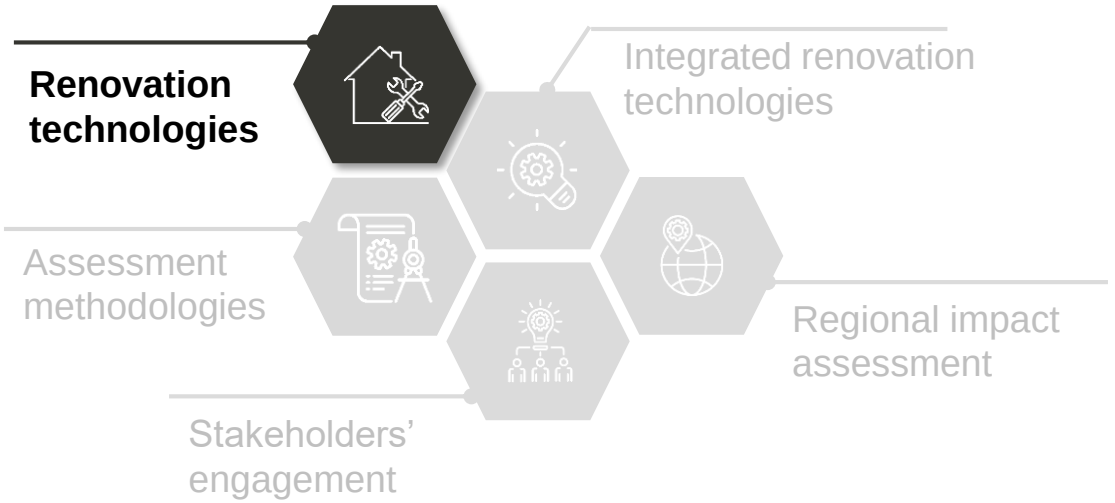
Final workshop, 21 March 2024

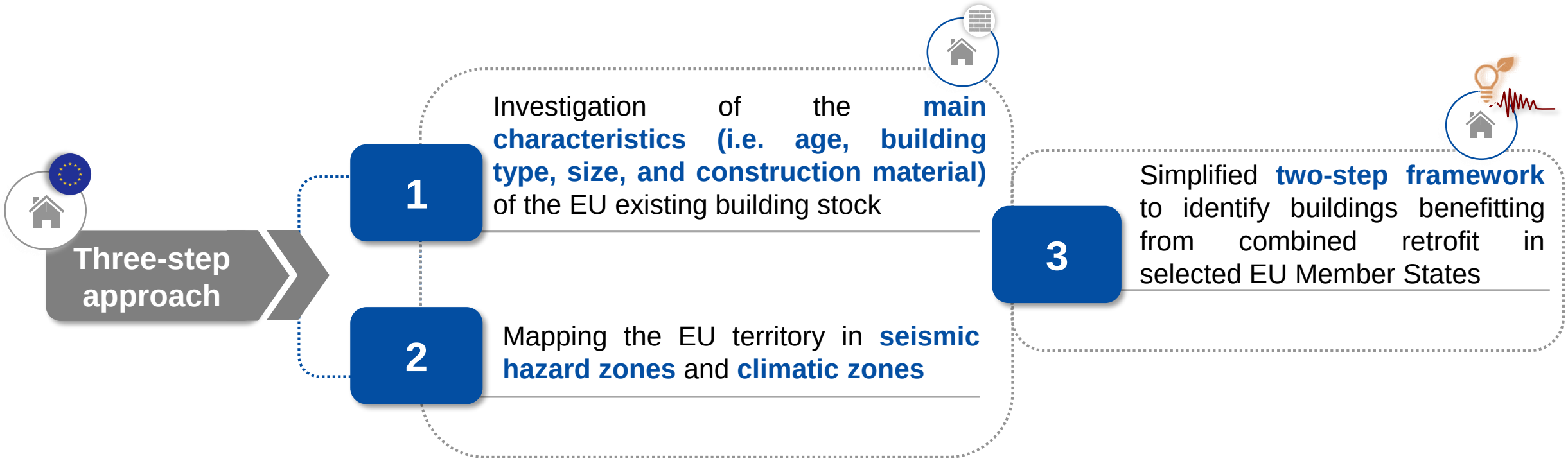
Contents



European Commission

1. EU buildings benefitting from combined retrofit

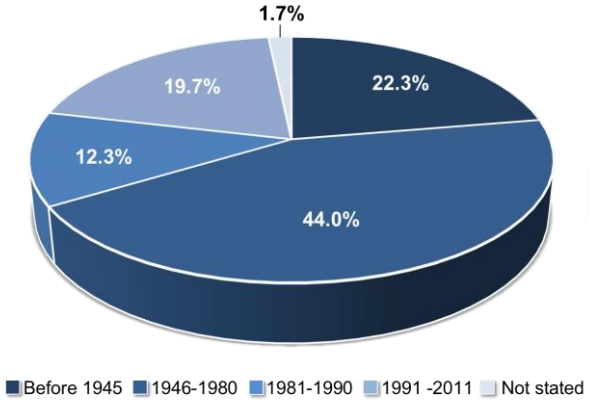
Three-step approach investigation



European Commission

Step 1. Main characteristics of EU building stock

Age | Distribution of dwellings in European residential buildings by year of construction (pre-1919 – 2011)

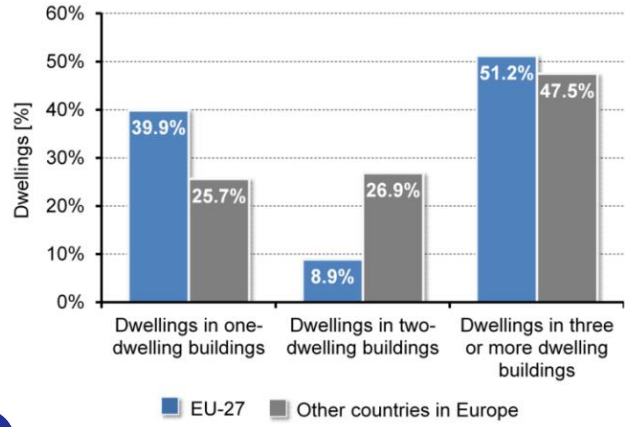


22% Dwellings before 1945

79% Dwellings before 1991

Source: Data - European Statistical System (EES), *2011 Population and Housing Census*

Building type | Distribution of dwellings in European residential buildings by type (i.e. one-, two-, three- or more dwelling building)



Highest share (SFH): *Ireland, Belgium, the Netherlands*

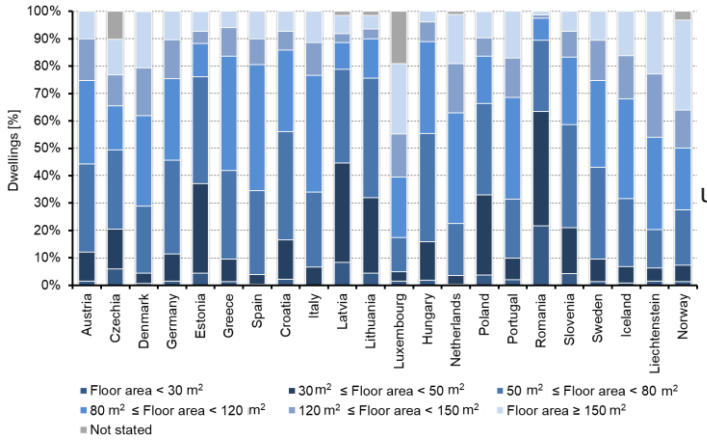
40% Dwellings in SFH

50% Dwellings in MFH

Highest share (MFH): *Estonia, Latvia, Spain, Italy*

Source: Data - European Statistical System (EES), *2011 Population and Housing Census*

Size | Distribution of dwellings in European residential buildings by size (i.e. useful floor area)



Highest share of dwellings – useful floor area **50-120 m²**

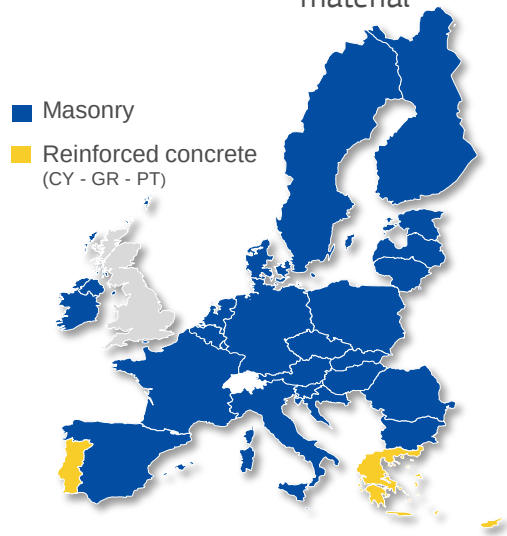
68 m² Average floor area SFH

100 m² Average floor area MFH

Source: Data – ENTRANZE tool, 2008

Source: Data - European Statistical System (EES), *2011 Population and Housing Census*

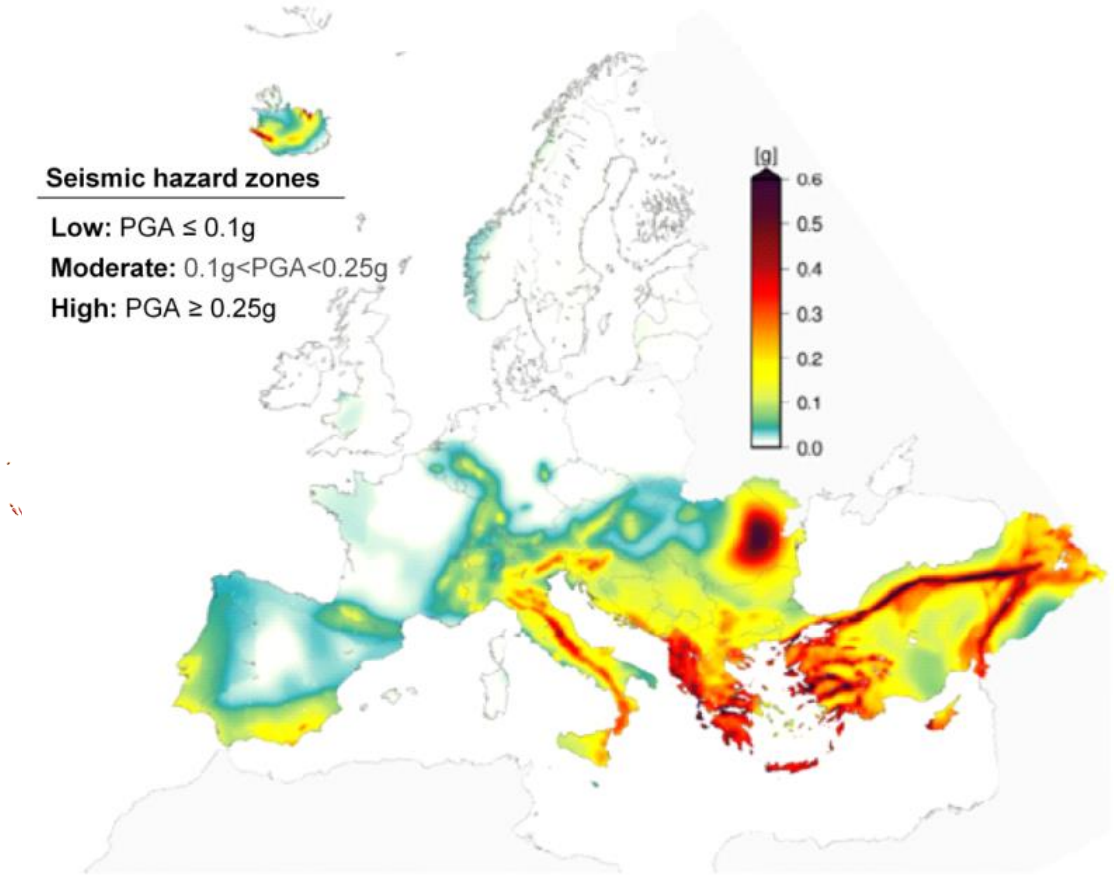
Construction material | Distribution of the EU building stock by construction material



European Commission

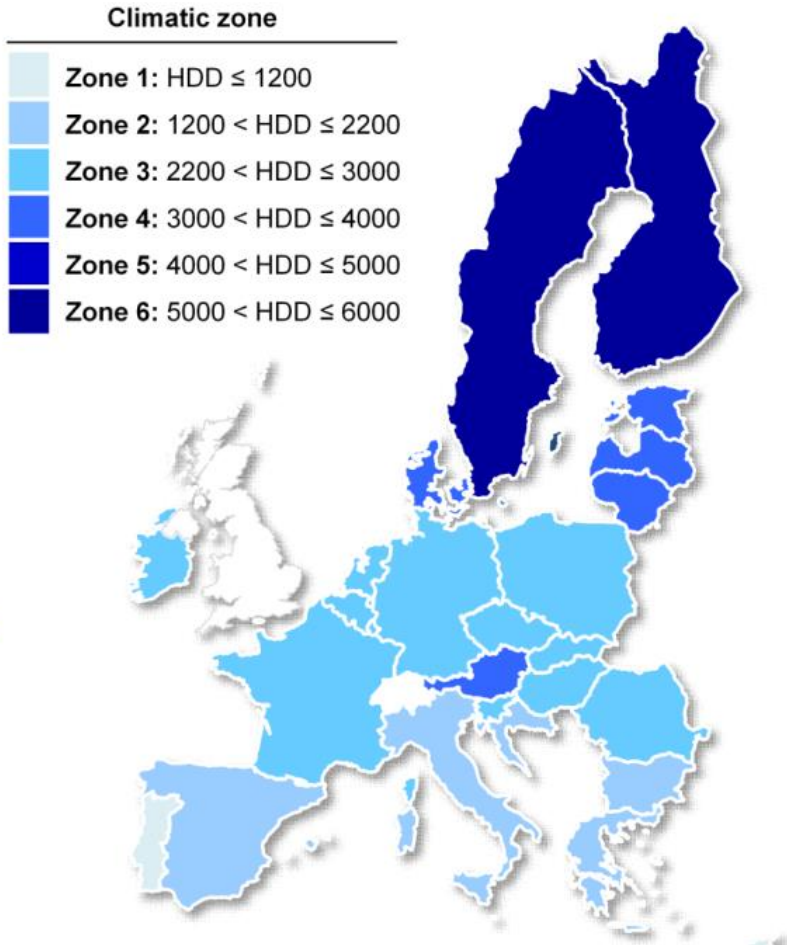
Step 2. Mapping EU in seismic and climatic zones

ESHM20 (mean) PGA (g)



Source:© Danciu et al., 2021

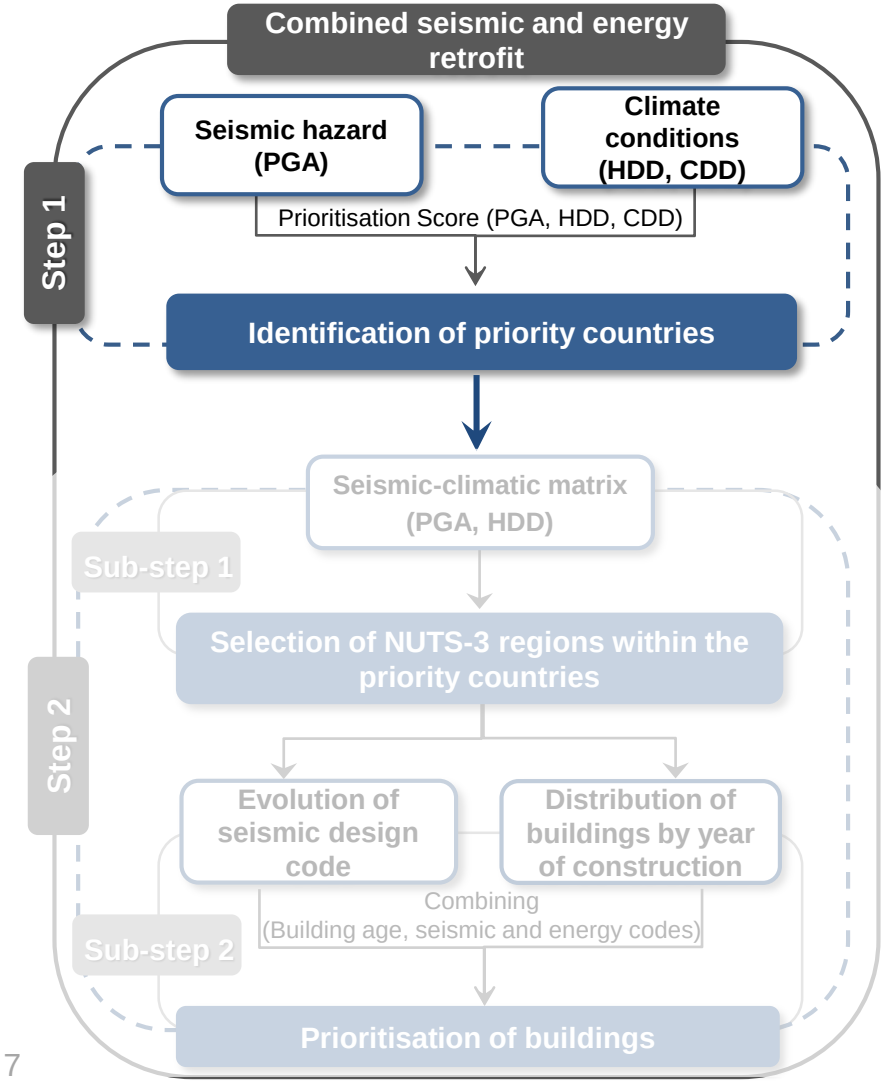
2019 annual average HDD at EU member state level

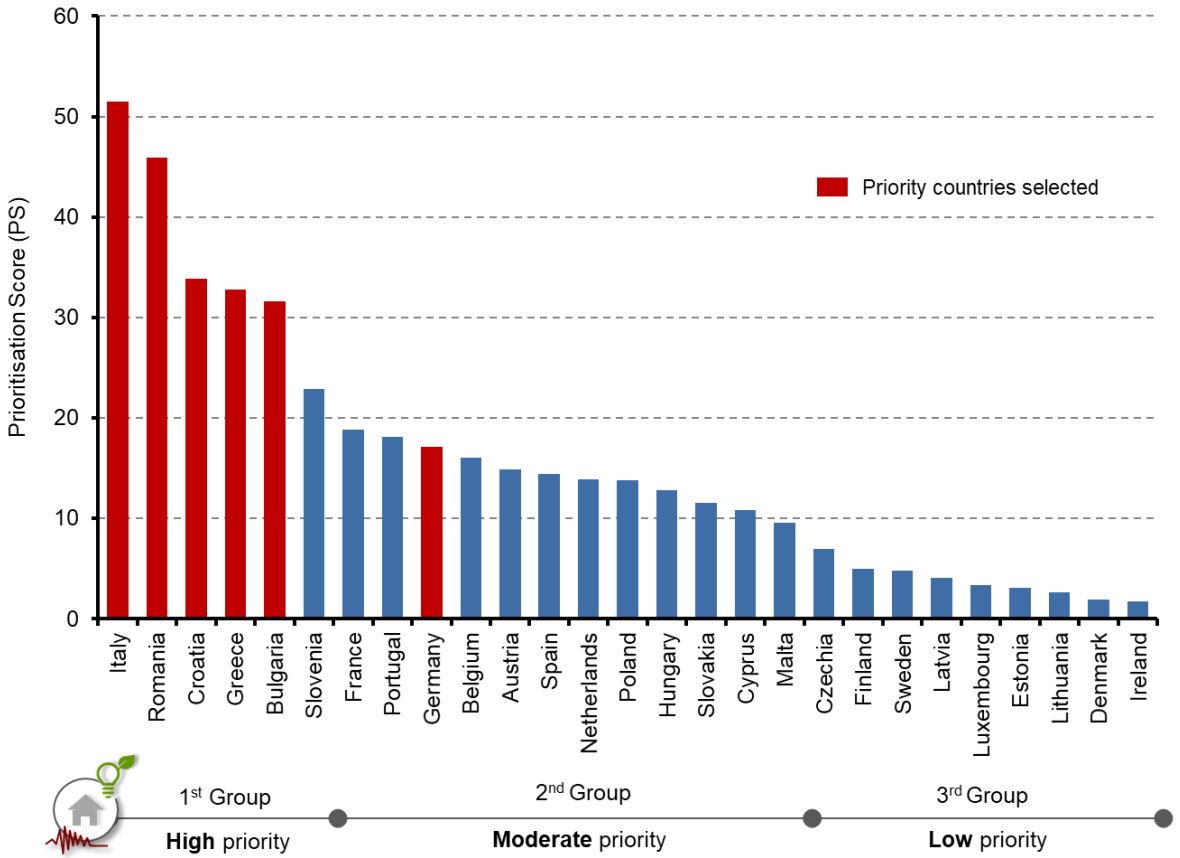


Source: Data – Eurostat, 2020

European Commission

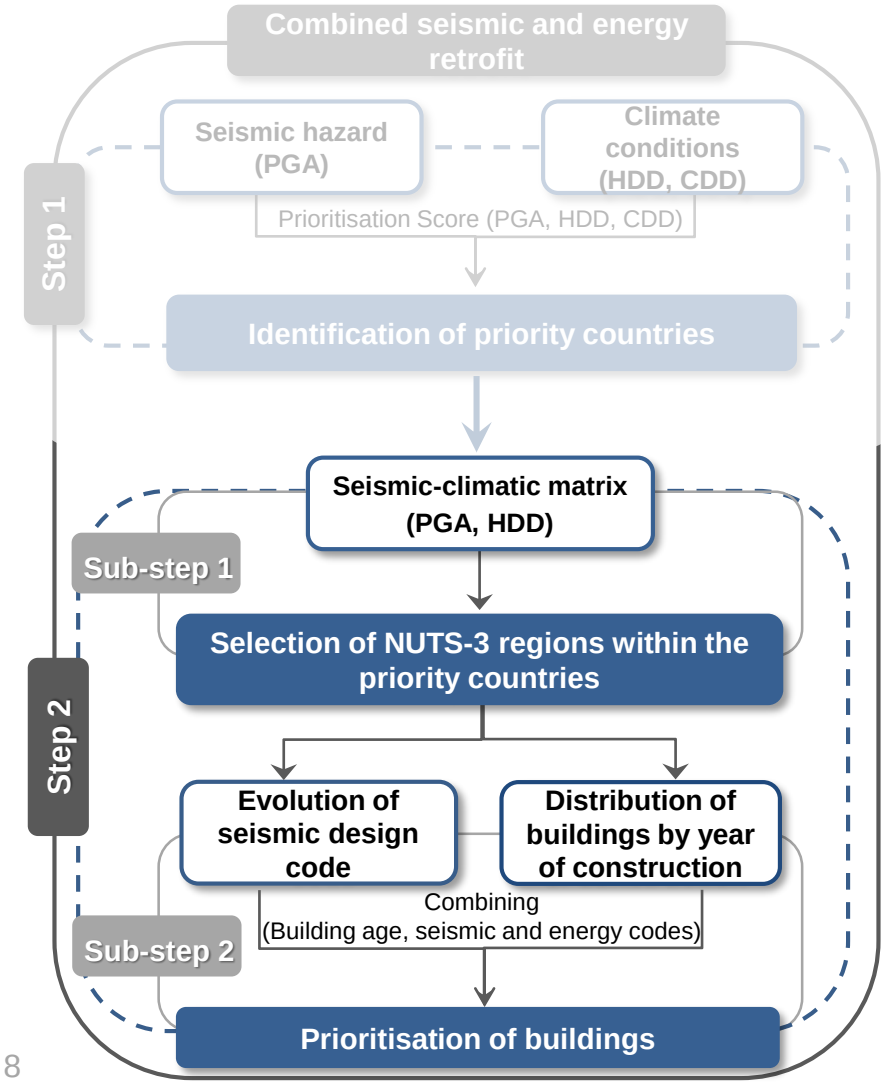
Step 3. Two-step framework: EU buildings benefitting from combined retrofit

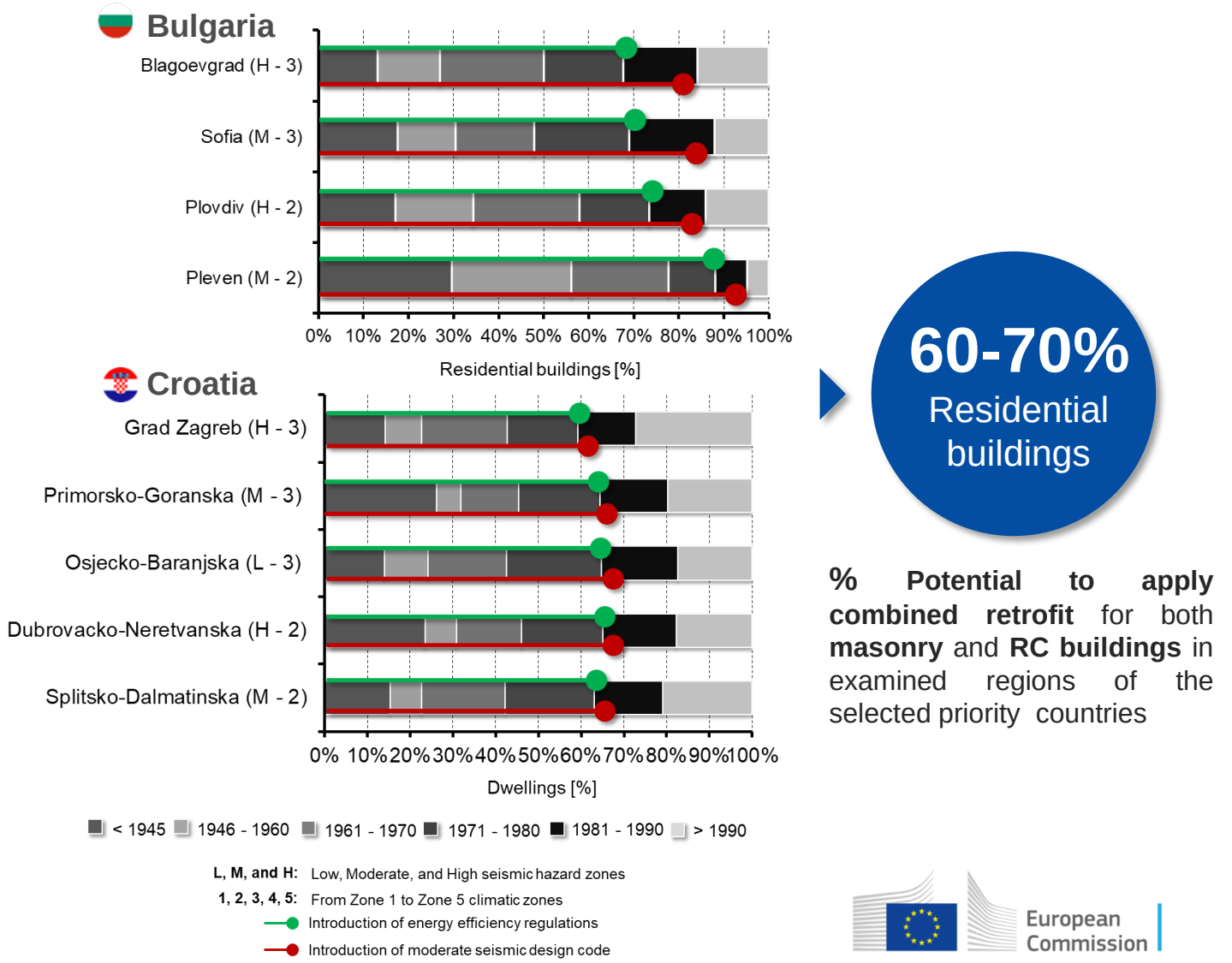




European Commission

Step 3. Two-step framework: EU buildings benefitting from combined retrofit





60-70%
Residential buildings

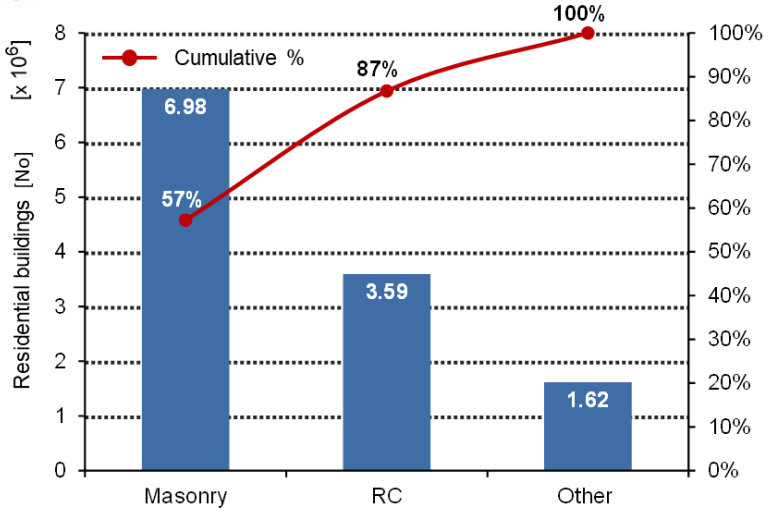
% Potential to apply combined retrofit for both **masonry** and **RC buildings** in examined regions of the selected priority countries

European Commission

Focus on Italian building typologies needing combined retrofit

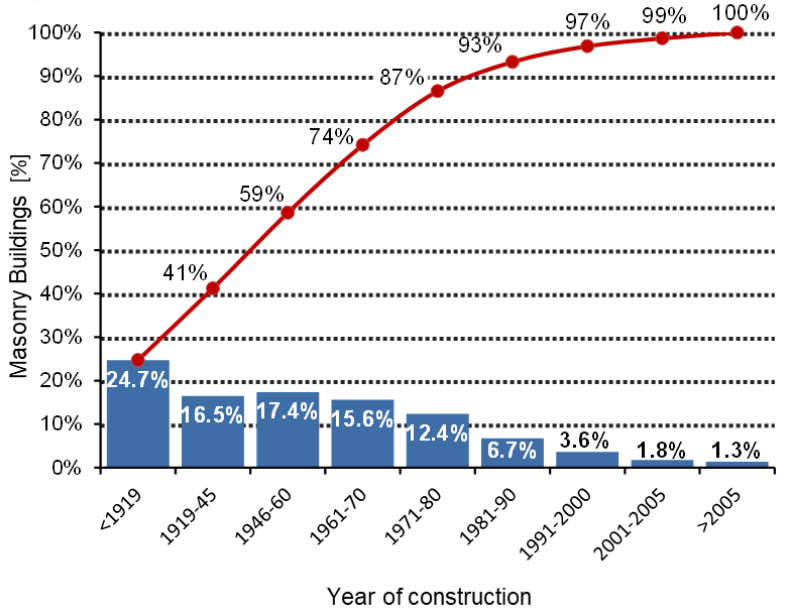
Analysis of **statistics** on **Italian masonry** and **RC** building stock

Distribution of the **Italian residential building** stock by **construction material**



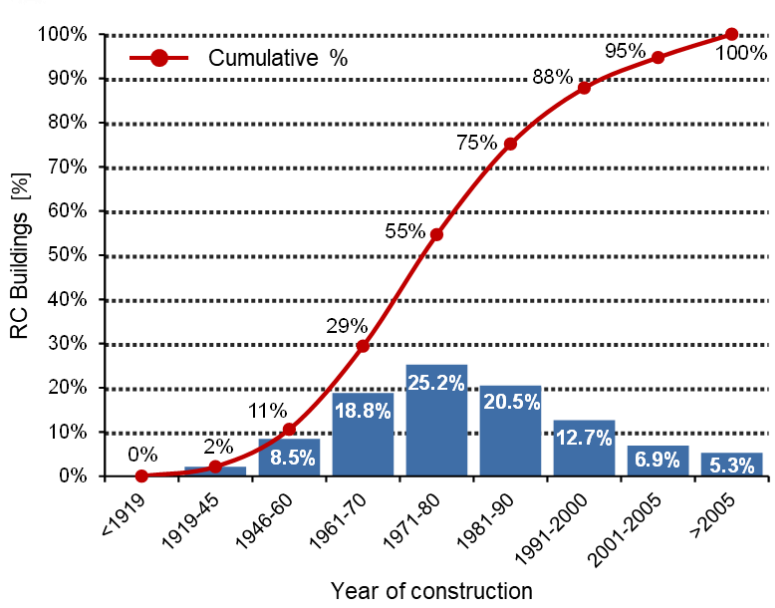
Source: Data – ISTAT, *2011 Population and Housing Census*

Distribution of the **Italian masonry residential building** stock by **year of construction**



Source: Data – ISTAT, *2011 Population and Housing Census*

Distribution of the **Italian RC residential building** stock by **year of construction**



Source: Data – ISTAT, *2011 Population and Housing Census*

90% of Italian **masonry** residential buildings
55% of Italian **RC** residential buildings

Built with no seismic provisions

88% of Italian **masonry** and RC residential buildings

Do not comply with modern energy requirements

European Commission

Focus on Italian building typologies needing combined retrofit

Masonry buildings

Identification of the selected Italian masonry building typologies vulnerable to earthquake in Emilia region (potentially applicable also to North-East Italy)

Masonry building typologies			
Main characteristics		4D-5D	6D
Structural Typology	Vertical structural components	Walls with regular layout and good quality of masonry	Walls with regular layout and good quality of masonry
	Tie rods/tie beams	Missing	Missing
	Horizontal structural components	4D: Flexible (e.g. timber planks, beams and shallow arch vaults, etc.) 5D: Semirigid (e.g. beams and flat hollow clay bricks, etc.)	Rigid (e.g. RC slab)
	Roof	Thrusting	Thrusting
Building size	Number of stories	2 or 3	2 or 3
	Total floor area [m^2]	300÷400	400÷450
Building age	Period of construction	<1945	<1971

Source: Data – Da.O.D, 2012 Emilia database (AeDES form) – Data retrieved from survey forms for post-earthquake damage and safety assessment of buildings (with reference to 2012 Emilia earthquake) (Baggio et al., 2007; Dolce et al., 2019)

Thermal transmittance (U-value) of the envelope components of the selected building type in the 'as is' scenario and threshold values required by the Italian Ministerial Decree on energy efficiency of buildings (DM 26/06/2015)

Building envelope component		U-value [W/m^2K]	
		Building type (1) (IT.MidClim.MFH.02.Gen)	Threshold values for existing buildings under renovation (2)
Opaque vertical components	Wall (60cm-thick)	1.19	0.28
Horizontal components	Roof	1.54	0.24
	Floor	1.20	0.29
Transparent vertical components	Window	4.90	1.40

(1) Data retrieved from TABULA WebTool.

(2) Threshold U-values (climatic zone E) in force from 1st January 2021 for existing building subjected to energy renovation (Annex B of DM 26/06/2015).

2. Seismic retrofit technologies and classification

Seismic retrofit technologies

Global retrofit

Involve the building as a whole

1. Reduction of seismic demand

Seismic isolation
Additional damping

2. Enhancing seismic capacity

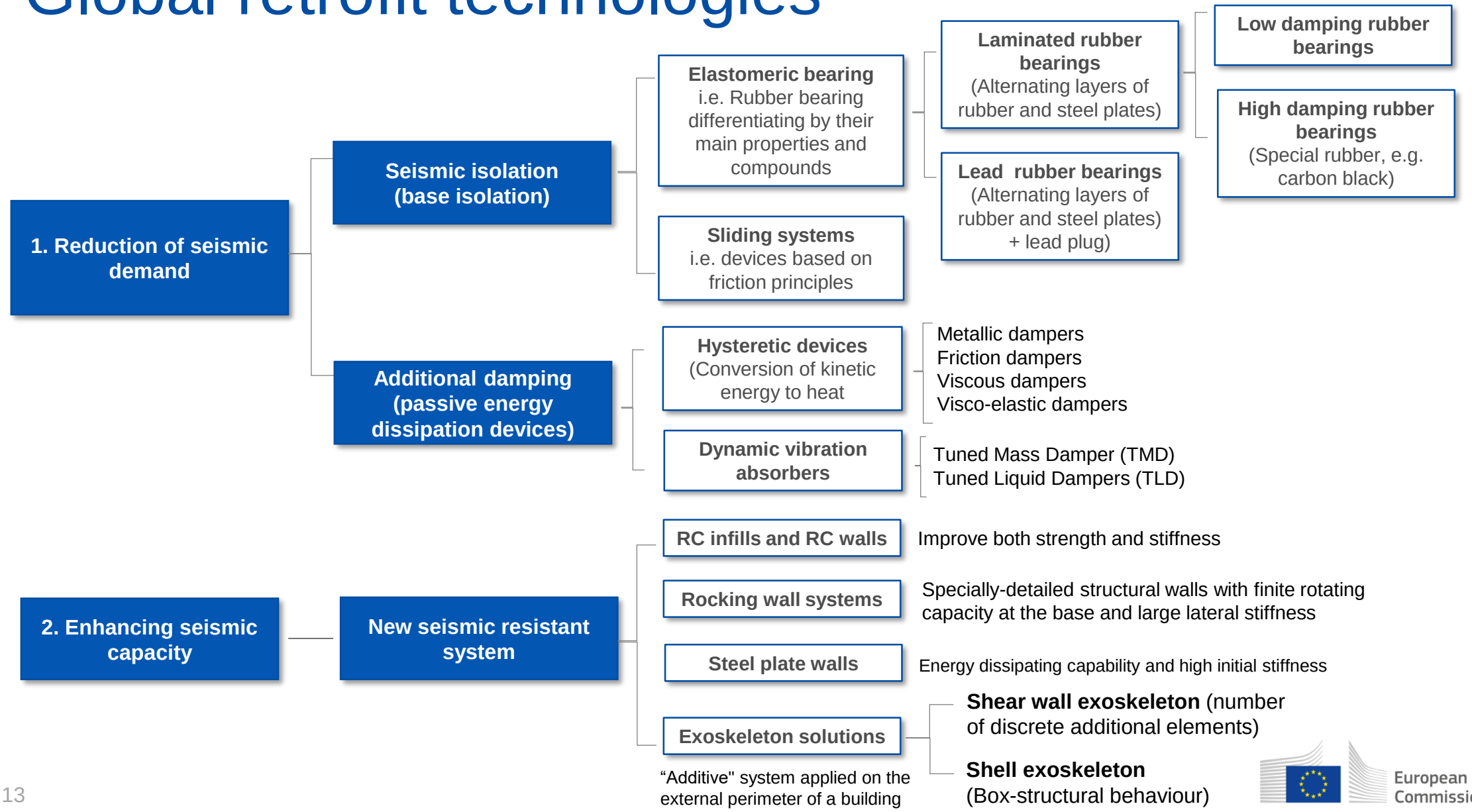
RC walls - Steel braces - Rocking wall systems – Shear wall exoskeletons, Shell exoskeletons (e.g. diagrid system, cross-laminated timber (CLT) panels)

Local retrofit

Operate on individual structural elements

Local strengthening measures by building typology (Focus on RC, masonry buildings)

Global retrofit technologies



Local retrofit technologies

RC buildings

RC Beam and column

Enhance their strength, ductility, and seismic capacity

RC jacketing

Steel jacketing

Enlarged cross-section of the members
Overweight in case of RC jacketing
Inner surface corrosion

Fiber reinforced polymers (FRP) wrapping

Enhance shear and flexural strength

High-performance fiber-reinforced concrete (HPFRC) jacketing

Beam-to-column joints

RC jacketing

Steel-plates jacketing

FRP-based solutions

HPFRC-solutions

Pre-stressed high-strength steel wires

Masonry buildings

Masonry wall

Enhance in-plane and out-of-plane behaviour

Improvement of masonry quality and continuity of masonry leaves via different measures, such as grout injection, repointing of walls, and reconstruction of wall portions

Structural coatings

Floor/roof diaphgram and connection to wall via different measures:

- Thin ordinary RC slab
- Second timber deck by means of planks, plywood, CLT panels

Perimeter ties
Horizontal steel tie-bars, located outside or inside wall thickness.

SRTs qualitative classification

17 Life Cycle Thinking (LCT) criteria

Holistic/integrated renovation compatibility - Incremental renovation - Occupants' disruption - Replacement of finishes - Potential to recycle/re-use - Duration of on-site works - Maintenance - Initial economic investment - Life cycle cost - Repairability - Demountability - Adaptability for future use.

Rating of seismic retrofit technologies

(***Score**: from 1 to 5)*

Global retrofit technologies

LCT-effective

Steel bracing system

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

External shell exoskeleton

CLT panel solutions *vs* Steel diagrid systems

- (x) Less compatibility with incremental renovation
- (x) More difficult reparability
- (x) Slightly higher initial economic investment

Local retrofit technologies

RC buildings

- (x) Difficult re-use/ demountability of components
- (x) Relocation of occupants
- (x) Replacement of finishes

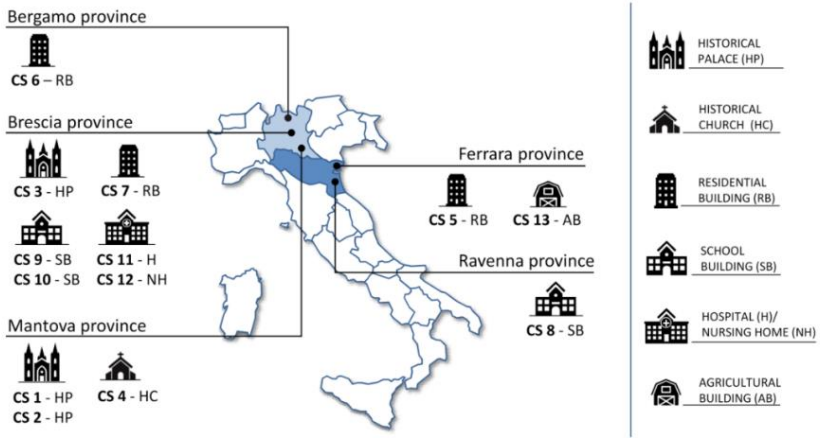
Masonry buildings

- ✓ Low maintenance
- ✓ Moderate initial economic investment
- ✓ Low life cycle cost
- (x) Barely compatibility with holistic renovation
- (x) Quite long duration of works
- (x) Relocation of occupants
- (x) Difficult re-use/demountability of components

SRTs quantitative classification

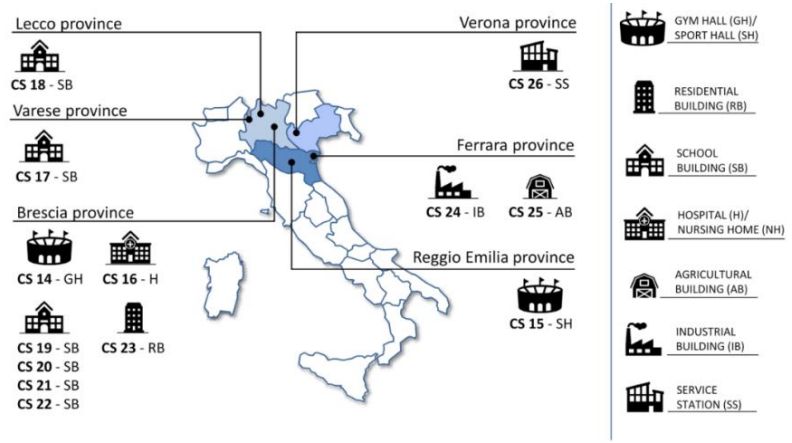
Two-phase cost analysis - 26 seismic retrofit projects of residential and non-residential buildings

13 Masonry buildings



Case study	Seismic retrofit interventions					Static loads retrofit	Energy retrofit
	Quality masonry improvement	Perimeter ties	Roof/floor diaphragm	In-plane resistance of walls	Foundation system retrofit		
CS 1	✓	✓	✓			✓	
CS 2	✓	✓	✓			✓	
CS 3	✓	✓	✓	✓	✓	✓	
CS 4	✓	✓	✓	✓		✓	
CS 5	✓	✓	✓			✓	
CS 6		✓	✓	✓	✓		✓
CS 7	✓			✓			
CS 8			✓	✓	✓		
CS 9			✓	✓			
CS 10			✓				
CS 11	✓	✓	✓	✓	✓		
CS 12	✓	✓	✓	✓		✓	✓
CS 13	✓	✓	✓				

13 RC buildings

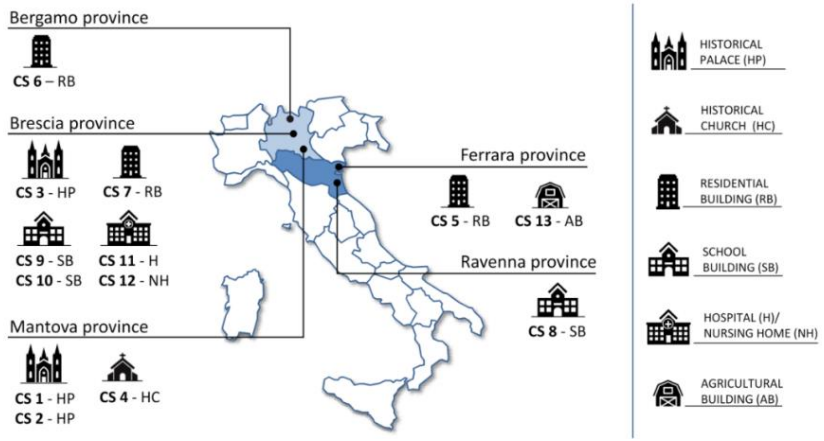


Case study	Seismic retrofit interventions				Static loads retrofit	Energy retrofit
	Joint strengthening	Exoskeleton (Shear wall)	Exoskeleton (Shell)	Roof/floor diaphragm		
CS 14			✓	✓		✓
CS 15		✓		✓		
CS 16	✓	✓				
CS 17		✓				
CS 18		✓				✓
CS 19	✓	✓		✓		
CS 20	✓			✓	✓	
CS 21		✓		✓		
CS 22		✓		✓		
CS 23		✓		✓		✓
CS 24	✓					✓
CS 25	✓					✓
CS 26	✓	✓				

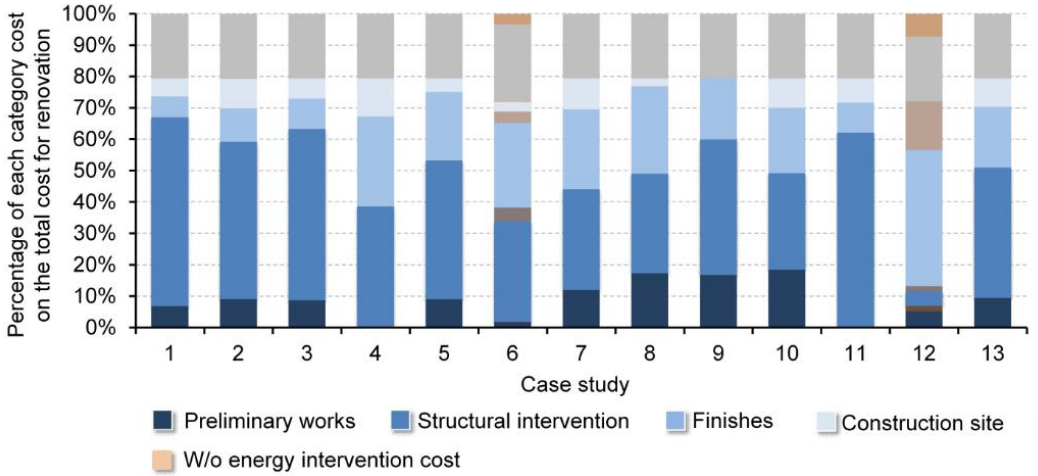
SRTs quantitative classification

First phase – Cost breakdown analysis of the 26 seismic retrofit projects

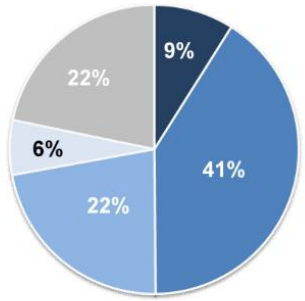
13 Masonry buildings



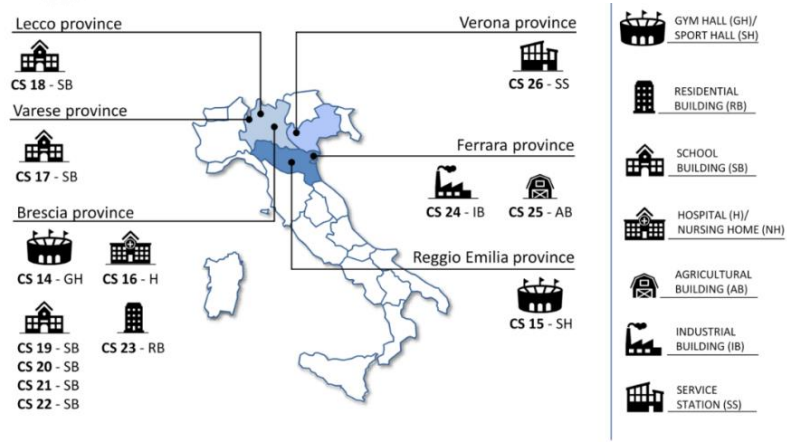
Cost breakdown of retrofit activities



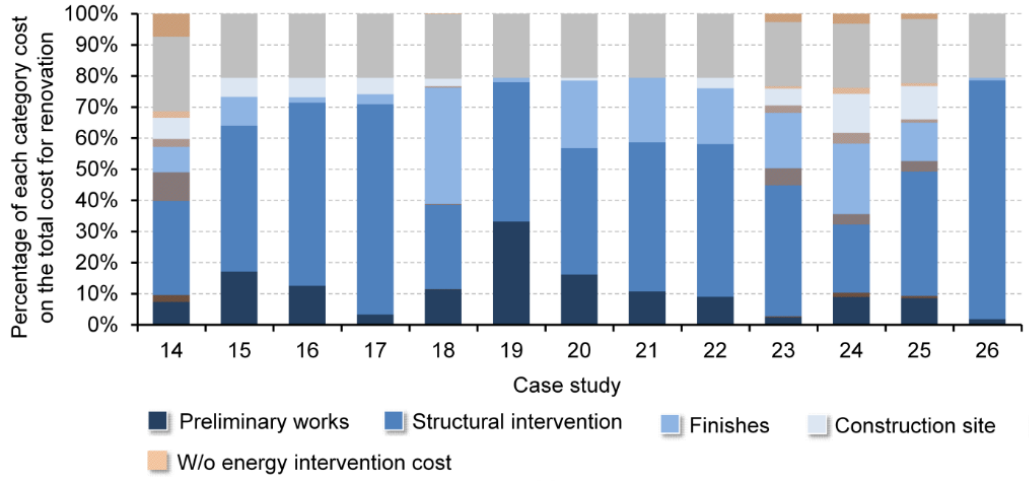
Average cost ratios per category



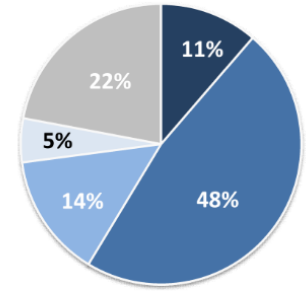
13 RC buildings



Cost breakdown of retrofit activities



Average cost ratios per category



SRTs quantitative classification

Second phase – **Average unit-cost ranges** of selected seismic retrofit technologies for **masonry buildings**

Building	Seismic retrofit technology	Average unit-cost range	SRT details	Disruption time	Energy retrofit
Masonry	Shear walls (outside the building)	**530–910 €/m²** of vertical area of wall **510–880 €/m²** of vertical area of wall	Steel braced shear wall (+ foundations) RC shear wall (+ foundations)	✓ Low	✓ Full compatibility
	Strengthening of vaults (extrados solutions)	**350–415 €/m²** of vault plan **365–420€/m²** of vault plan	UHTSS strips and mortar layer FRC matrix coatings	**(x)** High	✓ Full compatibility
	Continuity of masonry walls	**200–235 €/m²** of vertical area of wall	Partial replacement of external leaf	**(x)** High	Possible driver
	Strengthening of masonry walls with structural coatings or steel bracings	**220–280 €/m²** of vertical area of wall **230–240 €/m²** of vertical area of wall **340–400 €/m²** of vertical area of wall	Steel bracing plates FRM system UHTSS strips	**(x)** High (Internal wall or double faces of perimeter wall) ✓ Low (External face of perimeter wall)	✓ Full compatibility
	Improvement of masonry quality	**80–90 €/m²** of vertical area of wall **225–315 €/m³**	Repointing of masonry walls Injections of three leaf walls	**(x)** High	✓ Full compatibility
	Roof diaphragm	**135–225 €/m²** of roof area (Church) **195–300 €/m²** of roof area (Residential bldg)	Plywood panels and perimeter steel chords	✓ Low	✓ Full compatibility
	Floor diaphragm	**175-240 €/m²** of floor area (Residential bldg)	Plywood panels and perimeter steel chords	**(x)** High (Intrados) Medium (Extrados)	✓ Full compatibility
	Perimeter ties	**50-70 €/m²** in plan (Church) **90-110 €/m²** in plan (Residential bldg)	Steel perimeter ties (at sight)	Medium	Not applicable
		125-135 €/m of strip length (Church)	Galvanized UHTSS perimeter strips		

SRTs quantitative classification

Second phase – **Average unit-cost ranges** of selected seismic retrofit technologies for **RC buildings**

Building	Seismic retrofit technology	Average unit-cost range	SRT details	Disruption time	Energy retrofit
RC	Base isolation	**2500-3000 €/m²** of ground floor area	Cut of pillars	Medium	Possible driver
	Shear walls (outside the building)	**530–910 €/m²** of vertical area of wall **510–880 €/m²** of vertical area of wall	Steel braced shear wall (+ foundations) RC shear wall (+ foundations)	✓ Low	✓ Full compatibility
	Floor diaphragm	**155-230 €/m²** of floor area (Residential bldg) **275–350 €/m²** of floor area (Residential bldg)	RC slab (50-60 mm-thick) FRC slab (25 mm-thick)	**(x)** High (Intrados) Medium (Extrados)	✓ Full compatibility
	Local strengthening of RC elements: column	**235 €/m²** of coating-covered vertical area **330–370 €/m²** of coating-covered vertical area **350–380 €/m²** of wrapped vertical area **340–360 €/m²** of vertical area	RC coating (40 mm-thick) FRC coating (20-40 mm-thick) FRP wrapping Steel jacketing (L-profiles at the corner and plates)	**(x)** High	Possible driver
	Local strengthening of RC elements: beam-to-column joint (outside)	**270-300 €/m²**	Quadraxial CFRP strips	✓ Low	Possible driver
	Exoskeleton (Shear wall)	**250–580 €/m²** of vertical area of building **215–405 €/m²** of vertical area of building	Steel braced shear wall exoskeleton (+ foundations) RC shear wall exoskeleton (+ foundations)	✓ Low	✓ Full compatibility
	Exoskeleton (Shell)	**145–345 €/m²** of vertical area of building **165–345 €/m²** of vertical area of building	Steel diagrid (+ foundations) X-lam panel box structure (+ foundations)	✓ Low	✓ Full compatibility

3. Energy retrofit technologies and ranking

Energy retrofit technologies

Energy retrofit technologies (ERTs)

ACTIVE

Applicable to **energy system**

Benefit

Improvements to heating, ventilation and air conditioning **(HVAC) systems**, electrical lighting, etc, **directly** reducing energy consumption

PASSIVE

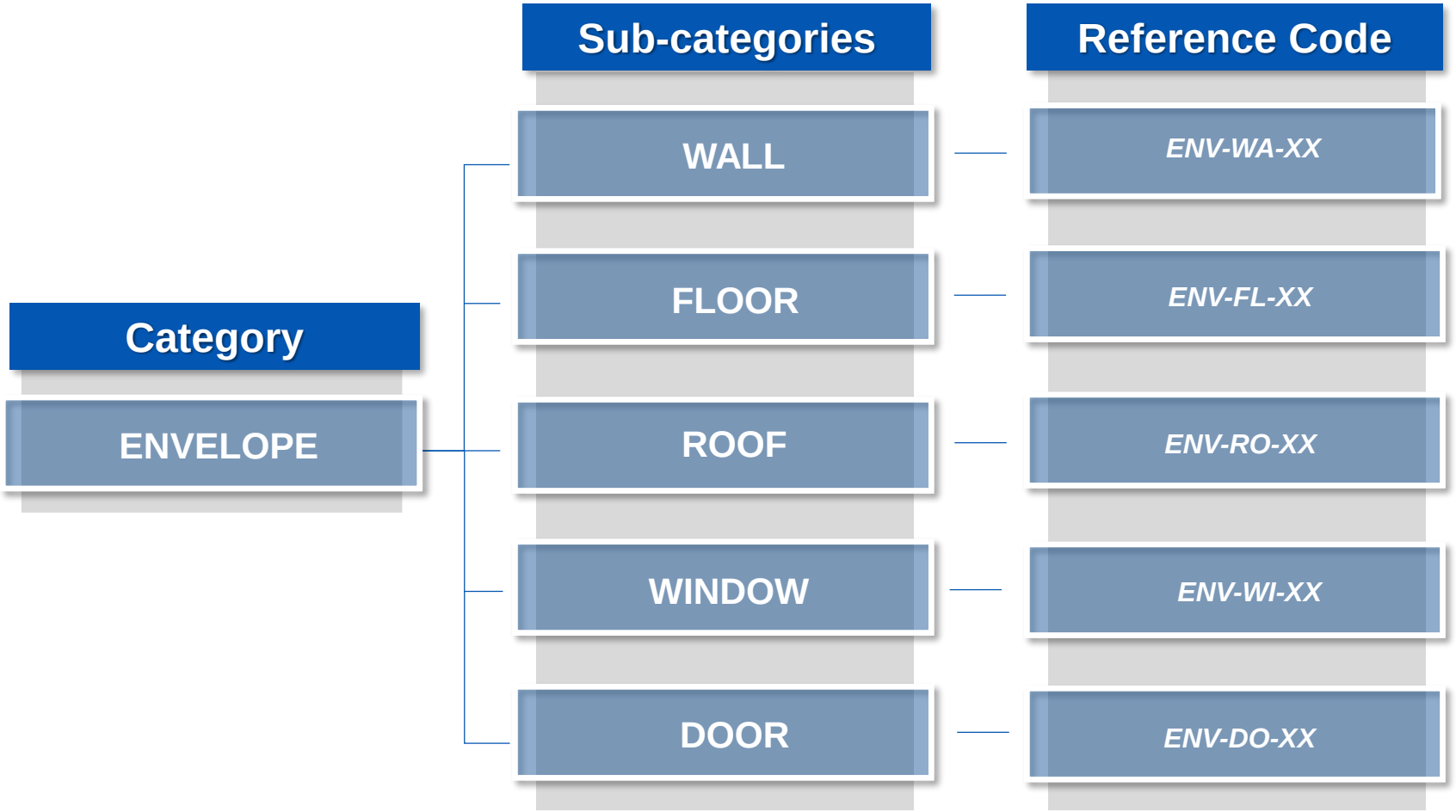
Applicable to **building envelope**

Benefit

Control **heat loss and gains,** reducing energy need of a building and **indirectly** energy consumption

Energy retrofit technologies

20 PASSIVE ENERGY RETROFIT TECHNOLOGIES (available in the construction market)



Energy retrofit technologies: walls

WALL

Code	Passive ERT	Main characteristics	Benefit
ENV-WA-01	**ETICS** - External Thermal Insulation Composite System	**Multi-layer system**: fastening to the supporting wall, insulation panel, reinforcement layer, external plaster.	**Improve thermal insulation .** **Global warming reduction** **Urban effects island mitigation**
ENV-WA-02	**External insulation** of party walls with **polyurethane spray foam**	Polyurethane foam sprayed on the wall; protected with a layer of paint or 1000 kg/m^3 polyurethane elastomer.	
ENV-WA-03	**Prefabricated systems** for external insulation of facades	**Prefabricated Units for External Wall Insulation,** comprising external skin, insulating layer and fixings devices. No gap between insulation and skin.	
ENV-WA-04	System of façade refurbishment with **cement panels sheathing**	**Exterior facade cladding:** metal support structure to which **cement panel** is screwed and the resulting chamber is insulated creating or not a ventilated facade	
ENV-WA-05	System of **interior insulation** by cladding	**Thermal insulation** on the **inside.** Compared to ETICS: reduction of living area and unsolved thermal bridges.	
ENV-WA-06	**Injection** of thermal insulation material **in air chambers**	**Injection** of thermal insulation material **by pressure** in cavities **through previous perforations.** Injection possible from both inside and outside	
ENV-WA-07	**Ventilated Façade**	**Outdoor cladding** solution, allowing **air circulation** between the supporting wall and the cladding material.	
ENV-WA-08	**Green Façade**	**Vertical structures** with **plants** or **greenery** attached to them, also presenting irrigation systems.	

Energy retrofit technologies: floors and roofs

	Code	Passive EET	Main characteristics
FLOOR	ENV-FL-01	**Insulation systems** on the **inside**, over slabs or floors, with existing pavement	**Thermal insulation** over an existing floor by using different material panels (XPS, mineral wall, etc.).
ROOF	ENV-RO-01	**External** insulation system for **flat roofs**	**Multi-layer system** for existing roof: thermal insulation panels (XPS, Mineral wool), properly fastened, a waterproofing layer, auto-protected from puncturing.
	ENV-RO-02	**External** insulation system for **sloping roof**	**Multi-layer system:** Base support, vapour barrier, 1st row of wooden strips, insulation, waterproofing layer, 2nd row of wooden strips, 3rd row of strips perpendicular to the second-row ones below, coverage (tiles).
	ENV-RO-03	**Internal** insulation systems on **non-habitable spaces**	Mineral/Rock wool batts or rolls onto the floor pitch of the attic.
	ENV-RO-04	**Internal** insulation systems over **dropped ceilings**	Insulation (batts of mineral/rock wool) on the inside by enclosing it into the structure of a dropped ceiling.
	ENV-RO-05	**Cool roof**	Reflect more sunlight and absorb less heat than a standard roof (65,5°C). Made of **highly reflective** type of paint or tiles or shingle.
	ENV-RO-06	**Green roof**	Roof covered by a **layer of vegetation**: waterproofing, soil, and plants. Two types: **extensive** and **intensive**.

Benefit

Improve thermal insulation .

Global warming reduction

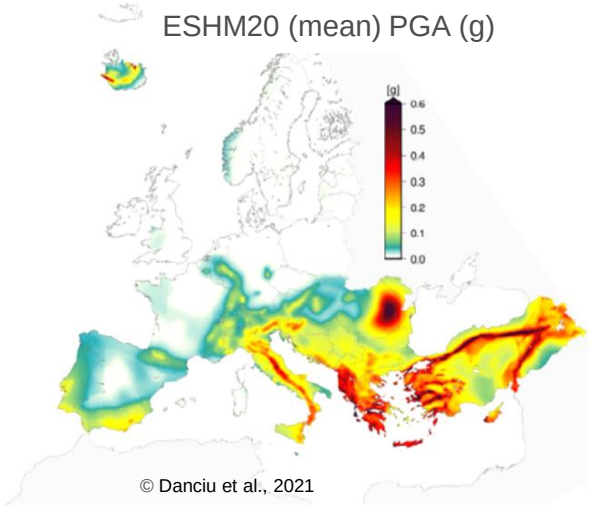
Urban effects island mitigation

Energy retrofit technologies: windows and doors

	Code	Passive EET	Main characteristics	Main benefits
WINDOW	ENV-WI-01	Window replacement	Responsible to up to 25-30% of heating and cooling energy use throughout the year. **Replacing** old, inefficient window assemblies with newer ones.	Reduce air inflitration
	ENV-WI-02	Window film	Typically **three layers**: adhesive layer against the glass, polyester film layer, and scratch-resistant coating. Block against solar heat gain and protect against glare and UV.	Control solar gains
DOOR	ENV-DO-01	Door replacement	Materials such as insulated metal or fiberglass are recommended.	Reduce air inflitration
	ENV-DO-02	Adding a vestibule	Vestibules help reduce the heating and cooling load related to exterior doors opening and closing.	
	ENV-DO-03	Weatherstripping	Weatherstripping can reduce the energy losses due to air leakage. Many different materials, such as foam rubber, EPDM rubber, felt, bent metal, and plastic can be used for this scope.	

Compatibility of ERTs with EU building stock

Geographical focus



TARGET REGION	
Target country (High seismic hazard)	Target country (Moderate seismic hazard)
1. Bulgaria	1. Austria
2. Croatia	2. France
3. Cyprus	3. Portugal
4. Greece	4. Spain
5. Italy	
6. Romania	
7. Slovenia	

Building stock analysis

Building use

Building age

Construction and thermal characteristics - considered to estimate building share to which the ERTs could be applied (construction compatibility) with different level of thermal performance compatibility (low, medium, high).

Fully construction compatibility with residential building stock

- Wall and floor insulation technologies
- Internal insulation of roofs
- Cool roofs
- Window and door replacement and weather-stripping
- Window films

Example

External thermal insulation composite system (ETICS) – Wall

Thermal performance compatibility*	High	Medium	Low
Apartment buildings	12%	80%	8%
SFH	12%	80%	8%
MFH	10%	58%	32%

* Thermal performance compatibility = qualitative thermal performance improvement an ERT may provide to the examined building stock

Insulation of external wall air chambers resulted the **less compatible** technology (as it can be implemented only in cavity walls).

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Ranking of selected ERTs

- 11 energy retrofit technologies Ranking -

Attractiveness for potential investment to implement **integrated seismic and energy retrofit** of residential buildings in the target region

- **Technologies** analysed according to a set of **indicators:**

  Unit cost of implementation
  Unit energy saved
  Unit cost-effectiveness
  Disruption time
  Life-span
  Generated waste

- **Multi-criteria decision analysis** (AHP method)

Unit cost of implementation Unit energy saved	**Highly important**
Life-span Generated waste	**Modestly important**

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**	

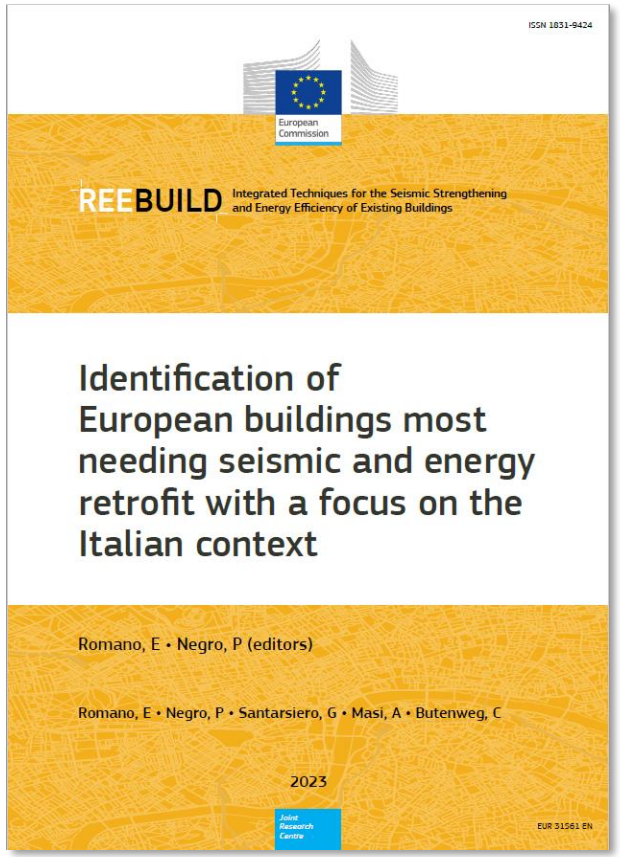
Concluding remarks

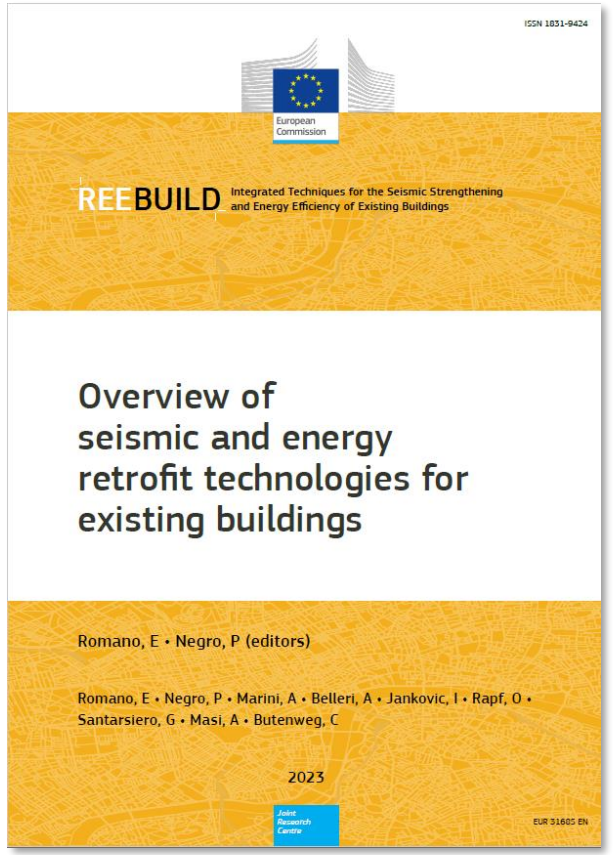
Conclusions

- EU **masonry** and **RC buildings** would **benefit from combined seismic and energy retrofit**, considering that 60-70% of buildings examined in selected EU countries were built with no or low seismic design and energy efficiency requirements.
- A catalogue of **seismic renovation technologies** was provided along with their classification in terms of cost with **exoskeleton** resulting a **promising solution** from a life cycle thinking perspective.
- **Average unit-cost ranges** (Italian market-dependent) were proposed as useful supporting tool in the preliminary phase of a renovation project to estimate budgets, enable project financing.
- A catalogue of **energy renovation technologies** at building component level was considered with **external insulation for walls** resulting as **highly compatible** with the EU building stock.
- Energy renovation technologies were ranked in terms of **attractiveness for combined renovation** with internal insulation of roofs and external walls resulting highly attractive due to low cost, low generated waste and high performance.

Publication

JRC Technical and Science for Policy reports





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Thank you

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