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Integrated techniques for the seismic strengthening and energy efficiency of existing buildings

Pilot Project Workshop
16–19 November 2020

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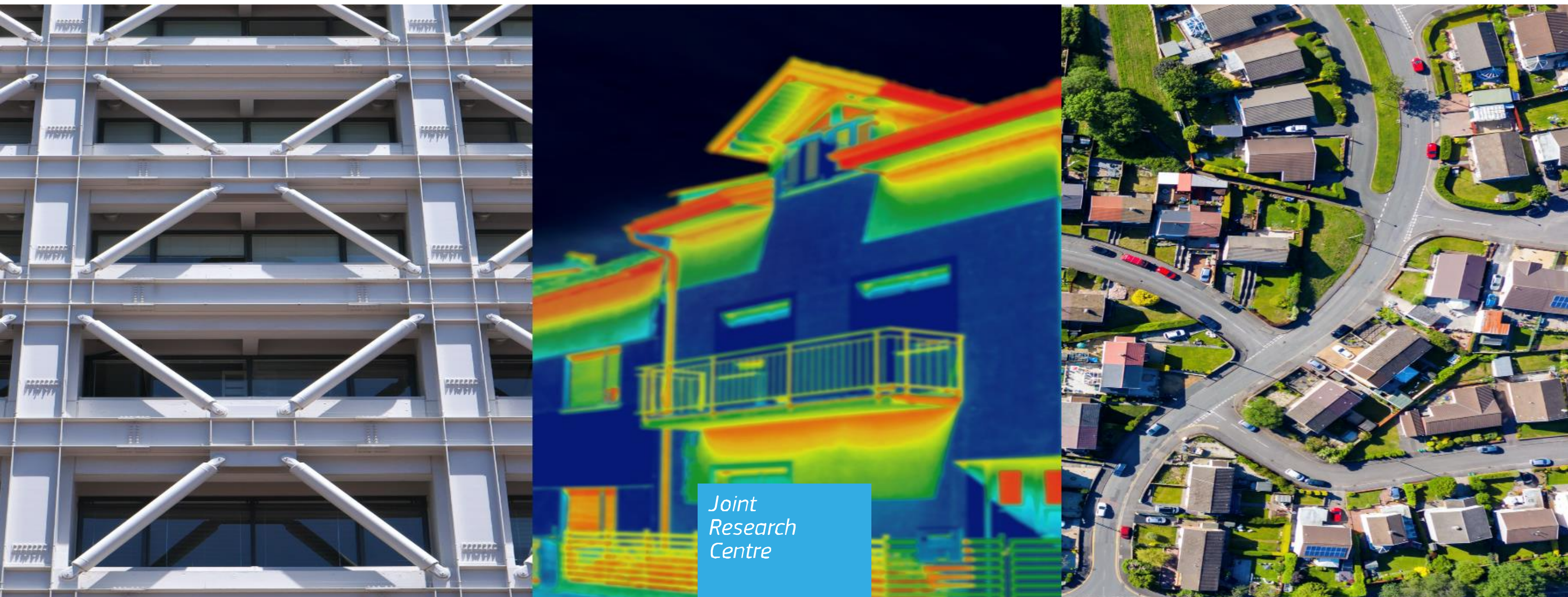

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Abstract

The report summarises the work prepared to date within the scope of the Pilot Project “Integrated techniques for the seismic strengthening and energy efficiency of existing buildings”, and presented during a Joint Research Centre (JRC) homonymous workshop that took place online on 16–19 November 2020. The objective of the midterm workshop was to improve stakeholder understanding on critical energy efficiency and seismic safety upgrades to ageing buildings, and to collect feedback on the Pilot Project. The workshop, spread along six different sessions, started with interventions from a Member of the European Parliament, a Member of the European Committee of the Regions, European Commission officers, and representatives from public authorities and a professional association. More than 30 technical presentations were delivered by JRC Pilot Project team members and external experts, complemented by discussions and polls that were organised throughout the workshop sessions. The report provides summaries of the presented work by action of the Pilot Project along with expected developments and issues that deserve further consideration. Topics include technologies for seismic, energy, and combined upgrading of existing buildings, methodologies to evaluate the effect of combined upgrading, regional prioritisation based on multiple indicators, implementing renovation measures, intervention scenarios, outreach activities as well as external activities and projects complementary to the Pilot Project objectives. Issues that attracted the attention of the workshop participants and relevant feedback received through interactive sessions and tools (e.g. discussions, polls, etc.) are further highlighted. The final part of the report is dedicated to the recently launched New European Bauhaus and feedback on the initiative received through relevant polls. Workshop participation statistics and satisfaction survey results indicate a positive reception of this first wide dissemination effort of the Pilot Project objectives and output from a diverse audience of stakeholders.

1 Introduction

1.1 The Pilot Project

The Pilot Project "Integrated techniques for the seismic strengthening and energy efficiency of existing buildings" is a two-year project, entrusted by the European Parliament to the JRC. It is designed and implemented by JRC Safety and Security of Buildings Unit, and financed under the Commission Decision C(2019) 3874 final of 28 May 2019.

The Pilot Project aims to define technical solutions that can reduce seismic vulnerability and increase energy efficiency of existing buildings, at the same time and in the least invasive way. Thereby, increased earthquake resilience and limited environmental impact of buildings is sought by reducing CO_2 emissions and the waste generated through building replacement actions or future earthquake disasters. The envisaged activities have the following main objectives:

— Define the tools and guidelines to reduce, all at once, vulnerability and energy inefficiency of buildings

— Stimulate the use of integrated solutions

— Create awareness about the topic in the aim of prevention

— Increase resilience of built environment to seismic hazard and climate change.

The Pilot Project will provide scientific advice to support the development of an action plan, which shall supplement existing European Union (EU) policies in the field of energy efficiency and disaster risk reduction. The modernisation of the European building stock is central to key priorities of the European Commission. Crucially, the European Green Deal (COM (2019)640) emphasises the need for a buildings' Renovation Wave (COM (2020)662), supported by the establishment of a New European Bauhaus to "bring the European Green Deal closer to people's minds and homes". This will be combined with the implementation of clean and circular economy principles for the construction sector to achieve ambitious energy and greenhouse gas reduction targets by 2030 and a climate-neutral society by 2050. The new Circular Economy Action Plan (COM (2020)98) will also address the revision of the Construction Products Regulation (Regulation (EU) 305/2011). The plans to put the European Green Deal into effect further contribute to the economic recovery following the COVID-19 pandemic.

The integrated retrofitting of buildings can be seen as the nexus between policies encouraging the energy renovation of buildings, as in the Energy Performance of Buildings Directive (Directive (EU) 2018/844), promoting circularity within the building sector, improving the disaster resilience of the EU, as well as protecting cultural heritage. The new idea for a holistic approach to the renovation of buildings behind a future action plan is in line with the Union Civil Protection Mechanism (Decision (EU) 2019/420), with respect to the importance of disaster prevention measures and integration of risk reduction and cohesion policies.

The geographical scope of the project intends to cover EU seismic prone regions. However, it can easily be extended to all EU regions considering the ageing of existing buildings and other hazards, including extreme climatic events. Therefore, all EU citizens are potential beneficiaries of the project.

1.2 Pilot Project actions

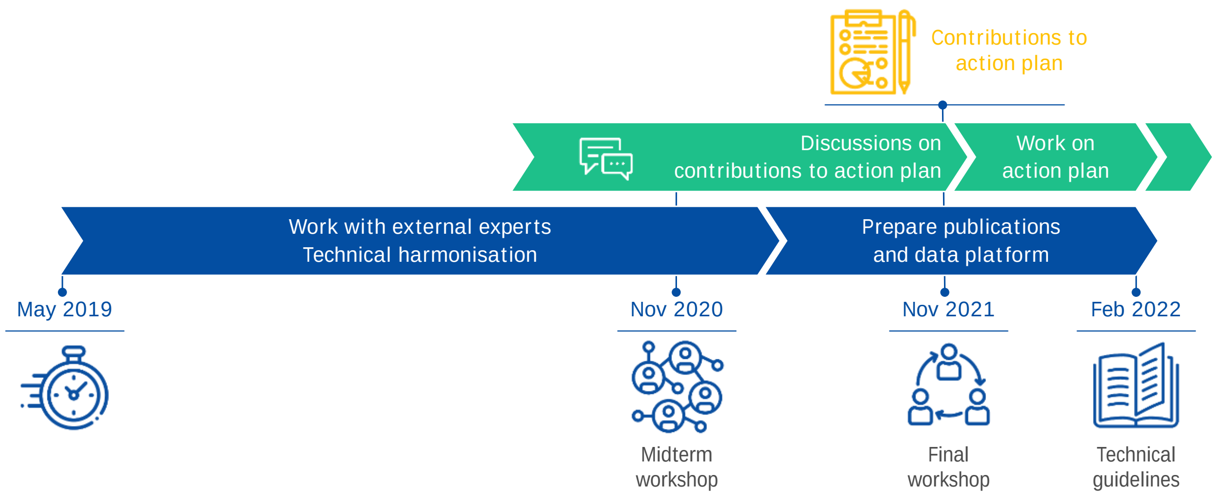
To achieve the Pilot Project objectives, several activities are foreseen. EU buildings requiring upgrading are identified and existing seismic and energy retrofit technologies are assessed. Technologies for combined seismic and energy upgrading of buildings are explored based on available technologies and recent scientific developments in the field. A simplified method for the assessment of economic advantages of the combined intervention is currently under development. It will be applied in case studies of representative types of European buildings retrofitted with the identified solutions. Seismic risk along with socioeconomic aspects are assessed at a regional level throughout Europe; the energy performance of existing buildings will also be evaluated. Such regional assessments are used to identify appropriate intervention scenarios based on their regional impact and highlight the regions where interventions are of higher priority. National, regional and local authorities, industrial associations and expert communities are involved in enquiries and discussions of relevant implementing measures (legislation, incentives, guidance and standards), technologies and methodologies for the combined improvement of seismic and energy performance of existing buildings. The Pilot Project activities have been organised in five main actions and several sub-actions briefly described in the following, while the timeline of the project is summarised in Figure 1.

1. Overview and classification of technologies for seismic strengthening and energy upgrading of existing buildings.
    1.1. Identification of building typologies needing upgrading: classes of buildings corresponding to the most representative typologies regarding both seismic and energy performance will be identified.
    1.2. Review of technology options for seismic upgrading: technology options will be classified in terms of expected seismic safety improvement, cost, and disruption of building occupancy, use of raw materials, and life cycle analysis effects.
    1.3. Review of technology options for energy upgrading: likewise, technology options will be classified in terms of expected energy efficiency improvement, cost, disruption in use, use of raw materials, and life cycle analysis effects.
2. Analysis of technologies for combined upgrading of existing buildings.
    2.1. Review of technology options for combined seismic and energy upgrading: relevant technologies will be reviewed taking into account environmental effects in a life cycle perspective.
    2.2. Analysis of novel technologies for combined seismic and energy upgrading: relevant technologies will be analysed and compared to conventional ones – needs for successful marketing will be defined.
3. Methodologies for assessing the combined effect of upgrading.
    3.1. State-of-the-art review of methodologies for assessing the improvement in seismic safety and energy/environmental performance.
    3.2. Definition of a simplified method for the combined assessment of upgrading.
    3.3. Case studies: representative types of buildings retrofitted with the identified technological options for combined upgrading will be investigated, through implementing the simplified and standard assessment methods.
4. Regional impact assessment and contributions to an action plan.
    4.1. Priority regions: EU regions will be ranked based on seismic risk, energy performance of buildings, and socioeconomic indicators.
    4.2. Implementing measures: legislation, incentives, guidance and standards prescribed in EU Member States regarding buildings' retrofit will be reviewed.
    4.3. Scenarios for interventions: concurrent (i.e. addressing seismic and energy upgrading) and non-concurrent intervention scenarios, considering also replacement of buildings, will be defined. Scenarios will be assessed at the regional level in terms of seismic safety and energy efficiency.
5. Stakeholders' engagement.
    5.1. Involvement of the stakeholders during the project: stakeholders will be involved in enquires on relevant measures, technologies and methodologies. The progress and results achieved will be discussed in two workshops.
    5.2. Dissemination and outreach: visibility of project results, awareness of the need for further measures at European level, and support to the follow-up action plan will be achieved by means of (*a*) a web platform including a repository of all collected/produced material, (*b*) technical and science for policy reports, and (c) public communication material.

1.3 Midterm workshop

To improve stakeholder understanding on critical energy efficiency and seismic safety upgrades to ageing buildings, and to collect feedback on the Pilot Project, the JRC organised a midterm workshop on 16–19 November 2020, held virtually to adhere to COVID-19 measures for events and travel. The workshop aimed to serve as a platform to develop a network for information sharing among stakeholders, gather insight to guide future project actions, and inform participants about the purpose and potential of the project.

Figure 1. Pilot Project timeline



Workshop activities took place over the course of four consecutive days and six different sessions to allow segmented audiences to attend the whole or parts of the workshop according to their interest. Sessions featured scientific teams that contributed research to the Pilot Project and involved interactive activities to maintain a dialogue between participants and presenters and gather audience perspectives. Building off this interaction, session moderators led discussions to clarify issues, gather insights, and exchange ideas among participants. The specific objectives of the Pilot Project objectives can be summarised as follows:

— create awareness among participants of the issue's challenges and opportunities;
— engage stakeholders to create a network for information exchange;
— present the Pilot Project and share the knowledge produced;
— exchange ideas on technical/scientific and policy issues;
— collect feedback on needs, knowledge gaps and expectations to inform efforts in the second phase of the Pilot Project.

On the first day of the midterm workshop, an opening session was held, moderated by Artur Pinto, Head of Unit Safety and Security of Buildings at JRC, including interventions from the European Parliament, the European Committee of the Regions, the European Commission, the Italian Civil Protection Department, the Bulgarian Ministry of Regional Development and Public Works, and the European Council of Civil Engineers (ECCE). Dan Chirondojan, Director of JRC's Directorate Space, Security and Migration opened the event and welcomed speakers and participants, highlighting the critical role of the project towards the modernisation of the European building stock in line with European Commission priorities. Silvia Dimova, Deputy Head of Unit Safety and Security of Buildings and leader of the Pilot Project, presented an overview of the Pilot Project describing the motivation, relevant policy goals, scope, objectives, timeline, actions and sub-actions tasks, along with the expected output. Aris Chatzidakis, ECCE President, presented the ECCE's position paper entitled "The need for integrating structural/seismic upgrade of existing buildings with energy efficiency improvements" (Chatzidakis et al., 2020) and called for a common method for the seismic classification of buildings similar to the energy performance classification. Dimitrios Athanasiou, policy officer in the European Commission's Directorate–General Energy, presented the Renovation Wave initiative (COM (2020)662) introducing its key principles, actions undertaken to boost quality renovations, and focus areas that deserve specific attention, while emphasising aspects of the initiative that address disaster prevention and specifically seismic safety. Ciarán Cuffe, Member of the European Parliament, discussed about the concept of integrated renovation programmes addressing the energy performance of buildings, inclusion of renewable energy services, accessibility, neighbourhood needs, targeted investments to consider societal aspects, the New European Bauhaus, and the opportunity to integrate seismic strengthening of buildings as part of this concept. Mauro Dolce, General Director of the Italian Civil Protection Department, made an intervention to present the features of Superbonus 110 (Law 2020/77), i.e. the Italian tax deduction scheme for energy and seismic upgrades. Mauro Dolce presented, among others, the evolution of energy and seismic upgrading incentives in Italy along with identified implementation challenges and suggestions for remediation. In a similar context, Dima Lekova, Head of Department in the Ministry of Regional Development and Public Works in Bulgaria, presented the Bulgarian legislative measure of technical passports for buildings (Ordinance 5/2006), i.e. a building's record of construction characteristics, maintenance measures, repair terms, and instructions for safe operation. Dima Lekova provided a description of the measure, underlining its values, identified weaknesses along with current and future developments. Tjisse Stelpstra, Member of the Council of the Province of Drenthe, Netherlands, and Member of the European Committee of the Regions, analysed aspects of the Renovation Wave (COM (2020)662) that are of interest to regional and local authorities, including legislative requirements, technical support needs, access to financing, and relevant social dimensions.

1.4 Scope and layout of the report

The Pilot Project will continue to foster the community of policy makers, industry players, experts, associations, and organisations. In this context, this report represents a follow-up to the Pilot Project midterm workshop summarising work prepared so far and reporting main conclusions and feedback received during the workshop. An interactive website, and a future workshop at the Pilot Project's culmination will further support its stakeholder engagement objectives.

Following this introductory chapter, Chapters 2 to 6 present the progress made in Actions 1 to 5, respectively. Summaries of the completed work and future developments within each Action are provided, along with topics discussed and feedback received during the midterm workshop. Chapter 7 provides a brief introduction to the recently launched New European Bauhaus together with relevant feedback on the topic received from participants during the workshop. Main conclusions of the report are summarised in Chapter 8. Finally, Annexes 1 and 2 enclose the midterm workshop agenda and the presentations delivered during the workshop by the JRC Pilot Project team members, respectively.

2 Overview and classification of technologies for seismic strengthening and energy upgrading of existing buildings

The second day of the midterm workshop on the Pilot Project was devoted to Action 1 "Technology options for seismic and energy upgrading of existing buildings", coordinated by *Paolo Negro* (Action Leader) and *Elvira Romano*. The idea behind the Action 1 session was to integrate the action progress with previous complementary research projects to provide an overview of the EU background activities in fostering the integrated structural and energy retrofit of buildings. The session was structured in two parts. The first (Section 2.1) was devoted to the complementary background research activities, focusing on a series of contributions related to one of the JRC institutional activities, i.e. the SAFEty and SUSTainability (SAFESUST) project. After the presentation of the SAFESUST objectives and outcomes by *Paolo Negro*, *Alessandra Marini* and *Ornella Iuorio* presented applications of this approach in two follow-up activities in 2015 and 2018. The second part of the session was dedicated to work progress in Action 1, aimed at analysing and disseminating the main results within its three sub-actions (Section 1.2). Details were provided by the corresponding experts in their specific presentations (Section 2.2). A summary of each speaker's contribution from both session parts is presented in the following.

2.1 Part 1: complementary background research activities

The first part of the session opened with *Paolo Negro* briefly introducing the Pilot Project and Action 1 with its three sub-actions. Afterwards, the speaker presented the SAFESUST project aimed at defining a holistic approach to optimise at the same time safety and sustainability (Caverzan et al., 2018). The Sustainable Structural Design (SSD) methodology for building design/retrofit consists of four main steps: (*i*) energy performance assessment, (*ii*) life cycle assessment (LCA), (*iii*) structural performance assessment, and (*iv*) combining outcomes from the three previous steps to a global assessment parameter, i.e. cost. The first step focuses on the assessment of the expected energy consumptions (kWh transformed into cost) during the lifetime of a building. The third step refers to the definition of a cost for safety by applying the simplified Performance-Based Assessment (sPBA) method (Negro and Mola, 2017), based on the consolidated Performance-Based Earthquake Engineering methodology developed by the Pacific Earthquake Engineering Research Center (PEER) (Moehle and Deierlein, 2004), and aimed at obtaining the expected economic losses due to seismic damage. As for the second step, LCA provides environmental performance results in terms of equivalent CO_2 emissions (tons). Thus, setting the price of carbon is fundamental to the calculation of the final assessment parameter. Data on carbon price already exist, but more effort is needed to establish an adequate (i.e. increased) value. The speaker briefly presented an application of the SSD methodology to a reinforced concrete (RC) building designed both as precast and cast-in-situ, in order to validate the method's efficiency in practice (Lamperti Tornaghi et al., 2018). A significant advantage of the SSD method is the capacity to offer a common language to all the design process operators, such as owners, stakeholders, engineers, etc. Finally, the extension of the SSD methodology to urban/regional/national level was presented as a decision-making tool for assessing the best way to allocate intervention resources (Caruso et al., 2018). The possibility to apply the SSD methodology for a broader structural assessment, not limited to seismic actions (Iuorio and Negro, 2020), was also introduced. These developments can be found in specific reports on the JRC Science Hub.

Alessandra Marini presented the major points emerged during the 2015 SAFESUST workshop "A roadmap for the improvement of earthquake resistance and eco-efficiency of existing buildings and cities". This event engaged experts from different disciplines (structural engineering, architecture and city planning, energy, and economy) to discuss the needs to overcome sectoral retrofit of buildings. The following concepts were pointed out: (*i*) eco-efficiency, safety and resilience need to be addressed at the same time for achieving an effective sustainable retrofit, (*ii*) buildings should be conceived as interacting dynamic sub-systems (structural, energy, functional etc.), and (*iii*) integrated multidisciplinary retrofit approach is envisaged. The speaker underlined that the quite low rate of EU buildings' renovation derives from different barriers such as intervention cost, execution time, inhabitants' relocation. The adoption of a life cycle thinking (LCT) approach for retrofit projects becomes an effective multi-performance methodology aimed at maximising structural and environmental/energy performances of a building during its entire life cycle—from cradle to grave—by reducing costs and overcoming renovation barriers. A new approach of conceiving buildings' retrofit projects, focusing on the various stages of their life cycle, needs to be defined. On the one hand, the approach envisages the use of sustainable and eco-efficient materials for reducing the environmental burden at the early stage of the retrofit design, and on the other hand the promotion of external interventions and the use of prefabricated elements at the construction stage, removing the barrier of residents' relocation. During the operation phase, it is fundamental to minimise impacts and costs; therefore, the retrofit project should ensure an adequate structural performance of the retrofitted building in case of a seismic event (e.g. preventing collapse). It is also essential to assess the post-earthquake usability of the building, through a careful damage control of structural and non-structural components, to guarantee an effective repair with a consequent improvement of resilience, and reduction of both building's downtime and expected annual economic losses. As for the end-of-life stage, the possibility to easily disassemble the structural and non-structural components, facilitating both elements' reuse and material's recycling with a potential reduction of construction and demolition waste, should be considered. Finally, the speaker demonstrated that LCT criteria can be addressed for the design of innovative integrated retrofit technologies. A retrofit system consisted of a second skin with insulated timber panels was presented as an effective example. It was developed within the Italian AdESA project for the integrated energy, seismic, and architectural retrofit of existing buildings. The specific technology ensures a minimum impact during the entire life cycle of the retrofitted building, due to the prefabrication of panels, and their ability to be disassembled and completely recycled. It is also characterised by standardised connections which can be easily replaced after a seismic event. This technology was recently applied to a 70's gym building in Brescia (North Italy) and allowed the existing structure to be upgraded to high energy efficiency and seismic safety classes according to the Italian classification at a cost of 380 €/m^2. Another advantage of this solution is the execution time (i.e. 4~5 months involving a team of three workers). In conclusion, the adoption of the SAFESUST approach based on LCT represents an opportunity to address building renovation in an integrated way, fostering safety and resilience of cities and communities. Further details are provided in Caverzan et al. (2016).

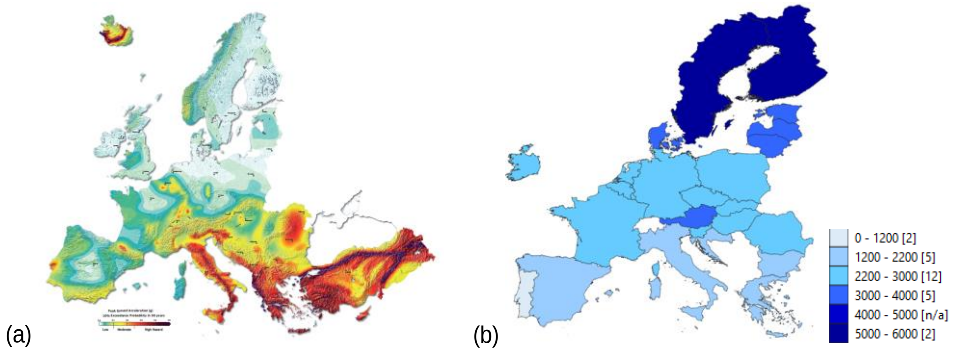
Ornella Iuorio provided a summary of the main outcomes derived from the 2018 SURECON workshop "A roadmap for a SUstainable integrated REtrofit of CONcrete buildings". In the workshop, approaches to increase safety and energy efficiency of existing buildings were discussed, drawing special attention to concrete buildings. Beyond the most common RC frame typologies, the workshop focused on large panel system (LPS) buildings, which were conceived in the former Soviet Union during the 50's, becoming widespread in the UK and Eastern European countries between the 60's and the 70's. This class of building was associated with two catastrophic events in the UK: the partial collapse of the Ronan Point building in 1968 due to a gas explosion, and the catastrophic fire event of the Grenfell Tower in 2017. The speaker underlined that the latest disaster shocked public opinion because a renovation project took place only a decade before the fire disaster. Thus, it has demonstrated the urgent need of an integrated retrofit to avoid economic and human losses. The workshop was conceived as a multi-player event with four sessions (i.e. structures, energy, sustainability and case studies) in order to enable a multidisciplinary discussion. The main outcome of the workshop was the importance of the coordinated contribution of all the stakeholders involved in a building retrofit process, such as engineers, architects, planners, economists, and the public. In the structural session, innovative techniques with steel systems were identified as effective measures for enhancing robustness and resilience of concrete buildings during their life cycle. As for the energy and sustainability sessions, the common goal of achieving decarbonised cities was reflected on the growing interest in low-carbon measures, mainly passive strategies, integration of renewable energy sources and efficient energy management systems, as well as the need for a holistic design approach to achieve sustainability. The speaker concluded that the global vision of the workshop was recognised in the necessity of developing an approach for improving structural resilience and energy efficiency by balancing solutions according to life cycle scenario analysis. Furthermore, the way forward was identified based on three main points: (*i*) development of new codes based on integrated design approaches, also focusing on sustainability and resilience, (*ii*) introduction of sustainability management to address the different competences, and (*iii*) development of economic incentives by introducing a payback time for the structural retrofit. Further details are provided in Iuorio and Negro (2020).

2.2 Part 2: Work progress in Action 1

The second part of the session opened with *Elvira Romano* providing a summary of the work progress in Action 1; further details were provided by the following experts' presentations.

Christopher Buteweng presented the main outcomes of sub-action 1.1 regarding the prioritisation of EU building typologies needing seismic and energy upgrading. The distribution of dwellings in both residential and non-residential buildings by age of construction, building typologies, and surface area for the EU Member States (EU27) was firstly presented according to the 2011 population and housing census database. It was pointed out that 80% of dwellings were built before 1990 and 22% before 1945. Moreover the "Typology approach for building stock energy assessment" (TABULA) and "Network of European research infrastructures for earthquake risk assessment and mitigation" (NERA) projects, were investigated to collect data on building typologies. The speaker underlined that the building stock consists of masonry structures in most of the EU Member States, whereas RC buildings are predominant in some countries, such as Cyprus, Greece and Portugal. The second part of the presentation was devoted to the mapping of the EU territory in climatic zones and seismic exposure. Maps of low, moderate and high seismic hazard zones depending on specific peak ground acceleration (PGA) ranges, according to the European Seismic Hazard Model 2013 (ESHM13) (Giardini et al., 2014), and of six climatic zones in terms of heating degree days (HDD) (Figure 2) were presented. Bulgaria, Croatia, Greece, Italy, and Romania were selected as representative countries characterised by high seismic and climatic exposure. Finally, the speaker focused on the building distributions in terms of age of construction and construction material existing in such seismic hazard–climatic zones within the selected EU countries. It was concluded that the majority of buildings in these countries consists of masonry constructions except for Greece, where the RC construction is predominant. In general, RC became the main construction material after 1960, with very few examples before 1945. However, in Bulgaria, despite the high seismic hazard levels, masonry represents the main construction material. Thus, building typologies most needing upgrading are both masonry and RC buildings.

Figure 2. (a) European seismic hazard map (Giardini et al., 2014) and (b) European climatic zones map in terms of HDD



Source: Eurostat data, 2019

Angelo Masi made a short introduction on masonry and RC building typologies most needing upgrading in Italy. *Giuseppe Santarsiero* first underlined that masonry and RC buildings in Italy account for about 87% of the residential building stock based on the 2011 census. According to Italian building distributions by period of construction and the evolution of both Italian seismic zonation and seismic codes, more than 90% and 55% of existing masonry and RC buildings were constructed without seismic provisions, respectively. The first building code for masonry was issued in 1987, while seismic provisions for RC buildings were issued after the catastrophic Irpinia–Basilicata earthquake in 1980. Moreover, 88% of residential buildings are not compliant with modern energy efficiency provisions because a stringent energy efficiency code was issued in Italy only in 1991. In the third part of the presentation, the combination of four seismic with six climatic zones (in terms of HDD) according to the Italian classification, was analysed. Four combined seismic and climatic zones (SCZ) were identified. It was estimated that a high percentage of buildings and population is concentrated in three of the combined zones, considered as priority areas for retrofit interventions. Finally, the speaker pointed out that post-earthquake data were used to define the most widespread masonry and RC building types in each region. The 2012 Emilia Romagna post-earthquake usability inspection data showed that masonry buildings are typically made of clay bricks with thrusting roofs. According to data collected with the AeDES form for usability and damage survey of ordinary buildings in post-earthquake emergency (Baggio et al., 2007), three main typologies of masonry buildings were identified, mainly varying in the type of horizontal structural elements. The typologies are characterised by walls of regular layout without tie rods/beams supporting flexible (e.g. wood) or semi-rigid (e.g. double layer wooden panels) floors, or walls with tie rods/beams and rigid (e.g. RC) floors. As for RC buildings, beyond post-earthquake data, vulnerability assessment studies provided details on typical residential buildings. The speaker pointed out that RC frame buildings are the most widespread RC structural typology (Masi et al., 2015), differentiated among two-storey and four- to six-storey buildings, grouped in three construction periods (i.e. 1950–1975, 1975–1990, and after 1990). Masonry infills also have a crucial role in both seismic and energy performance, thus their evolution was presented.

Andrea Belleri summarised the main findings to date related to sub-action 1.2, carried out with *Alessandra Marini*. Sub-action 1.2 aims to provide a review of standard seismic strengthening technologies by building typologies, and their classification in terms of cost, disruption time and compatibility with energy efficiency measures. The speaker firstly provided a brief overview of standard global and local seismic strengthening technologies. A framework was proposed for the qualitative classification of the identified technologies by assigning scores (from 1 to 5) to selected criteria, such as holistic/integrated compatibility, occupants' disruption, etc. The second part of the presentation was devoted to the quantitative classification of the seismic retrofit measures based on a cost analysis carried out in two main phases. The first refers to the investigation of real seismic retrofit projects, related to RC and masonry buildings in Italy, in order to carry out a cost breakdown of all retrofit activities, such as construction site management, structural interventions, technical expenses, energy upgrading (when foreseen), etc. The cost of the structural intervention was found to be equal to 30% and 40% of the total cost in masonry and RC buildings, respectively. The second phase focused on the use of data from the seismic retrofit projects to estimate the average cost range of selected seismic retrofit measures for masonry and RC buildings. Finally, a comparative assessment of the expected construction cost for three retrofit interventions resulting in the same performance of an existing RC building was presented to perform cost-effectiveness analysis. The proposed interventions refer to shear walls of steel braced exoskeleton arranged in parallel to the façades of the existing building, steel diagrid applied as additional exoskeleton, and cross-laminated timber (CLT) panel shell for a structural–energy–architectural retrofit. Costs' comparison demonstrated that both the total (including energy upgrading) and the structural costs of the second (total cost of 286 €/m^3, structural cost of 121 €/m^3) and third (total cost of 284 €/m^3, structural cost of 119 €/m^3) solutions are lower than the first one (total cost of 309 €/m^3, structural cost of 137 €/m^3).

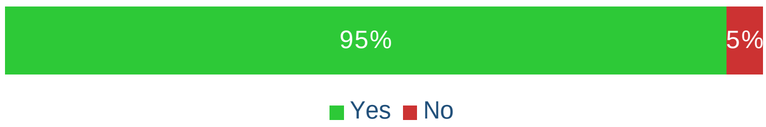
Ivan Jankovic presented the main findings to date related to sub-action 1.3, in which *Oliver Rapf* is also involved. Sub-action 1.3 aims at providing a review of energy efficiency technology (EET) options and their classification. The speaker firstly presented an overview of 20 passive EETs, compatible with seismic retrofit technologies. They were classified by envelope components, i.e. walls (insulation technologies, ventilated façades, green walls), floors and roofs (insulation technologies, green and cool roofs), windows (replacement, vestibule, and weatherstripping), and doors (replacement, films, weatherstripping). In order to assess EETs' compatibility with building typologies, EU countries characterised by high and moderate seismic hazard (according to ESHM13) were selected. The whole group of these countries is referred to as "target region". The building stock in the target region was investigated through the Hotmaps and TABULA projects, focusing on data concerning constructed and conditioned floor areas, number of buildings, construction materials, and thermal performance of building envelopes, related to specific building typologies. These typologies were selected by considering two criteria: building use (single family and terraced houses, multi-family houses, apartment buildings, and non-residential buildings), and building age. Different combinations of these criteria were analysed to estimate the building share to which the identified EETs could be applied. For example, the apartment building typology and the flat roof insulation resulted in no compatibility for 5% of the apartments buildings, while this EET was found to be applicable to 58%, 30% and 7% of the apartment buildings at low, medium and high level of compatibility, respectively. The second part of the presentation was devoted to the classification of EETs according to seven indicators, namely unitary cost of implementation, unitary energy saved, unitary cost-effectivity, disruption time, life span, generated waste, and risk of fire. Finally, selected EETs were ranked based on their attractiveness for a potential investment to implement an integrated seismic and energy retrofit of residential buildings in the target region. A multi-criteria decision-making analysis was carried out through the Analytic Hierarchy Process (Saaty, 1980) by assuming "unitary cost of implementation cost" and "unitary energy saving" indicators as highly important, while "life span" and "generated waste" as modestly important. According to preliminary results, insulation of wall air chambers and internal insulation of roofs were found to be highly attractive EETs for investment. Replacement of doors/windows and prefabricated units for external wall insulation or external thermal insulation composite systems revealed medium and low rank of attractiveness, respectively.

2.3 Action 1 session outcomes and polls

Based on the presentations, participants raised various issues. Regarding sub-action 1.1, main issues referred to the importance of considering seismic risk beyond seismic hazard, and the evolution of seismic codes with a particular reference to the Greek one. It was clarified that seismic risk is crucial to be considered, but within another action of the Pilot Project (i.e. Action 4). It was also underlined that attention will be paid to the information that was pointed out on seismic code evolution in order to include it in the final report of the relevant task. As for sub-action 1.2, main concerns focused on the inclusion of the foundation cost, as well as maintenance/repair cost within the total cost evaluation related to the three proposed seismic retrofit solutions resulting in the same performance of the existing RC building. The cost of foundations was included in the total cost estimation; specifically, the first solution with the shear walls of steel braced exoskeleton was characterised by the presence of micro-piles which contributed to a total cost increase, while the foundation cost was lower for the other two solutions. As for the maintenance cost, it was clarified that only the cost of galvanised coating to protect the steel elements of exoskeleton solutions was considered.

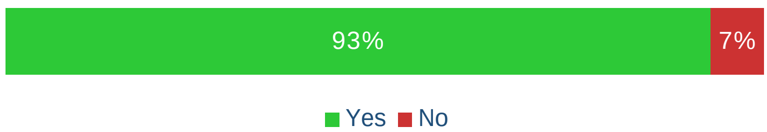
During the session, participants were invited to reply to online polls. Specifically, two questions were related to the New European Bauhaus initiative, thus they are presented in Chapter 7. Two additional questions intended to link the Action 1 theme with the idea of the New European Bauhaus as a multidisciplinary movement to create bridges among different expertise and perspectives. Participants were invited to choose if considering cost, disruption time, life cycle aspects, and technological compatibility is consistent with the goal of bringing together different expertise. In Figure 3, it is demonstrated that the majority of participants agreed with the idea.

Figure 3. Workshop participants' feedback on "Do you think that considering cost, disruption time, life cycle aspects, and technological compatibility is consistent with the goal of bringing together different expertise?"



The second poll was on the potential of the workshop to create synergies with other complementary projects. A very high percentage of participants agreed that the workshop had this potential (Figure 4), thus it represents an opportunity to foster future collaborations and extend networks.

Figure 4. Workshop participants' feedback on "Do you think that this workshop has a potential to create synergies with other complementary projects?"



3 Analysis of technologies for combined upgrading of existing buildings

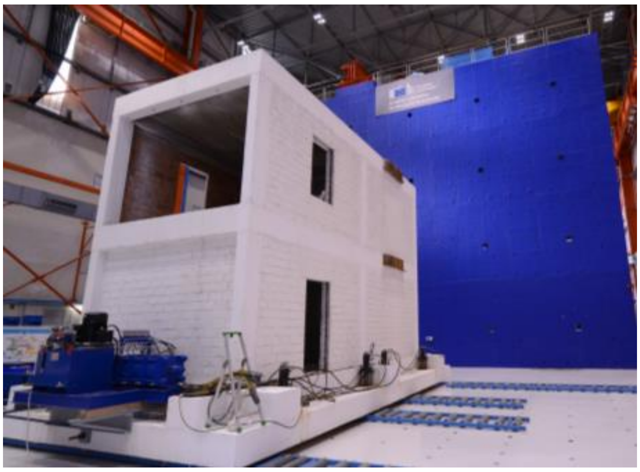
The session on Action 2 presented the work progress on identifying adequate technology options for the combined seismic and energy retrofitting of existing buildings. The day opened with Dionysios Bournas and Daniel Pohoryles presenting complementary JRC institutional activities carried out over the last 3 years, exploring the application of advanced composite materials for combined retrofitting. Specifically, the activities within the projects "Innovative seismic plus energy retrofitting of the existing building stock" (iRESIST+) and "Seismic plus energy upgrading of masonry buildings using advanced materials" (SPEctRUM) were briefly presented. Figure 5 exemplifies the ongoing experimental activity in the iRESIST+ project.

Reference was also made to the collaborative project "Development of textile-reinforced mortar and capillary tube panel retrofitting technology to simultaneously improve seismic and energy performance of the existing buildings" (SEP+), between the JRC and the Korea Construction Engineering Development (KOCED) institute.

3.1 Complementary background research activities on integrated retrofitting

In iRESIST+, the effect of combined seismic and energy retrofitting using textile-reinforced mortars (TRM) combined with thermal insulation was evaluated (Bournas, 2018). Next to the ongoing experimental activity at the JRC's ELSA facility (Figure 5), a series of numerical analyses were carried out, evaluating the effect of combined retrofitting on different building typologies in Italy (Gkournelos et al., 2019). The analysis was expanded to 20 case study cities across different seismic and climatic zones in Europe (Pohoryles et al., 2020). A foresight study up to 2030 was carried out, investigating the impact of different building renovation rates (1%, 2% and 3%) in terms of the reduction of energy consumption and carbon emissions, and seismic losses as well. The combined retrofitting scheme was shown to lead to significant energy performance improvements, with reductions in energy use for heating and cooling up to 32.5% for the 3% renovation rate. The combined retrofitting was found cost-effective for moderate and high seismic areas. A combined monetary metric, the expected annual losses, was used in this evaluation. In zones with moderate seismic hazard, the combined interventions presented financial benefits versus the energy retrofitting alone, measured in terms of payback periods. In zones of severe seismic hazard, the payback period of the combined interventions showed a significant reduction when compared to separate seismic and energy retrofitting payback periods.

Figure 5. iRESIST+ experimental prototype at JRC's European Laboratory for Structural Assessment (ELSA)



3.2 Experts' presentations

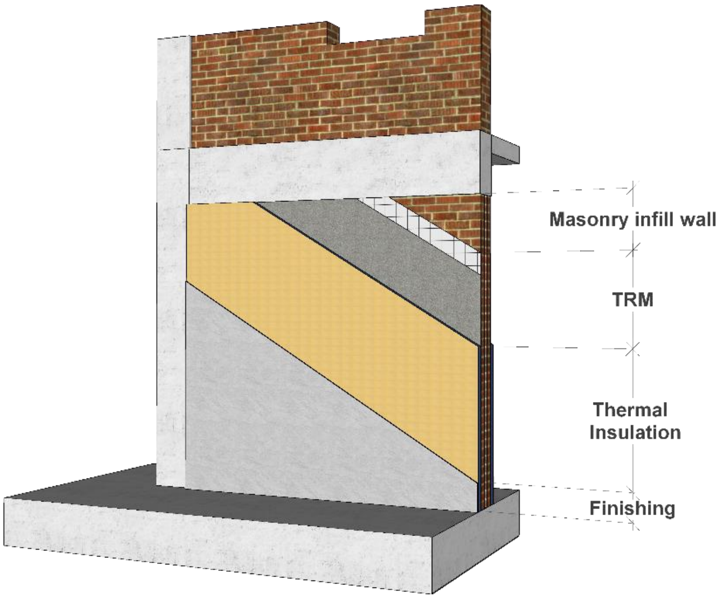
Presentations from all five experts of Action 2 were delivered during the workshop. In a first part, novel scientific developments and advanced solutions in the field of seismic upgrading of existing buildings were identified and their effectiveness was discussed. Both local and global techniques were presented by *Thanasis Triantafillou* for RC, masonry, steel and timber buildings. The possibility to combine various techniques was highlighted, addressing the specific characteristics of buildings, so that an economic strengthening scheme can be designed. The overview of novel seismic retrofit techniques for RC buildings encompassed composite materials (TRMs, fibre-reinforced polymers (FRPs) and hybrid solutions), novel bracing solutions (including diagrid exoskeletons), isolated or strengthened infill walls, as well as base isolation (e.g. Figure 6) and energy dissipation devices. For masonry buildings, FRP and TRM retrofitting of walls, and techniques for global integrity enhancement were presented, while additional energy dissipation devices were regarded as less common. These were in turn presented in-depth for steel buildings, including various types of metallic yield dampers, shape-memory alloy dampers, as well as active and hybrid dampers. Finally, for timber structures, local measures including FRP strengthening of walls, carpentry joints and beams were presented. A short overview of advanced materials for integrated retrofitting, encompassing CLT panels (e.g. Margani et al., 2020) and TRM solutions (Triantafillou et al., 2017; 2018; Gkournelos et al., 2020), was also given. Finally, a brief insight on research and standardisation needs for novel technologies was provided, highlighting the difference in the maturity of solutions for RC and masonry buildings compared to steel and timber structures, for which further research is required in terms of retrofitting. Particularly for timber, more research is needed to investigate the compatibility of existing and new material and their fire performance.

Figure 6. Base-isolation of a residential building in L'Aquila, Italy (courtesy of D. Pohoryles)

Bjørn Petter Jelle presented advanced thermal insulation materials for energy upgrading of existing buildings. Emphasis was put on research into novel materials and pathways to their development. The potential of advanced materials to create extremely thin thermal insulation layers, required to match today's low heat transmittance requirements and even stricter future requirements, was discussed. Advanced insulation materials and solutions including vacuum insulation panels, gas-filled panels and aerogels were presented. However, these materials and solutions are still under further scientific development, in order to reduce costs and improve efficiency, and as such, they are far from being widely found on the market. Developments include research into aerogel incorporated mortars for cost reduction by decreasing the quantity of the high-cost aerogels, while aiming to maintain low values of thermal conductivity and adequate mechanical characteristics (e.g. Ng et al., 2016). Next to state-of-the-art thermal insulation materials, concepts for future high-performance thermal insulation materials were introduced, with a focus on different categories of nano insulation materials (Jelle et al., 2010). Experimental advances in their developments were highlighted.

Two sessions on combined retrofitting technologies followed. *Francesca da Porto* first highlighted the financial, organisational, and technical barriers for combined retrofitting. Next, she presented the opportunities offered by adopting combined retrofit solutions, including interventions for the exterior walls of buildings, their openings (fenestration), as well as building floors. The solutions were assessed in terms of their potential for improving the thermal properties and seismic capacity of buildings, together with the level of invasiveness of interventions (low, medium, high), downtime, need for resident's relocation and costs. Engineered exoskeletons were found to require low downtime and result in high seismic strengthening and energy efficiency improvements. However, they are highly invasive and require new foundations to be built. Moreover, their suitability does not extend to heritage structures. The replacement of existing envelope elements with better-performing materials (e.g. da Porto et al., 2020) as well as integrated interventions on existing building envelopes, such as TRM and thermal insulation in Figure 7, were deemed to have higher downtime, with potential need for resident relocation. Nevertheless, they have the potential for improving the global behaviour without the need for new foundations. While replacing the existing envelope would only be feasible for RC buildings, integrated interventions on existing building envelopes (e.g. TRM + thermal insulation) can also be effective for load-bearing masonry walls. Timber-panel based solutions for masonry and RC buildings were presented as potentially environmental-friendly and easily prefabricated solution for integrated retrofitting, however coming at a higher price and with a strong visual (positive/negative) impact on the façade. Finally, seismic strengthening of openings together with improved window fixtures, as well as combinations of seismic strengthening and thermal insulation for horizontal diaphragms were presented. The solutions included stiffening of floor slabs and integrating insulation and ventilation layers on the roof structure.

Figure 7. Combined seismic and energy retrofitting with TRM and thermal insulation (Pohoryles et al., 2020)



Giuseppe Santarsiero discussed combinations of seismic and energy retrofitting technologies in terms of their level of invasiveness, noting that the higher the invasiveness (and cost) of the intervention, the higher its effectiveness. To achieve adequate combined solutions, the level of invasiveness of the two interventions should match. For instance, a local seismic intervention comprising strengthening of the beam-column joints with FRP can be combined with roof insulation, installation of thermostatic valves and windows replacement, so as to achieve a low level of disruption and down-time. On the other end of the spectrum, global interventions, like seismic isolation or insertion of dissipative braces which can strongly modify the seismic behaviour of the building, come with a significant disruption of the building occupancy. Energy interventions can then be extended to the use of insulation material on the building façade together with the replacement of heating/cooling mechanical systems with more efficient ones. Finally, fully integrated techniques aim to achieve energy and seismic performance improvement at once, with a single high-engineering system or material. Such systems will need more in-depth conception but may be easier to be applied in real life interventions than combinations of separate interventions, since they are all-inclusive systems, hence reducing down-time and labour-costs. A review of fully integrated retrofit technologies, i.e. the use of single systems or materials to guarantee both the required seismic and energy performance, highlighted three main research directions: (*i*) exoskeleton/double-skin interventions (e.g. shell or wall systems), (*ii*) replacement of envelope elements by higher performance elements (e.g. CLT panels), and (*iii*) improvement of envelope elements to achieve higher energy and seismic performance (e.g. TRM combined with thermal insulation). The presentation was concluded with a brief analysis of costs based on previous experience from post-earthquake interventions after the 2009 Abruzzi earthquake (Dolce and Manfredi, 2015).

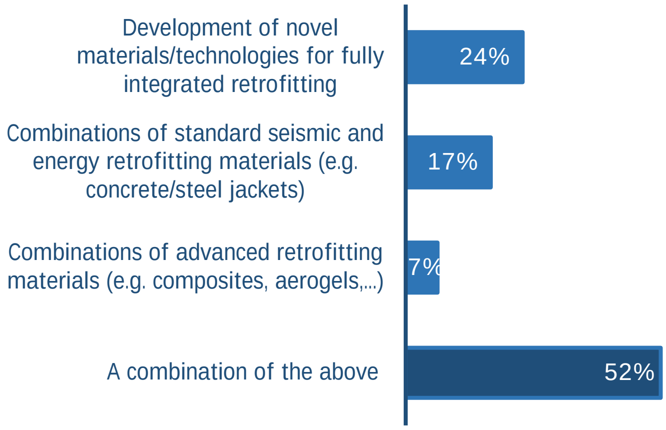
Finally, *Daniel Oliveira* delivered a very timely presentation on technologies, assessment methods and guidelines for the improvement of cultural heritage buildings (CHB), that closed the round of presentations. The presentation highlighted the diversity and values of cultural and build heritage, and the importance of considering authenticity in conservation practice. With half of the World Heritage sites located in Europe, an emphasis on their preservation is needed to protect them from long-term degradation, but also extreme events including earthquakes, flooding and fires. The main challenges in safeguarding CHB were presented, highlighting the need to maintain them without losing their heritage value. To achieve adequate interventions on CHB, modern approaches in data collection, diagnosis and monitoring, as well as structural assessment through advanced modelling were highlighted. Emphasis was put on design codes, guidelines and recommendations, which are sparse, but all stress the importance of a minimum intervention approach when working in structural conservation. Minimum intervention techniques for seismic strengthening include steel ties, connections and improvements of the horizontal diaphragms, grout injections and inorganic matrix composites (e.g. TRMs).

3.3 Discussions, polls and outcomes

The discussion covered the topics of thermal insulation materials and their potential to address other aspects (e.g. fire, sound isolation), as well as phase changing materials and thermal inertia. Regarding standardisation for novel seismic retrofitting technologies, it was noted that well-established and generally accepted research results and computational tools typically precede by several years the adoption of state-of-the-art knowledge on standards. The effectiveness of different combinations of TRMs with thermal insulation materials was discussed, including evidence from previously performed experimental tests on this topic. Finally, the topic of exoskeletons was also discussed, with questions on the feasibility of the solution for different building types, the issues on connecting exoskeleton systems on old buildings' envelopes, as well as the impact on the weight of the structure.

The discussion was complemented by a wide participation in the polls. Following the presentation on combined retrofitting technologies, the audience was asked to voice their opinion on the most promising avenues for integrated upgrading (Figure 8). The majority of participants replied that they lie in a combination of existing materials, novel materials, together with the development of new materials/technologies for fully integrated retrofitting.

Figure 8. Workshop participants' feedback on "In your view, the most promising avenues for achieving integrated retrofitting may lie in:"



As a next step, the information from the expert deliverables will be collected to make a state-of-the-art report on integrated retrofitting technology options. The valuable opinions gained from the discussions and the expert presentations will help in formulating this report. These preliminary outcomes, together with future expert reports, will allow to identify emerging solutions for integrated retrofitting by means of novel technologies and/or integration of advanced materials with adequate thermal and structural properties.

4 Methodologies for assessing the combined effect of upgrading

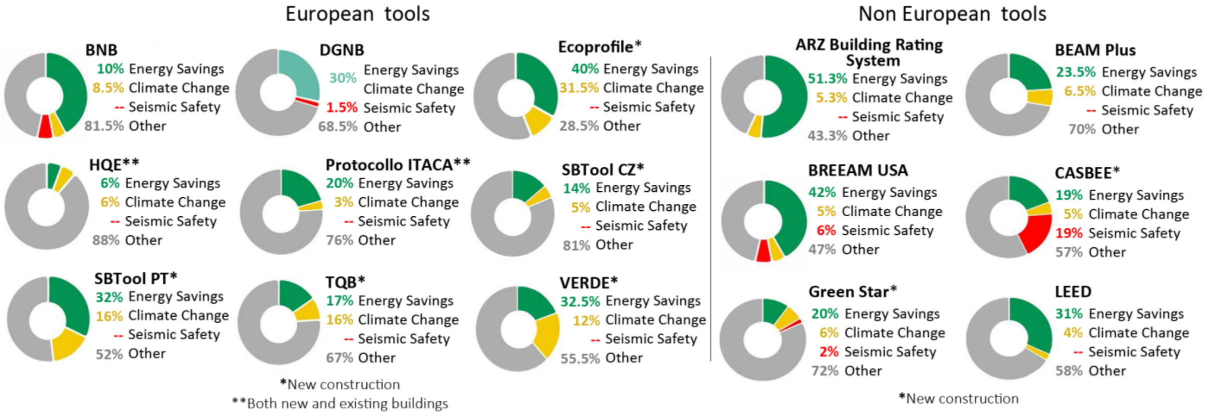
The fourth and last day of the midterm workshop on the Pilot Project was devoted to Action 3 "Methodologies for assessing the combined effect of upgrading", coordinated by *Paolo Negro* (Action Leader) and *Elvira Romano*. The concept of the Action 3 session was to integrate the work progress within this action with complementary ongoing national research projects in order to enlarge the vision of research activities devoted to seismic vulnerability reduction and energy efficiency improvement of buildings. The session was structured in two parts. The first (Section 4.1) was devoted to work progress in Action 3, aimed at analysing and disseminating the main outcomes resulted to date from the three relevant sub-actions (Section 1.2). Detailed results for each sub-action were provided by the corresponding experts in their presentations. The second part (Section 4.2) was devoted to the research activities within the Work Package 5 (WP5) of a 3-year project led by the Network of Seismic Engineering University Laboratories (ReLUIS) and the Department of Civil Protection (DPC) in Italy (ReLUIS–DPC 2019–2021). The coordinators of WP5, i.e. Andrea Prota and Francesca da Porto, focused their presentations on the analysis of low-impact and integrated interventions along with applications to RC and masonry buildings, carried out by various research units involved in the project. A summary of each speaker's contribution is presented in the following.

4.1 Part 1: Work progress in Action 3

The first part opened with *Paolo Negro*, briefly introducing the Pilot Project and Action 3 with its three sub-actions. Subsequently, *Elvira Romano* provided a summary of the work progress in Action 3; further details were provided by the following experts' presentations.

Petr Hájek presented the main findings to date related to sub-action 3.1, which aims to provide a state-of-the-art review of existing methodologies for the combined assessment of upgrading along with their classification. To this end, the speaker provided an outline of the available methods and tools based on an extensive literature review. The investigated methods were grouped in four main categories: (*i*) methods for seismic vulnerability assessment, (*ii*) methods for energy/environmental assessment, (*iii*) methods for sustainability assessment, and (*iv*) methods for combined seismic and energy assessment. Each method/tool was evaluated considering the scope of assessment (i.e. new or existing buildings), essential indicators (i.e. energy use, climate change in terms of associated CO_2 emissions, and natural disaster/seismicity) and their importance, and the country where the method/tool is commonly used. The first category includes seismic loss estimation methods based on a four-step quantitative assessment consisted of hazard, structural, damage and loss analysis. Rating systems are also included, such as the Resilience-based Earthquake Design Initiative (REDi™) (Almufti et al., 2013), and the RELi™ 2.0 rating guidelines for resilient design and construction (USGBC, 2018) which allow users to assess both new and existing buildings (mainly used in the USA). The second category of methods focuses on LCA (ISO 2006a; b) and life cycle energy assessment (LCEA) (Ramesh et al., 2010) based tools to assess the environmental impact and the energy consumption of buildings during the entire life cycle, respectively. The third category includes European and non-European rating systems (Figure 9) used for a qualitative assessment of sustainability based on indicators of different weights. The last category includes the SSD methodology, identified as the only quantitative approach for a combined energy, environmental and structural assessment, measured in economic terms to obtain a single global parameter and facilitate the decision process (Section 2.1). Finally, the expert compared the European and non-European sustainability assessment systems (Figure 9) in terms of the relative weight (expressed as a percentage) of each essential indicator. A global comparison considering all the analysed methods/tools within the four identified categories was also carried out. It was pointed out that existing rating systems are mostly developed for the assessment of new buildings. Energy efficiency and CO_2 emissions are included in all rating systems as "highly relevant" indicators, whereas seismic safety is considered only in a few systems for sustainability assessment with a low weight, such as the German Sustainable Building Council (DGNB) system (DGNB, 2020) in Europe or the Building Research Establishment Environmental Assessment Method (BREEAM) (BRE, 2017) in the USA. Moreover, regional constraints in terms of seismic safety are not properly considered in the rating systems. Thus, the most relevant methodology specifically addressing the combined assessment of improved seismic safety and energy/environmental performance is currently the SSD methodology.

Figure 9. European and non-European sustainability rating systems analysed by selected essential indicators (seismic safety in red, energy savings in green, climate change in yellow, other in grey) and their relevance based on indicators' weights (percentages)



Source: BNB (BMVBS, 2011), DGNB system (DGNB, 2020), Ecoprofile (Pettersen, 2000), HQE (Cerway, 2014), Protocollo ITACA (iiSBE Italia, 2011), SBTool CZ (iiSBE Czech – CSBS, 2011), SBTool PT (Mateus and Bragança, 2011), TQB (ASBC, 2010), VERDE (GBCe, 2019), ARZ Building Rating system (LGBC, 2019), BEAM Plus (HKGBC, 2016), BREEAM USA (BRE, 2017), CASBEE (JSBC, 2014), Green Star (GBCA, 2017), LEED (USGBC, 2019).

Costantino Menna and *Andrea Prota* jointly presented the main outcomes related to sub-action 3.2, focusing on the identification of requirements for the definition of a simplified method for the assessment of the combined effect of upgrading. *Costantino Menna* firstly presented a set of sought requirements classified in three main levels: (*i*) general principles, related to both sustainable development principles and life-cycle thinking in the construction sector, (*ii*) technological characteristics, devoted to guarantee an effective technological integration of energy and seismic retrofit measures, and (*iii*) engineering computation requirements, aimed at addressing the computational stage of the novel assessment method and its related outcomes while avoiding complex analysis. Afterwards, the speaker briefly introduced the framework of the proposed method consisted of four interconnected steps: (*i*) input information, (*ii*) selection of techniques, (*iii*) integrated retrofit design, and (*iv*) optimised solutions. The first step aims at collecting performance data and boundary conditions for an existing building needing upgrading. In the second step, the physical and mechanical characteristics of the seismic and energy retrofit techniques, separated or combined, are analysed to identify a preliminary set of potential compatible and feasible retrofit measures. A simplified approach for the classification of the available combined retrofit techniques (to be selected for the subsequent integrated retrofit design) is also introduced based on predefined seismic and energy performance targets. The third step, addressing the computational tool for retrofit design and assessment, and the fourth step aimed at comparing different integrated retrofit solutions were both presented by *Andrea Prota*. The simplified method was developed as an assessment tool that can be easily used by practitioners without requiring complex calculations. The starting point of the proposed tool was the SSD methodology. Indeed, the third step of the simplified method integrates the evaluation of seismic, energy and environmental performances, which are converted into equivalent costs and subsequently combined to obtain a single global result in monetary units. The equivalent economic performance of the retrofitted building is obtained by combining three main cost contributions associated with three different stages of its life cycle, i.e. initial (time of the retrofit intervention), extended lifetime, and end of life. The final economic result expresses the variation of the total life cycle cost over the lifetime of the building. In detail, the total initial cost (€/m^2) is the sum of the equivalent costs of seismic and energy retrofit interventions, and the equivalent CO_2 costs for the manufacturing of the materials adopted in the retrofit. As for the extended lifetime stage, the seismic, energy and environmental performances are assessed on a yearly basis, expressed in economic terms and combined in a global "integrated retrofitting performance parameter" (IRPP) (€/m^2year). Thus, IRPP is defined as the sum of expected annual seismic losses, expected annual costs related to energy consumption, and equivalent CO_2 costs due to both seismic damage and energy consumption. The difference in IRPP before and after the retrofit represents the total extended lifetime cost which includes the economic savings due to the retrofit interventions and provides also the opportunity to consider fiscal incentives. Finally, the total end-of-life cost (€/m^2) is the sum of the equivalent cost for dismantling seismic and energy retrofit measures and the cost associated with the environmental impact of dismantling and/or recycle/reuse retrofit materials and components. It is worth noting that simplicity of the method in calculating expected annual seismic losses and costs related to energy consumption at the extended lifetime stage is ensured by using generalised seismic (i.e. fragility curve) and energy (i.e. thermal energy demand vs HDD curve) performance results based on simulation procedures (i.e. nonlinear static and energy dynamic analyses, respectively) for the combination of different representative building classes and retrofit techniques. The fourth and last step of the proposed method consists of carrying out a comparative quantitative assessment of the different combined seismic–energy retrofit solutions analysed in the previous step to identify the most suitable and effective retrofit intervention based on the corresponding total life cycle cost over time.

Antonio Formisano presented results from sub-action 3.3, in which *Raffaele Landolfo* is also involved. Sub-action 3.3 includes the identification of four case studies and applications of standard and simplified assessment methods. RC frame buildings and rubble stone/brick masonry buildings represent the predominant building typologies in the EU. Considering also the most common envelope elements in the EU building stock, according to the TABULA database, led to the selection of the following four case studies: (*i*) a public rubble masonry building with pitched timber roof and steel hollow-tile floor slabs, (*ii*) a residential brick masonry building with pitched timber roof and RC hollow-tile floor slabs, (*iii*) a residential RC building with pitched RC hollow-tile roof, hollow brick infill walls and RC hollow-tile floor slabs, and (*iv*) a public RC building with flat RC hollow-tile roof, hollow brick infill walls and RC hollow-tile floor slabs. Then the expert proposed a seismic–climatic hazard matrix to identify potential locations for the case studies. The average value of the PGA range defining a moderate seismic hazard zone (i.e. $0.1g \le PGA \le 0.25g$) in the ESHM13 (Giardini et al., 2014) was considered to define two macro-seismic hazard areas, i.e. low-to-moderate ($PGA < 0.175g$) and moderate-to-high ($PGA \geq 0.175g$). The identification of climatic zones was based on the 2017 Eurostat HDD average annual values for each EU Member State, and on their variation by province/municipalities. Three climatic zones were defined, i.e. "A" with HDD < 2200, "B" with 2200 ≤ HDD ≤ 3500, and "C" with HDD > 3500. The combination of the aforementioned seismic and climatic zones resulted in a six-column matrix identifying regions with different levels of seismic hazard and climatic exposure, where the four case studies should be conducted (Figure 10). Italy was considered suitable for the location of the case studies, as it includes all possible scenarios identified in the matrix.

In the second part of the presentation, the expert described the application of the selected standard combined assessment method, i.e. the SSD methodology with its four main steps, to the four case studies before and after the seismic and energy retrofit. The first step of the SSD methodology is devoted to the energy performance assessment. The annual electricity and heating consumptions (in-use energy) were evaluated in kWh/m^2/year through a dynamic analysis. Then, they were transformed into kWh (electricity) and m^3 (gas) by multiplying them with the building surface and building life cycle (50 years), and subsequently converted into costs using the Eurostat unitary price of electricity (€/Kwh) and gas (€/m^3). In the second step, LCA analysis was employed to evaluate the environmental impact of all the building components in terms of equivalent CO_2 (tons) which were also transformed into costs. The EU unitary carbon price of 2016 (i.e. 8.05 €/ton) was considered. During the third step, the sPBA method was used to estimate expected losses according to the following sub-steps: (*i*) definition of limit states (i.e. low, heavy, severe structural damage, and collapse/ replacement of the building) and corresponding interstorey drift ratios, (*ii*) performing standard pushover analysis to estimate the PGA values which result in the interstorey drift ratios defined in step *i*, (*iii*) estimation of the return periods and probabilities of exceedance in 50 years (i.e. service life for ordinary structures) of the seismic actions associated with the PGA values obtained from step *ii* (i.e. for each limit state), and (*iv*) loss analysis to calculate the expected repair cost at each limit state. Finally, in the fourth step of the SSD method, energy and environmental impacts, converted into monetary units, were combined with the seismic performance results (i.e. expected economic losses) by obtaining a global assessment parameter in terms of cost. The Santini RC primary school in Loro Piceno, Italy, represents the first case study. It was retrofitted with an exoskeleton of concentric steel x-braced frames and a double-skin envelope. The second case study is a rubble masonry building that hosts the city hall of Barisciano, Italy. Various local strengthening interventions and the replacement of the heating system and windows were considered for the seismic and energy retrofit, respectively. The third case study is a residential RC building located in Toscolano Maderno, Italy, retrofitted with steel exoskeletons, external expanded polystyrene cladding, and heating system replacement. Finally, the fourth case study is a residential brick masonry building located in Dalmine, Italy, seismically retrofitted with prefabricated steel shear walls, while a new heating system and windows, as well as roof insulation were applied for its energy upgrading. Retrofit interventions provided an effective seismic and energy improvement in all four cases, in terms of total cost (i.e. the sum of energy, environmental, and structural costs represented by the global assessment parameter in the fourth step of the SSD methodology). Specifically, total cost reductions of approximately 60%, 25%, 65%, and 43% for each case study were evaluated, respectively, compared to the non-retrofitted buildings. Forthcoming work will focus on the implementation of the simplified assessment method in the aforementioned case studies.

Figure 10. Seismic–climatic matrix and corresponding case study location

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

4.2 Part 2: complementary ongoing research projects

The second part of the Action 3 session opened with Paolo Negro, presenting objectives that are common to the Pilot Project and the ReLUIS–DPC (2019–2021) project, in particular to the research activities within WP5 dealing with low-impact, rapid and integrated interventions to improve seismic resistance and energy efficiency of buildings.

Andrea Prota presented the main outcomes of WP5 with reference to RC buildings. Based on the 2011 census, more than 50% of the Italian RC building stock, including residential and school buildings, were designed and built before the 80's, exhibiting low energy efficiency and without considering modern seismic codes. As a consequence of the 2016 Central Italy earthquakes, several buildings that were retrofitted for energy efficiency improvement collapsed, leading to the loss of the energy upgrading investment. The current challenge of buildings' interventions is not only avoiding structural failure, but also limiting non-structural damage. Considering the casualties and the economic impact resulted from earthquakes in Italy during the last 50 years, the Italian government launched "sismabonus" (Law 2016/232) to offer incentives for the seismic retrofit of buildings. In this context, the ReLUIS–DPC (2019–2021) project was activated. Specifically, WP5 aims at developing retrofit solutions that improve the structural and energy performance of existing buildings, and are applicable in a short time, at reduced cost and with no service interruption. Local interventions which improve structural members' strength and/or ductility, and prevent local failure mechanisms represent a promising approach in both RC and masonry buildings. The second part of the presentation provided a summary of the analysis of interventions for RC buildings, which can be classified in the following broad categories: (*i*) innovative technologies for the strengthening of beam-to-column joints, such as active confinement systems and composite materials, (*ii*) technologies based on the use of steel elements including shear strengthening with steel angles, innovative devices consisted of dissipative steel plates, external braced frames combined with active confinement systems and FRPs, eccentrically braced systems with shear links, and (*iii*) low-impact global retrofit interventions of external steel exoskeletons. Afterwards, the speaker reported the outcomes on integrated design/assessment methodologies based on a life cycle approach and cost–benefit analysis. Finally, three levels of increasing performance and invasiveness were defined to be used in the integrated retrofit design and assessment of case studies, i.e. (*i*) local structural interventions at the exterior façade of buildings combined with externally applied energy upgrading measures, (*ii*) local interventions applied both externally and internally to the building perimeter, and (*iii*) global standard interventions (e.g. bracing systems, steel exoskeletons, RC shear walls, etc.) combined with energy upgrading measures. The assessment of seismic safety and energy improvement in an RC school building was presented for each of the three aforementioned levels. In addition, an economic analysis was carried out resulting in retrofitting costs of 270, 440, and 660 €/m^2 for levels (*i*), (*ii*), and (*iii*), respectively, and an estimated execution time of 2 to 4 months with a team of three workers.

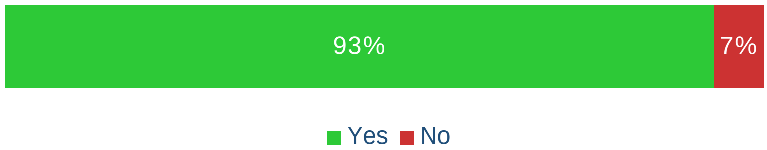
Francesca da Porto addressed WP5 activities dealing with masonry structures including the application of retrofit solutions to case studies. Based on the 2011 census, Italian masonry residential buildings constructed before the 80's (i.e. "pre-seismic code" buildings) account for 85% of the residential building stock, thus require retrofitting. Focusing on typical structural deficiencies of masonry buildings, the speaker underlined that the efficiency of local retrofit interventions depends on the quality of existing masonry buildings. Masonry walls of poor quality with consequent disintegration phenomena complicate the use of local retrofit strategies such as ties connecting walls or anchors connecting floors with external walls. In the case of good-quality masonry, local and low-impact interventions become effective towards resisting out-of-plane failures. Several research studies assessed intervention measures used to improve the quality of masonry walls through grout injection. Technologies for enhancing masonry strength can be considered when the quality is better; TRM with reinforced repointing as well as integrated solutions, such as TRM combined with external thermal insulation, were investigated. Regarding connections, traditional ties, hooping, and innovative interventions creating light tie-beams or hooping systems with composite materials were analysed. Strengthening intervention techniques for timber floors and roofs were briefly presented; used to increase the in-plane stiffness through wood-panel solutions, they also provide the ability to integrate oriented strand board (OSB) floor panels or roof insulation/ventilation layers. Moreover, integrated solutions for the strengthening of masonry walls using CLT elements and OSB panels are experimentally investigated. Finally, the speaker briefly presented the selected case studies used to assess the interventions' effectiveness. The former courthouse in Fabriano, Italy, was presented in more detail. Similarly to the RC case studies, three seismic and energy intervention levels of increasing performance and invasiveness were considered, i.e. (*i*) local structural interventions applied to walls and energy upgrading measures applied to the buildings' envelope, (*ii*) local structural interventions applied to floors and replacement of the heating, ventilation, and air conditioning (HVAC) system, and (*iii*) structural interventions applied to walls and floors along with energy upgrading measures targeting the envelope and the HVAC system. Retrofit costs ranging from 400 to 730 €/m^2 were obtained for levels (*i*) to (*iii*). Finally, quite short payback periods were estimated for both seismic and energy interventions for all three levels when fiscal incentives were taken into account.

4.3 Action 3 session outcomes and polls

On the basis of the presentations, participants raised various issues. As for sub-action 3.1, the main concerns referred to environmental issues, as well as the importance of considering cooling degree days (CDD), apart from HDD, due to the climate change. It was underlined that it is possible to develop a unique EU assessment tool, but local conditions should be considered. As a way forward, climate characteristics differentiated also in terms of CCD should be implemented for an effective assessment of building retrofit depending on the EU regions. As for sub-action 3.2, the need for simplified assessment methods and clear definitions of concurrent seismic strengthening and energy efficiency technologies was pointed out. The idea behind the proposed simplified assessment method is to create a framework applicable irrespective of the site conditions, and adaptable to different structural typologies and rehabilitation techniques. Moreover, it was clarified that the proposed method takes CDD indirectly into account, but efforts will be made to include CDD as an explicit input. Regarding the issue of retrofit technologies, it was underlined that two potential types can be considered, i.e. integrated/combined and independent solutions. The proposed assessment method is capable of evaluating both types, thus identifying proper intervention solutions in terms of initial cost. However, contemporary retrofit needs to be evaluated considering the life cycle of a building. Therefore, the possibility to assess different technological approaches should not be seen as a barrier, but as a means to highlight advantages and disadvantages of interventions. Finally, as for sub-action 3.3, participants were interested in the possibility to include additional structural typologies in the case studies, such as LPS structures. LPS buildings are not investigated within the Pilot Project, however, it is fundamental to evaluate their structural details and their envelope characteristics prior to proceeding with an integrated retrofit. Although a case-by-case approach should be followed, a potential solution could be an intervention activated in parallel with the load-bearing panels.

Participants were invited to express their opinion on the need for integrating life cycle analysis in the approach discussed within Action 3. In Figure 11, it is seen that more than the majority agreed with the idea.

Figure 11. Workshop participants' feedback on "Do you think that life cycle analysis should possibly be integrated in the approach being defined?"



5 Regional impact assessment and contributions to an action plan

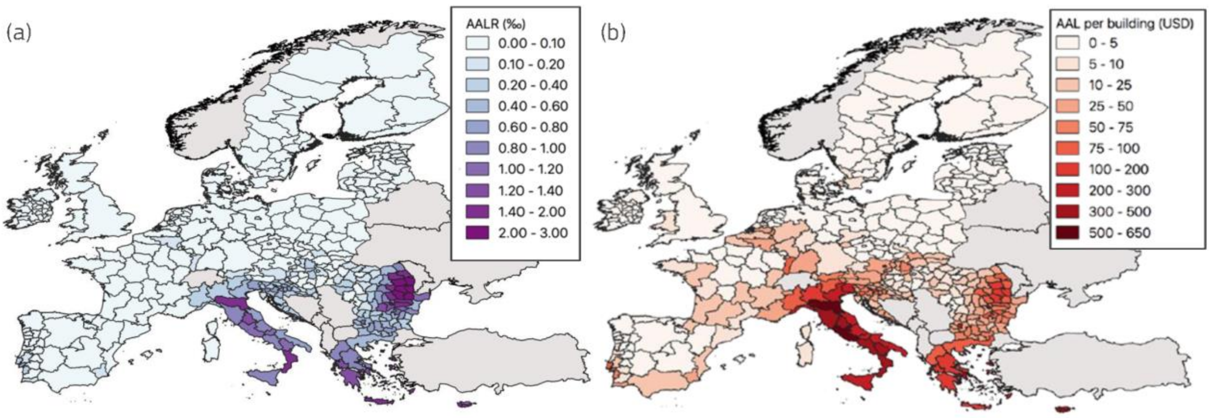
The objective of Action 4 “Regional impact assessment and contributions to an action plan” is to draw lessons, identify gaps and propose good practices for the redevelopment and modernisation of the European building stock. Regions where interventions are of higher priority will be identified considering the seismic and energy performance of buildings, complemented with socio economic indicators. In addition, proposals will be formulated for efficient policy measures and tools to successfully implement combined seismic and energy upgrading of existing buildings in Europe. The output will further inform the action plan regarding the areas where renovation may achieve a high impact through assessing alternative regional intervention scenarios.

5.1 Priority regions

Helen Crowley presented an overview of the work prepared so far on the regional seismic risk assessment and prioritisation. Regional seismic risk assessment is based on the evaluation of average annual economic losses (AAL). Adopting AAL as a risk metric, requires the hazard to be defined within a frequency-based seismic performance assessment approach considering all potential earthquakes that affect a specific site over a given time, together with their probability of occurrence. The OpenQuake engine (Pagani et al., 2014; Silva et al., 2014; GEM, 2019) is used to perform risk calculations. During the first stage of analysis, the ESHM13 (Woessner et al., 2015) was employed. Site amplification was incorporated into the ground motion modelling of regional risk models by using topography to infer the average shear wave velocity to a depth of 30 m (Wald and Allen, 2007). The exposure models for residential and commercial buildings described in Crowley et al. (2019; 2020) were used. Risk calculations were run at the highest available level of subdivision, as defined by the Database of Global Administrative Areas (GADM) (i.e. 0: country; 1: region; 2: province; etc.). However, risk results were aggregated to the first administrative level (i.e. 1: region) in each country. Furthermore, GEM’s vulnerability models (Martins and Silva, 2020) were implemented, describing the probability of loss (ratio of total repair costs to total replacement cost) conditional on the intensity measure.

Based on the above framework, preliminary results provide an initial insight into the areas of highest priority for intervention. In general, the ranking of AAL is influenced by the level of seismic hazard but also the size of the country and the value of the exposure. Hence, the average annual loss ratio (AALR), obtained by dividing AAL by the replacement cost, was calculated and mapped in Figure 12a at the first subdivision in each country. AALR highlights regions where losses are high relative to the value of the exposure, therefore countries with lower construction costs are often higher in the relevant ranking. To identify areas where absolute losses are expected to be high, but not necessarily due to the higher replacement cost of buildings, an additional risk metric was considered. AAL per building, obtained by dividing AAL by the total number of buildings, is presented at the first subdivision in Figure 12b. Regional prioritisation considers both AALR and AAL per building metrics. Selecting the top 20 regions from each metric ranking (i.e. having the highest annual losses) results in 38 different administrative units. The impact of alternative regional intervention scenarios will be investigated in these units on the basis of cost–benefit analysis. Risk assessment results will continue to be revised and updated as further developments to the hazard, exposure and vulnerability models are undertaken, e.g. replacement of ESHM13 with its updated version (i.e. ESHM20), use of geology and topography-based site amplification models, replacement of GEM vulnerability models for reinforced concrete

Figure 12. (a) AALR and (b) AAL per building at the first subdivision level in the EU27 and the UK

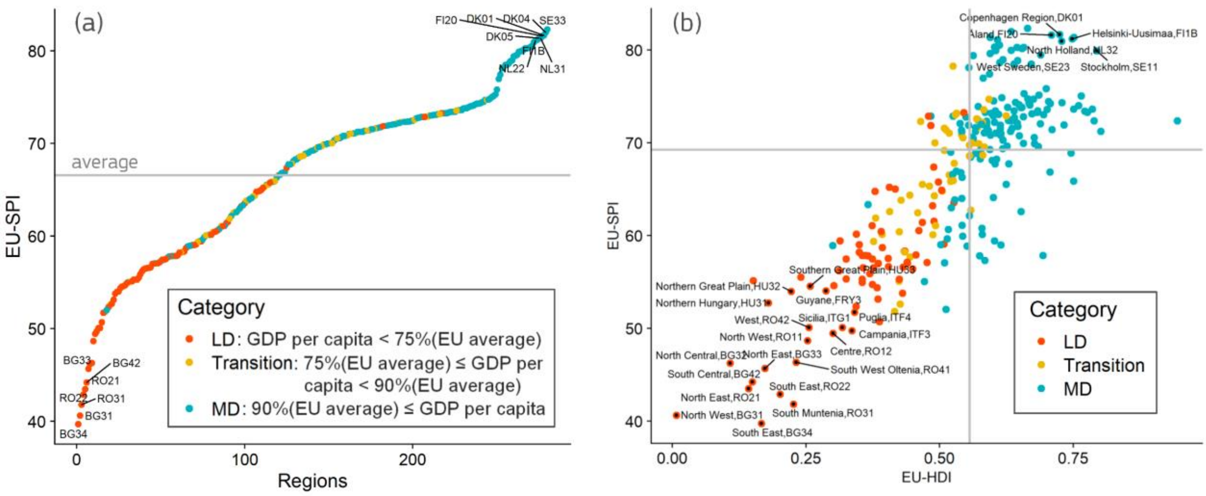


buildings with updated models (Romão et al., 2019) developed in the "Seismology and earthquake engineering research infrastructure alliance for Europe" (SERA) project, use of damage-loss models for loss of life, etc.

In addition to seismic risk metrics, socioeconomic indicators will be employed in regional prioritisation. *Hedvig Norlén* has been working in this direction. Regional socioeconomic indicators were selected (e.g. Eurostat, Gallup World Poll) and integrated within composite indicators to provide more robust information about socioeconomic aspects. The EU Human Development Index (EU-HDI) (Bubbico and Dijkstra, 2011), the EU2020 index (Athanasoglou and Dijkstra, 2014), and the EU Social Progress Index (EU-SPI) (Annoni et al., 2016) were used to measure a region's overall achievement in key dimensions of human development, "adherence" to the Europe 2020 strategy (COM (2010)2020) for smart, sustainable and inclusive growth, and performance on social and environmental aspects, respectively. Based on each indicator, separate regional rankings were derived and the correlation of each index to the gross domestic product (GDP) per capita was explored. Regions were differentiated among "less-developed" (LD), "transition", and "more-developed" (MD) based on their GDP compared to the EU average (Figure 13a). Unsurprisingly, MD regions perform better than transition and LD ones in terms of EU-HDI, EU2020, and EU-SPI. The correlation between indices and GDP per capita is generally strong and positive. Higher level of social progress leads to higher levels of economic development. Yet, this relationship is not linear. At lower income levels, small differences in GDP are associated with larger improvements in social progress compared to improvements at higher income levels. In a similar context, the correlation between pairs of indices was found to be positive and strong (e.g. Figure 13b) with Pearson coefficients of 0.71–0.82. Nevertheless, such values also indicate that each composite indicator may provide complementary information. In this context, a method was proposed to prioritise group of regions by properly combining all three indicators. Regions were classified in three performance classes, i.e. low, medium, and high, by exploring different set cut-offs in the distributions of the three indicators. For example, defining low- and high-performance regions as those that fall below the 25th and above the 75th percentiles in all three indices, results in 38 and 32 regions in each class, respectively, out of the 281 considered regions at the second level of the Nomenclature of Territorial Units for Statistics (NUTS) classification.

Forthcoming work will focus on energy performance assessments of existing buildings at regional level along with exploration of approaches to combine regional prioritisation based on seismic risk, energy performance, and socioeconomic aspects towards more informed decision-making.

Figure 13. (a) EU–SPI scores plotted in increasing order and (b) EU–SPI vs EU–HDI scores in the EU27 and the UK



5.2 Implementing measures

Implementing measures for seismic strengthening and energy upgrading of buildings were collected across 16 EU Member States, namely Austria, Bulgaria, Croatia, Cyprus, France, Germany, Greece, Hungary, Italy, Malta, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden. Measures were classified by sector (seismic, energy, combined), class (legislation and standards, programmes, strategies, guidance, other/generic), type (financial/administrative and/or technical), etc. with a view to facilitating the evaluation of their efficiency. Evaluation criteria include, among others, significant impact, implementation challenges, programmes' high-cost effectiveness and funding sustainability. The distribution of the collected measures by sector and class is provided in Figure 14, whereas the relevant distributions per Member State can be seen in Annex 2. Figure 15 reports feedback, received from participants during the workshop, on the most significant implementation challenge towards integrated retrofit, indicating "cost and affordability" as the most crucial parameter. In the following, some representative examples of implementing measures are briefly introduced.

Figure 14. Distribution of collected implementing measures in 16 EU Member States (MS) by sector and class

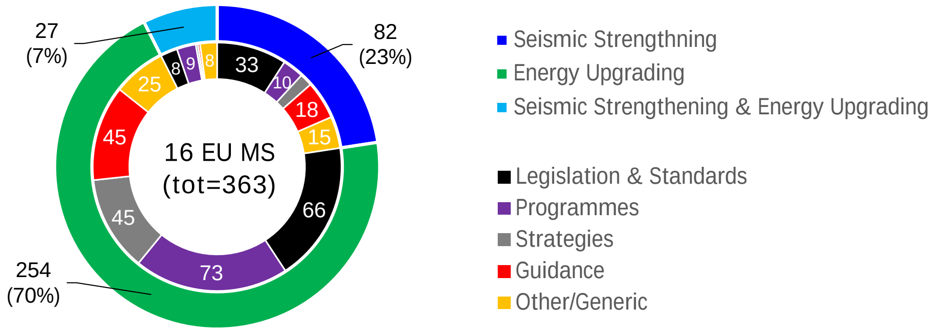
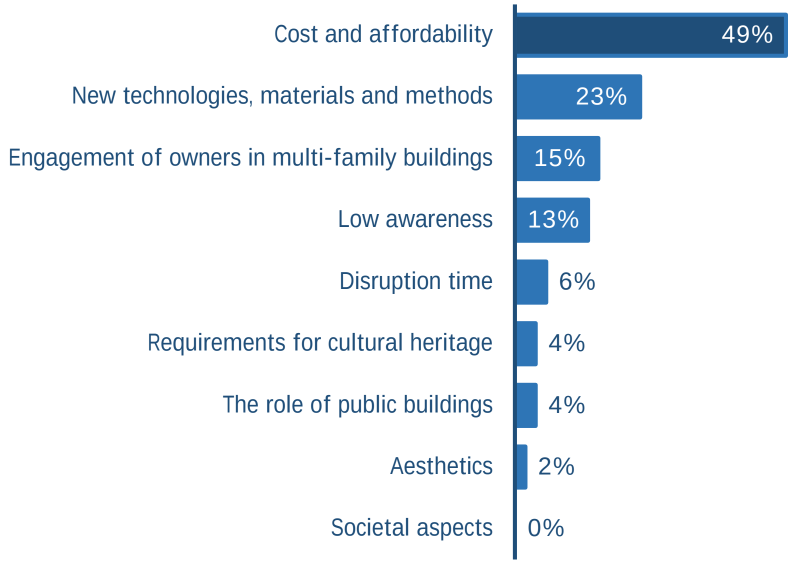


Figure 15. Workshop participants' feedback on "What is the most significant implementation challenge towards integrated retrofit of buildings?"



Since the 80s, several building codes and programmes were introduced in Italy to improve the seismic and energy performance of buildings. *Angelo Masi* has been collecting and evaluating such measures. Issued financial incentives were mainly based on tax deduction. "Ecobonus" and "sismabonus" (Law 2016/232) provided significant fiscal benefits (i.e. tax deduction of 50–85% as a share of the intervention expenses) in case of upgrading the energy and/or seismic performance of buildings with particular attention to multi-family buildings. "Ecosisma bonus" (Law 2017/205) further promoted interventions based on an integrated approach by providing an increased amount of benefits in the case of combined renovation. Recently, to stimulate the construction sector towards the mitigation of the COVID-19 economic impact, tax deduction was further increased to 110% (Law 2020/77). Collected data on fiscal benefits from Italy, indicate the complexities associated with deploying structural interventions in multi-family buildings, e.g. need to intervene to the whole building, service interruption, consent of various owners, etc.

Christoph Butenweg presented measures in Austria, Germany, Hungary, Slovakia and Sweden. These countries display a commitment towards continuously evaluating and improving the energy performance of buildings. Sweden has introduced successfully since the 90s the energy and carbon tax programme (Brännlund et al., 2014) with a view to improving energy use efficiency. The measure is considered to have had a pivotal role in switching energy consumption by Swedish households towards non-fossil alternatives. "Energy performance certificate" measures, present in all countries, further incentivise energy renovations by increasing property values. Caritas energy–savings check measure in Germany provided technical assistance in the form of free energy efficiency checks for low-income households while contributing to job creation by training long-term unemployed people to become energy audit assistants. On the other hand, there is a lack of seismic strengthening and combined measures in these countries, mainly associated with low seismicity.

Roumiana Zaharieva presented measures in Bulgaria, Croatia, Cyprus, Greece, Romania, and Slovenia. In Bulgaria, some measures addressing both the seismic and energy performance were identified. Legislative measures include the technical passport of buildings (Ordinance 5/2006). Technical passports contain technical information about the building, records of completed construction/repair works along with prescriptions for required retrofitting. In general, technical passports represent a record of the condition of buildings and their degree of safety during operation, accessible by all relevant stakeholders. Technical passports are expected to be issued for every existing building in Bulgaria by 2022. An implementation challenge towards this goal relates to the cost of drafting passports (e.g. non-regulated prices, uninhabited dwellings) that obstruct the wide and rapid implementation. Interestingly, in the share of combined measures in Bulgaria, contributing programmes target mainly energy upgrading and address implicitly the structural/seismic performance of the building. For example, energy upgrading may be funded only in the case of a previous positive evaluation of the seismic resistance of the building. In Romania, the national programme on increasing the energy performance of apartment buildings, currently at a third phase of implementation since its introduction in 2009, aims among other objectives to the energy upgrading of residential buildings and the reduction of greenhouse gas emissions. Although state funding (up to 80%) is provided mainly for energy renovation works, the ordinance that extended the programme in 2015, introduced requirements for a detailed seismic evaluation of buildings prior to carrying out energy upgrading works.

Helena Gervasio presented measures in France, Malta, Portugal, and Spain. In France, Portugal, and Spain, the transposition of European Directives to national legislation has led to an increased number of energy-related national strategies and programmes. The situation in Malta is slightly different as the country has a temperate climate and the lowest energy consumption in dwellings among all EU Member States. In the case of existing buildings in France, the code requirements relevant to seismic strengthening apply in the case of major renovations or when the renovation results in an increase of the seismic vulnerability of buildings. In Spain, recent seismic events in moderate seismicity regions led to increased awareness and action plans are currently under development. The recent Decree-Law PT 95/2019 in Portugal, expected to boost seismic renovation rates, requires seismic vulnerability assessments and seismic strengthening under specific conditions (e.g. change of use), prescribing in addition requirements for the energy efficiency of buildings. In Portugal, a programme currently under development in the municipality of Lisbon, aims to provide financial incentives for buildings' renovation, addressing seismic safety, energy efficiency and societal aspects. In addition to implementing measures, data on existing seismic insurance schemes were collected. In France and Spain, public insurance schemes provide earthquake coverage (among other hazards) as an automatic extension to fire insurance, including unlimited building and content damage along with profit loss due to service interruption. Hence, 95% of residential and commercial properties in France, and approximately 75% of residential properties in Spain are insured against earthquakes. In Portugal, earthquake coverage is offered by private insurers as an optional add-on to residential/commercial property insurance schemes resulting in low ratios of insured properties (i.e. ~16% of residential buildings) (OECD, 2018). Coverage value depends on the building type and age; in addition, depending on the regional seismic hazard it may include only content damage.

Forthcoming work will further assess the efficiency of collected measures, explore further insurance schemes in Europe and abroad, and make proposals in support of an action plan.

5.3 Scenarios for interventions

Angelo Masi has been working on the definition of intervention scenarios for the Italian building stock. Based on the 2011 census in Italy, exposure data (number of buildings, population) were aggregated at municipality level and distributed among seismic (OPCM 2006/3519) and climatic (Decree 1993/412) classification zones. Seismic zones (SZ) are defined as a function of PGA having an exceedance probability of 10% in 50 years: (*i*) SZ1: PGA > 0.25g; (*ii*) SZ2: 0.15g < PGA ≤ 0.25g; (*iii*) SZ3: 0.05g < PGA ≤ 0.15g; (*iv*) SZ4: PGA ≤ 0.05g. Climatic zones (CZ) are ordered by increasing energy demand (i.e. HDD) and range from A to F. Subsequently, combined SCZ were defined by juxtaposing and merging SZ and CZ zones. Exposure data were finally distributed to the combined seismic and climatic zones to define generic intervention scenarios (Table 1). Such scenarios are based on seismic and energy demand while the distributed exposure data imply the potential scenario impact in terms of the required scale of renovation and the associated cost. Interestingly, the largest share of exposure lies in SCZ2b where energy efficiency is the main concern.

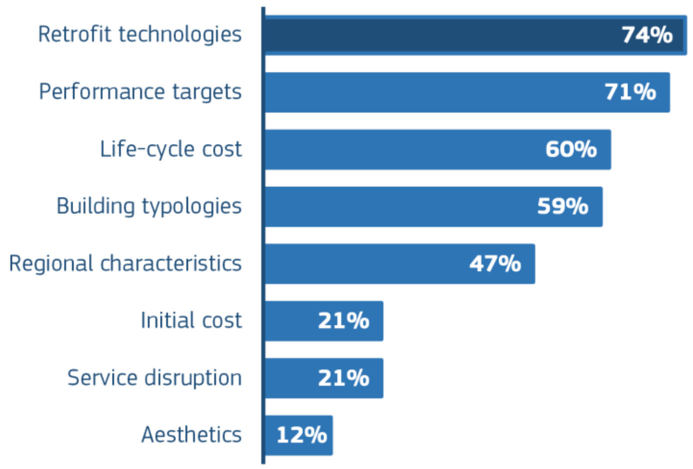
An effort was subsequently made to integrate vulnerability of the Italian building stock based on the age of construction. Vulnerability at the municipality level was simplistically expressed as the ratio of the mean age of buildings over the period (i.e. number of years) during which seismic code prescriptions were applied for the design of buildings within the municipality. Risk indices (R_s) were evaluated for each municipality by integrating seismic hazard (NTC, 2018). Two seismic risk zones were defined (replacing SZ1, 2 and SZ3, 4, in Table 1): (*i*) moderate-to-high risk with $R_s \geq \text{median}R_s$; (*ii*) low-to-moderate risk otherwise The number of buildings and population were re-distributed in the combined seismic risk and climatic zones. Exposure data distributions were found to be similar to those in Table 1 apart from approximately one million buildings and 4.5 million inhabitants that were relocated from SCZ3 to SCZ2a associated with a scenario for interventions aiming mainly for seismic upgrading.

Table 1. Distribution of buildings and population by combined seismic–climatic zones.

SCZ	SZ	CZ	Buildings (10^6)	Buildings (%)	Population (10^6)	Population (%)	Intervention scenario
1	1, 2	D, E, F	3.84	31.5	19.13	31.6	Combined seismic–energy upgrading (or replacement)
2a	1, 2	A, B, C	1.55	12.7	8.00	13.2	Major seismic upgrading and minor energy upgrading
2b	3, 4	D, E, F	4.96	40.7	25.18	41.7	Major energy upgrading and minor seismic upgrading
3	3, 4	A, B, C	1.84	15.1	8.14	13.5	Minor (or none) seismic and energy upgrading
Total			12.19	100.0	60.45	100.0	

Intervention scenarios such as concurrent (i.e. improving at the same time the earthquake safety and energy efficiency of existing buildings) and non-concurrent, as well as demolition and new construction will be defined at regional level across the EU. These regional scenarios will consider specific building typologies (material, structural type, period of construction/code level, etc.), retrofit technologies and materials, target performance after retrofit in terms of seismic safety and energy efficiency, and cost of intervention, whereas their impact will be assessed through cost–benefit analysis with a view to providing insight on the associated benefits. Figure 16 provides valuable feedback, received by workshop participants, on the critical aspects a regional intervention scenario should address.

Figure 16. Workshop participants' feedback on "What are the three most significant elements that a regional intervention scenario should address?"



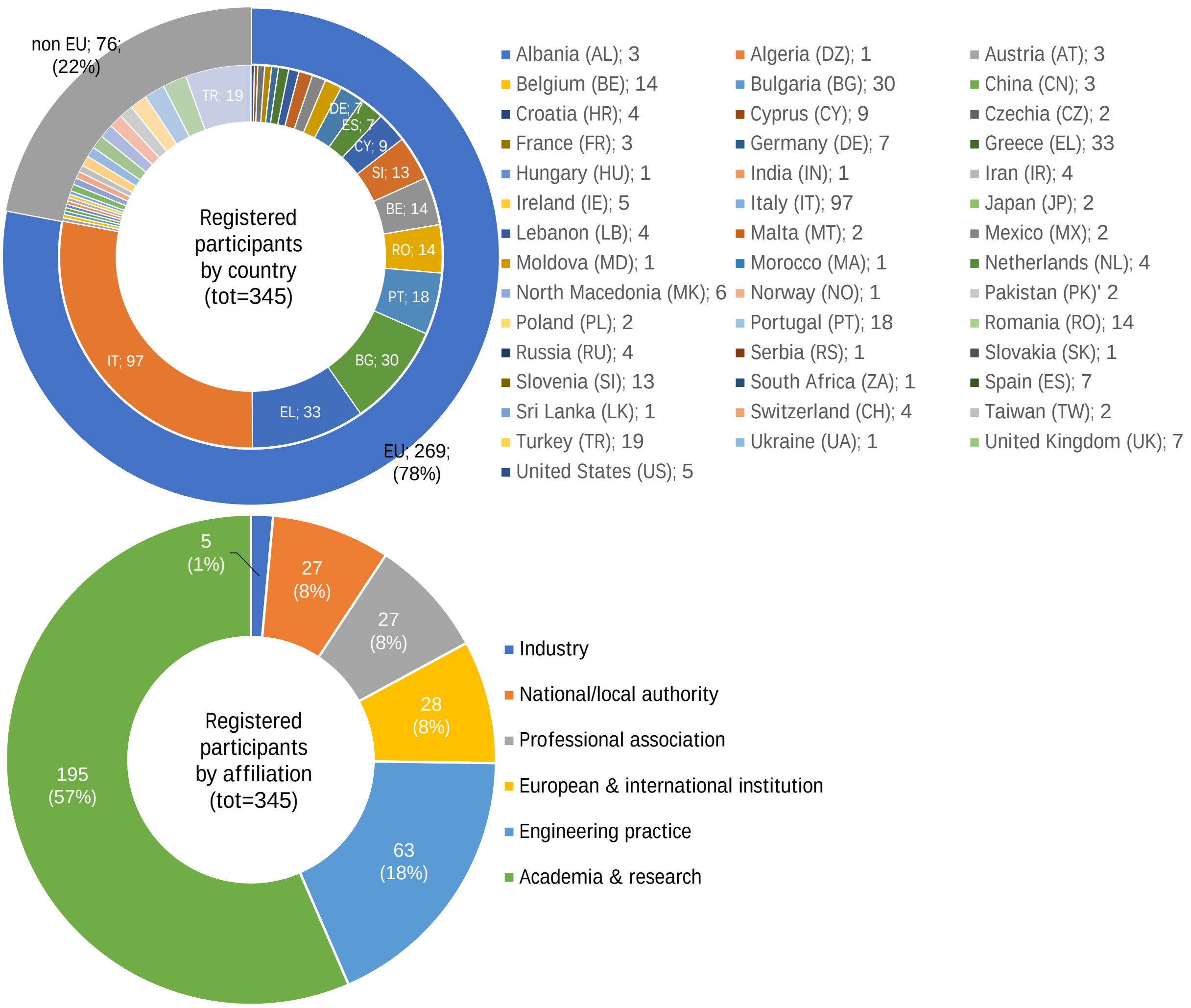
6 Stakeholders' engagement

In Pilot Project's Action 5 "Stakeholders' engagement", EU Member States, industrial associations and expert communities are engaged through the organisation of two workshops (Section 6.1) on technical and policy issues including relevant implementing measures, technologies and methodologies for the combined improvement of the energy and seismic performance of buildings. Furthermore, Action 5 aims at communicating the Pilot Project scope, objectives and output to the public by increasing visibility of the project output and building awareness of the "renovation" topic through the development of communication and interaction channels at the EU, Member State, and regional level. Various means of dissemination and outreach are employed according to Section 1.2. Here, public communication material/activities and developments in the web platform are briefly presented (Section 6.2).

6.1 Organisation of workshops

The two workshops consist of (*i*) the midterm workshop virtually held on 16–19 November 2020 where the Pilot Project work progress was presented to the stakeholders and (*ii*) a final workshop in which the project results will be presented with the aim of disseminating the developed solutions and discussing contributions to a future action plan. Following the interventions of the opening session (Section 1.3), more than 30 technical presentations were delivered by JRC Pilot Project team members and external experts, complemented by discussions and polls. The detailed agenda of the midterm workshop is provided in Annex 1. 345 participants from 43 countries registered to the midterm workshop (Figure 17).

Figure 17. Midterm workshop participants by country and affiliation



Participants were from academic and research institutions, the engineering practice, European and international institutions, professional associations (Buildings Performance Institute Europe, European Builders Confederation, European Council of Civil Engineers, Housing Europe, national engineering associations and chambers, etc.), national and local authorities, and the industry.

JRC Pilot Project team members and invited speakers presented the following projects and activities that also deal with the combined seismic and energy upgrading of existing buildings:

— SAFESUST: Safety and sustainability of buildings

— iRESIST+: Innovative seismic plus energy retrofitting of the existing building stock

— SPEctRUM: Seismic plus energy upgrading of masonry buildings using advanced materials

— SEP+: Development of textile-reinforced mortar & capillary tube panel retrofitting technology to simultaneously improve seismic and energy performance of the existing buildings

— ReLUIS–DPC 2019–2021: Integrated, rapid and low-impact interventions for the reduction of seismic vulnerability and energy consumption (WP5)

— SUPERB: Novel integrated approach for seismic and energy upgrading of existing buildings

— PERSISTAH: Earthquake-resilient school projects in the territory of Algarve and Huelva

Participants were asked to provide an overall assessment of the midterm workshop and express how much the different sessions met their expectations. The rate of satisfaction was more than 90% (satisfied and very satisfied) for the event as a whole.

Figure 18. Participants' satisfaction survey: "What is your overall assessment of the workshop?"

6.2 Dissemination and outreach

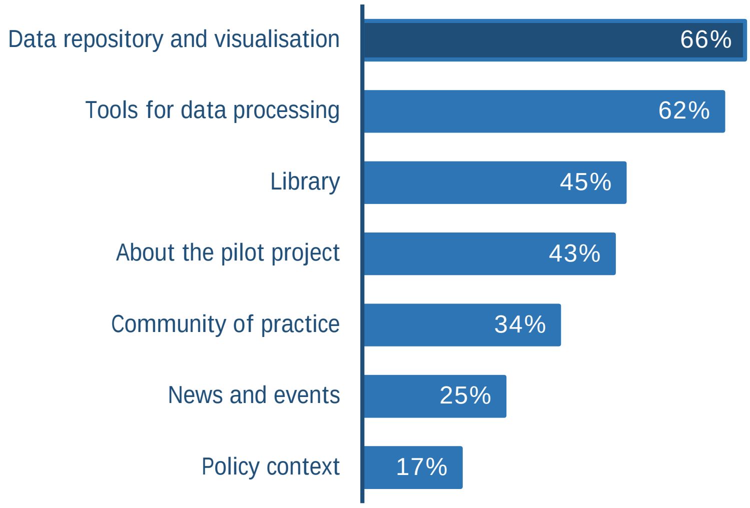
The Pilot Project participated in the 18th European Week of Regions and Cities, by organising a side event entitled "Seismic and energy retrofit of buildings" within the "Green Europe" theme. The side event was held virtually on 20 October 2020. The objective of the side event was to raise awareness of the Pilot Project and engage main European stakeholders. 186 participants from 27 countries registered to the side event. The participants were from the European Institutions, European and international associations, national and local authorities, industry, universities, research institutions and engineering practice.

A series of seven leaflets were prepared and circulated. A general leaflet (Figure 19) provides a general description of the Pilot Project including its scope, social and policy relevance, and a brief description of actions. Five additional leaflets were prepared addressing technical and policy contributions from each action.

The Pilot Project web platform, currently under development, will serve as a means of visualising and sharing the project's output. The output will include geo-referenced data at regional level on the characteristics of the building stock, socioeconomic indicators, expected loss/impact of scenarios, implementing measures, etc. The web platform will also comprise an interactive map with case studies and a searchable database of documents collected and produced during the project. The web platform will include sections on the Pilot Project objectives, policy background and expected impact, details on the input, methodologies and output of the different actions, and a community of practice for stakeholders' interaction. Search and visualisation tools will provide open access to interactive geo-referenced content and data (maps, graphs, etc.) considering pre- and post-mitigation states. The web platform will also include tools for simple calculations of user-defined regional intervention scenarios and impact assessments. Figure 20 presents workshop participants' response to the significance of different web platform features, indicating open access to data and processing tools as the most crucial ones.

Figure 19. General leaflet (Gkatzogias et al., 2020)

Figure 20. Workshop participants' feedback on "Which of the following web platform sections are you keen to use?"



7 The New European Bauhaus

The State Bauhaus school was founded in 1919 in Weimar, Germany, by the architect Walter Gropius. Bauhaus, literally translated to "building house", later became an international movement having a long-lasting influence on architecture, design, and society throughout the world. The Bauhaus school contributed to improve people's daily lives following principles that still apply today, namely emphasis on new techniques, materials and ways of construction, smart use of resources, design for mass production and industry, no essential difference between the artist and the craftsman, or "form follows function".

A century later, Europe is facing major transformations related to environmental degradation, climate crisis and digital transition. In response to these issues, the European Commission launched the European Green Deal (COM (2019)640) to make Europe the world's first climate neutral continent by 2050, i.e. a sustainable economy with net-zero greenhouse gas emissions in line with the EU's commitment to global climate action under the Paris Agreement (Decision 1/CP.21/2016) and the United Nations' Sustainable Development Goals (Resolution 2015/A/Res/70/1).

Concrete initiatives under the Green Deal are focusing on the sectors that use most resources and where the potential for circularity is high, such as construction and buildings. In fact, the built environment is responsible for over 35% of the EU's total waste generation and account for at least 40% of all greenhouse gas emissions. Among the initiatives that are relevant to the construction sector, it is worth recalling the Renovation Wave for Europe (COM (2020)662), which addresses challenges of more efficient and affordable energy and resources throughout the life cycle of buildings, and the New Industrial Strategy for Europe (COM (2020)102) aiming to accelerate the transition of the European industry to a sustainable model based on the principles of circular economy (COM (2020)98). In addition to its environmental and economic ambitions, the Green Deal intends to be a new cultural project for Europe, incorporating a process of systemic change, and having a strong brand image that merges design with sustainability. To this end, the European Commission recently launched the New European Bauhaus (European Commission, 2020a, b, c) that aims to build a bridge between the world of science and technology, and the world of art and culture, while looking for creativity and innovation.

The New European Bauhaus will be a forum for discussion, an experimentation lab, an accelerator for new solutions, a hub for global networks and experts, a meeting place for citizens interested in the topic. It will be a driving force to bring the European Green Deal closer to people and places where they live, but in an attractive, innovative and human-centred way, showing that the necessary can be beautiful at the same time. It will be a movement based on sustainability, multidisciplinary networking, inclusiveness, accessibility and aesthetics, intending to make reuse, recycling, waste reduction, renewable energies and energy efficiency the new normal in people's daily lives. The New European Bauhaus should also take advantage of digitisation, to foster a transition towards smart and sustainable buildings and cities, leading to a higher quality of life of their inhabitants (European Commission, 2020b).

The New European Bauhaus will be implemented in three phases, i.e. design, delivery and spreading ideas phase (European Commission, 2020c).

Scope and priorities were defined at the design phase. The European Commission is going to support the process of mapping key actors, networks and policy frameworks, foster citizens' engagement and implement the delivery tools, like calls for proposals and other mechanisms. The design phase will also draw on the expertise and engagement of people from different backgrounds, namely designers, architects, artists, digital experts, scientists, entrepreneurs, engineers and students aiming at exploring ideas and shaping the movement.

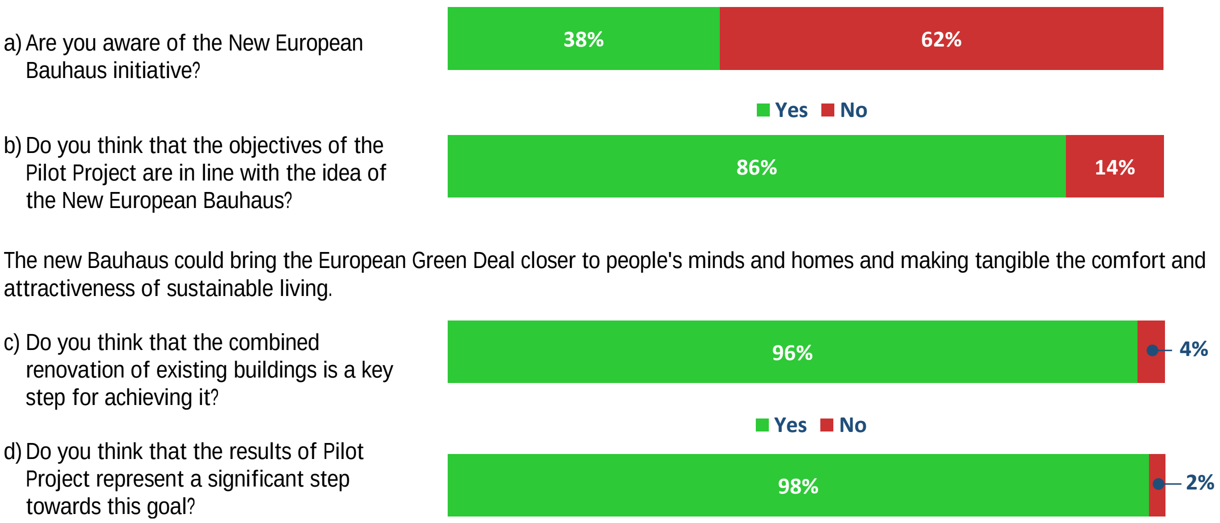
In the delivery phase, starting in 2021, at least five New European Bauhaus projects will take place in different EU Member States. All of them will be committed to sustainability, combined with art and culture. Each of them will be adapted to local conditions but will have different goals, for instance the use of natural building materials, the improvement of energy and resource efficiency, or the implementation of innovative, digital and sustainable solutions in a range of spaces and contexts, such as public or residential spaces and urban or rural areas.

The third phase will be about the dissemination of the Bauhaus' projects and ideas, within and beyond Europe's borders. A platform, creative spaces and a Bauhaus knowledge hub will be set up aiming at identifying technologies and materials, using big data and artificial intelligence, engaging with stakeholders and citizens, and facilitating cultural debates.

The New European Bauhaus is part of the European broader vision that aims at "building the world of tomorrow for a tomorrow that is greener, more beautiful and humane" (European Commission, 2020c).

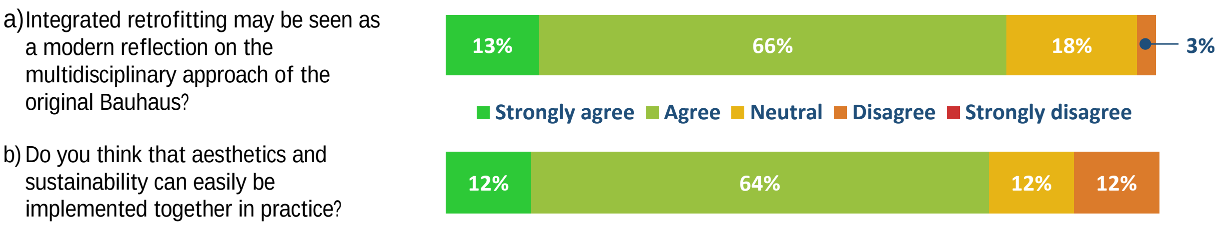
During the midterm workshop several opinion polls were carried out to better understand people's perspectives on possible contributions of the Pilot Project to the New European Bauhaus and other policy areas like the Renovation Wave. Before setting the polls, the workshop organisers made a first survey to clarify whether the participants were aware of the New European Bauhaus initiative. The survey indicated that the majority of participants (62%) was not aware of the initiative (Figure 21a), probably due to its recent announcement in October 2020, and to its early design stage. After a brief introduction to the initiative, the polls revealed that 86% of the participants believed that the objectives of the Pilot Project are in line with the idea of the New European Bauhaus (Figure 21b). Under the assumption that the new Bauhaus could bring the European Green Deal closer to people's minds and homes and make tangible the comfort and attractiveness of sustainable living, the polls showed that a large majority of people agree that (*i*) the combined renovation of existing buildings is a key step for achieving this, and (*ii*) the results of the Pilot Project represent a significant step towards this goal, that is, 96% and 98% of the respondents believe the last two statements, respectively (Figure 21c, d).

Figure 21. Workshop participants' feedback on the New European Bauhaus



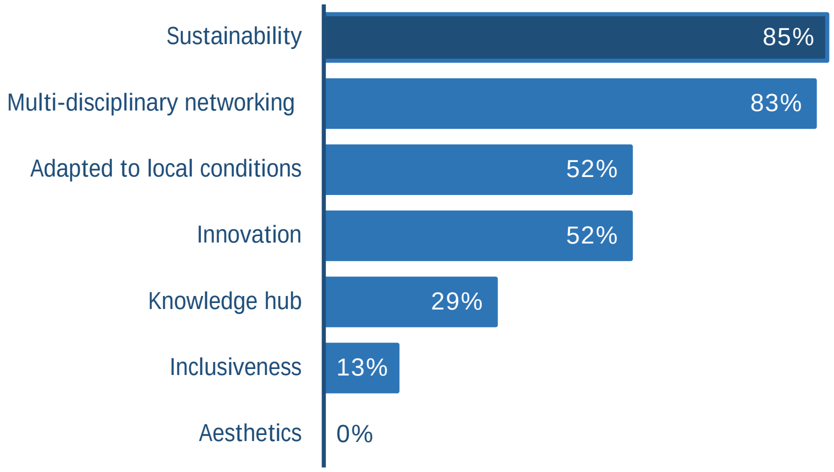
The next poll reported that 79% of the participants strongly or simply agreed that the integrated retrofitting may be seen as a modern reflection on the multidisciplinary approach of the original Bauhaus, while 18% of the respondents chose the neutral response to the question (Figure 22a). Still a majority (i.e. 76%) strongly or simply agreed that aesthetics and sustainability can easily be implemented together in practice (Figure 22b). This poll received the highest percentage of responses showing disagreement with the statement (12%).

Figure 22. Workshop participants' feedback on the New European Bauhaus



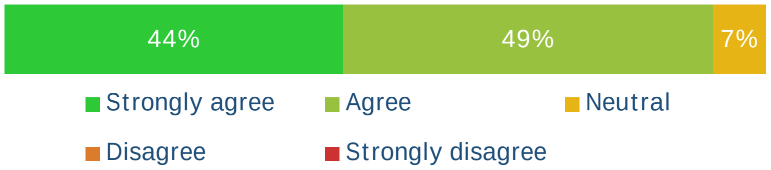
The last poll on the European Bauhaus led to the conclusion that sustainability and multidisciplinary networking were the two components of the initiative most recognised in the Pilot Project, respectively by 85% and 83% of the workshop participants (Figure 23). On the other hand, none of the participants recognised aesthetics as a component of the Pilot Project.

Figure 23. Workshop participants' feedback on "Which of the following components of the New European Bauhaus do you recognise in the Pilot Project?"



The Renovation Wave, a concrete initiative under the Green Deal, aims at increasing the pace and quality of renovation of existing buildings. A poll made during the workshop reflected a high level of agreement among participants (93% agreed/strongly agreed) on the statement that integrated retrofitting may help accelerating renovations in seismic countries in the EU within the scope of the Renovation Wave (Figure 24).

Figure 24. Workshop participants' feedback on "Integrated retrofitting may help accelerating renovations in seismic countries in the EU within the scope of the Renovation Wave"



In conclusion, the polls provided positive feedback concerning the potential contribution of the Pilot Project to the New European Bauhaus. In fact, the majority of participants agreed that the objectives and results of the Pilot Project are in line with the goals of the New European Bauhaus to bring the European Green Deal close to people, to be a place-based policy, and to create an attractive framework for sustainable living. Participants also identified the contribution of the Pilot Project to the Renovation Wave, as most agreed that the holistic approach of the Pilot Project may foster renovations in EU seismic countries.

8 Conclusions

The work prepared to date within the Pilot Project "Integrated techniques for the seismic strengthening and energy efficiency of existing buildings", presented during a recent JRC workshop, is summarised in this report. Main conclusions and feedback received during the workshop are presented in the following.

Existing seismic and energy upgrading techniques were presented along with their classification, considering, among others, cost and technological compatibility. Their applicability depends on building and structural typologies as identified during the ranking of energy efficiency technologies and the analysis of seismic retrofit measures, respectively. Thus, the comprehensive investigation of the EU building stock, starting from Italian exposure data, represents the starting point for analysing the effective use of both energy and seismic retrofit solutions. A strong interaction between the two expert communities (structural engineering and energy efficiency in buildings) was observed during the workshop discussions, identifying the important role of buildings' structural typologies and the use of heating degree days, without neglecting regional differences. In this multidisciplinary approach, cost represents a common language among different experts and stakeholders, as demonstrated by the classification of seismic and energy technologies.

A variety of potential solutions for combined and integrated retrofitting are being investigated and their applicability also depends on the particularities of building typologies. Care should be taken to ensure a similar level of invasiveness when different retrofit solutions are combined. Retrofit effectiveness, cost and down-time are of crucial importance but rely heavily on the type of the intervention and the building under consideration. Finally, special attention should be drawn to the built heritage, balancing the need for safeguarding and applying minimal interventions.

Developments in novel materials and technologies in the fields of seismic retrofitting and energy upgrading may lead to further advancements of fully integrated solutions that offer reduced downtime compared to combined solutions, while achieving high seismic and thermal performance with lower environmental impact. Further research and long-term progress in standardisation are still required to achieve such integrated solutions.

The analysis of potential standard and novel techniques for integrated retrofit indicates the need for a method to assess the combined effect of seismic and energy upgrading. A state-of-the-art review of existing methodologies served as a basis for the proposal of a simplified method capable of assessing the seismic, energy, and environmental performance of a retrofitted building during the entire life cycle through a global assessment parameter measured in monetary terms. The proposed method provides a simplified approach for practical design. Four representative case studies addressing public and residential masonry and RC buildings were identified. A standard method for the combined assessment (i.e. the Sustainable Structural Design methodology) was implemented in all the case studies considering both non-retrofit and retrofit scenarios. Forthcoming work will focus on the proper integration of the environmental building performance, including an adequate price for carbon, along with the implementation of the simplified assessment method in the aforementioned case studies.

Regions where interventions are of higher priority were identified, considering the seismic performance of buildings and socioeconomic indicators. The selection of data and methodology for seismic risk assessment was discussed, highlighting the general calculation framework along with seismic hazard, exposure and physical vulnerability models. Following the implementation of the framework, loss metrics at national and regional levels were calculated, providing initial insights into regional prioritisation. Socioeconomic indicators were selected and integrated within regional composite indicators, while a methodology for prioritising regions using multiple composite indicators was proposed. Priority regions will be revised and updated as further development of models is undertaken, whereas regional energy performance assessment of buildings will be also considered.

Implementing measures, such as legislation, incentives, guidance and standards for seismic strengthening and energy upgrading of buildings were collected across 16 EU Member States. Identified measures were classified, and their efficiency is being assessed.

Generic intervention scenarios, defined for the Italian building stock, indicate that 30% of buildings are located within areas associated with a need for combined seismic and energy upgrading. Forthcoming work will assess the impact of detailed intervention scenarios across EU regions, and inform an action plan regarding the areas and the means to achieve a high impact.

Finally, past, ongoing, and future dissemination and outreach activities within the Pilot Project were presented, aiming to engage stakeholders, increase the visibility of projects results, and develop awareness. Participation statistics of the midterm workshop and results from a subsequent satisfaction survey indicate a positive reception of this first wide dissemination effort from a diverse audience of stakeholders. An interactive website, a second workshop at the Pilot Project's culmination, and future science for policy and technical reports will further support the project's outreach objectives.

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List of abbreviations and definitions

AAL	Average Annual Loss
AALR	Average Annual Loss Ratio
AeDES	Form for usability and damage survey of ordinary buildings in post-earthquake emergency
ASBC	Austrian Sustainable Building Council
BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung (German Federal Ministry of Transport, Building and Urban Development)
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CDD	Cooling Degree Days
CHB	Cultural Heritage Buildings
CLT	Cross-Laminated Timber
COM	Commission Communication
CZ	Climatic Zone
CSBS	Czech Sustainable Building Society
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council)
DPC	Dipartimento della Protezione Civile (Department of Civil Protection, Italy)
ECCE	European Council of Civil Engineers
EET	Energy Efficiency Technology options
ELSA	European Laboratory for Structural Assessment
ESHM	European Seismic Hazard Model
EU	European Union
EU-HDI	EU Human Development Index
EU-SPI	EU Social Progress Index
FRP	Fibre-Reinforced Polymer
GADM	Database of Global Administrative Areas
GBCe	Green Building Council España
GDP	Gross Domestic Product
GEM	Global Earthquake Model
HDD	Heating Degree Days
HKGBC	Hong Kong Green Building Council
HVAC	Heating, Ventilation, and Air Conditioning system
iiSBE	International Initiative for a Sustainable Built Environment
iRESIST+	"Innovative seismic plus energy retrofitting of the existing building stock" project
IRPP	Integrated Retrofitting Performance Parameter
ISO	International Organization for Standardization
JRC	Directorate–General Joint Research Centre
JSBC	Japan Sustainable Building Consortium
KOCED	Korea Construction Engineering Development institute

LCA	Life Cycle Assessment
LCEA	Life Cycle Energy Assessment
LCT	Life Cycle Thinking
LD	Less-Developed regions based on GDP per capita
LGBC	Lebanese Green Building Council
LPS	Large Panel System buildings
MD	More-Developed regions based on GDP per capita
MS	Member State
NERA	“Network of European research infrastructures for earthquake risk assessment and mitigation” project
NTC	Norme tecniche per le costruzioni (Technical standards for construction, Italy)
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Co-operation and Development
OPCM	Ordinanza del Presidente del Consiglio dei Ministri (Ordinance of the President of the Council of Ministers)
OSB	Oriented Strand Board panel
PEER	Pacific Earthquake Engineering Research Center
PGA	Peak Ground Acceleration
REDi™	Resilience-based Earthquake Design Initiative rating system
ReLUIS	Rete dei Laboratori Universitari di Ingegneria Sismica (The Laboratories University Network of Seismic Engineering, Italy)
RC	Reinforced Concrete
SAFESUST	“Safety and sustainability” project
SCZ	Combined Seismic and Climatic classification Zone
SERA	“Seismology and earthquake engineering research infrastructure alliance for Europe” project
SEP+	“Development of textile-reinforced mortar and capillary tube panel retrofitting technology to simultaneously improve seismic and energy performance of the existing buildings” project
sPBA	Simplified Performance-Based Assessment method
SPEctRUM	“Seismic plus energy upgrading of masonry buildings using advanced materials” project
SSD	Sustainable Structural Design method
SURECON	“Sustainable integrated retrofit of concrete buildings” workshop
SZ	Seismic Zone
TABULA	“Typology approach for building stock energy assessment” project
TRM	Textile-Reinforced Mortar
USGBC	US Green Building Council
WP	Work Package

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Annexes

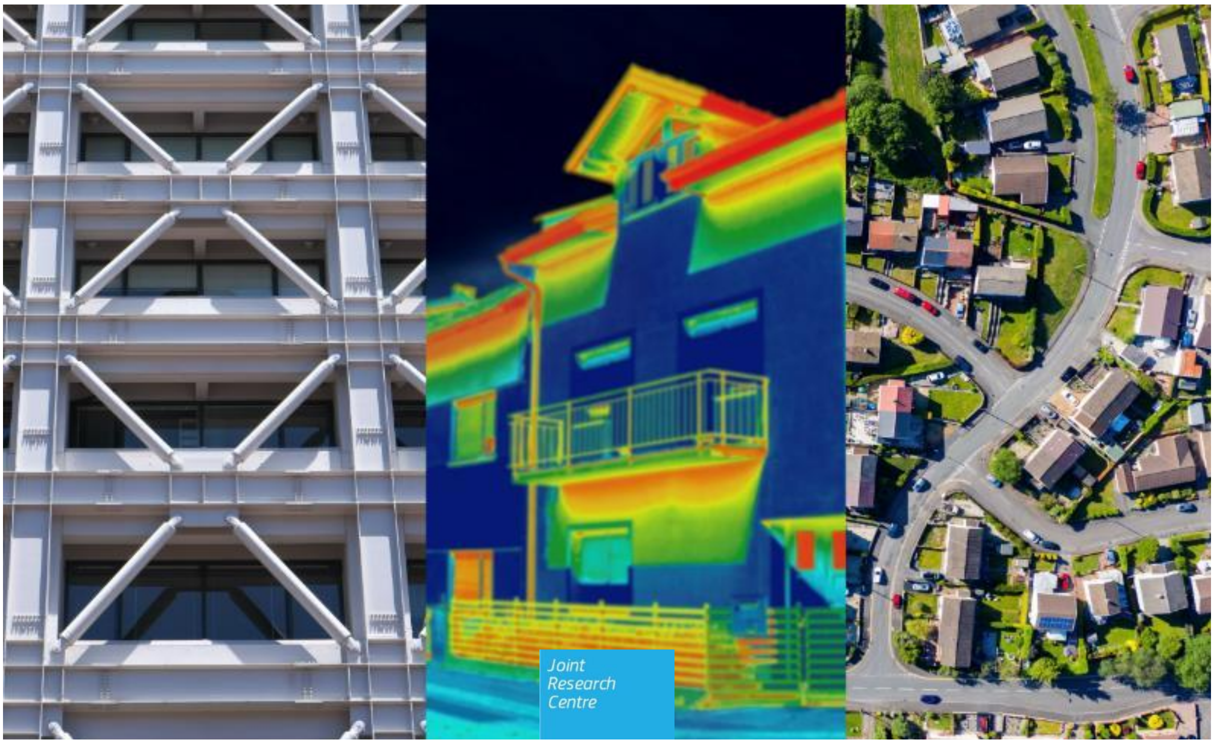
Annex 1. Midterm workshop agenda

European Commission

Workshop Agenda

Integrated techniques for the seismic strengthening and energy efficiency of existing buildings

16–19 November 2020



16 November 2020 (8:30–14:00 CET)

Opening session (08:30–11:00 CET)

Moderator:	Artur Pinto Head of Unit, Joint Research Centre, European Commission
08:30–09:00	Virtual waiting lobby
09:00–09:10	**Welcome** Dan Chirondojan Director, Joint Research Centre, European Commission
09:10–09:20	**European Pilot Project: Integrated techniques for the seismic strengthening and energy efficiency of existing buildings** Silvia Dimova Deputy Head of Unit, Joint Research Centre, European Commission
09:20–09:30	**Intervention by MEP** Pernille Weiss Member of the European Parliament
09:30–09:40	**The need for integrating seismic upgrade of existing buildings with energy efficiency improvements** Aris Chatzidakis President, European Council of Civil Engineers
09:40–09:50	**The Renovation Wave** Dimitrios Athanasiou Policy officer, DG Energy, European Commission
09:50–10:00	**Strategy for a sustainable built environment** Manfred Fuchs Policy senior assistant, DG Internal Market, Industry, Entrepreneurship and SMEs, European Commission
10:00–10:10	**Intervention by MEP** Ciarán Cuffe Member of the European Parliament

10:10–10:20 **Superbonus 110: Italian tax deduction scheme for energy and seismic upgrades**

Mauro Dolce
General Director, Italian Civil Protection Department

10:20–10:30 **Bulgarian perspective for implementation of technical passports for buildings**

Dima Lekova
Head of Department, Ministry of Regional Development and Public Works, Republic of Bulgaria

10:30–10:40 **Intervention by the Committee of the Regions**

Tjisse Stelpstra
Member of the Council of the Province of Drenthe, Netherlands

10:40–11:00 Break

Regional impact assessment and contributions to an action plan (11:00–14:00 CET)

11:00–11:05 **Introduction**

Georgios Tsionis
Project officer, Joint Research Centre, European Commission

11:05–11:30 **Overview of the Pilot Project and work in Actions 4 and 5**

Konstantinos Gkatzogias
Project officer, Joint Research Centre, European Commission

11:30–12:00 **Seismic risk assessment at European regions**

Helen Crowley
EUCENTRE

12:00–12:15 **Discussion**

12:15–12:30 Break

12:30–12:40 **Implementing measures for upgrading buildings in Bulgaria, Croatia, Cyprus, Greece, Romania and Slovenia**

Roumiana Zaharieva
Associate Professor, University of Architecture, Civil Engineering and Geodesy, Sofia

12:40–12:50 **Implementing measures for upgrading buildings in France, Malta, Portugal and Spain**

Helena Gervasio
Assistant Professor, University of Coimbra

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12:50–13:00 **Implementing measures for upgrading buildings in Austria, Germany, Hungary, Slovakia and Sweden**

Christoph Butenweg
SDA Engineering

13:00–13:10 **Implementing measures for upgrading buildings in Italy**

Angelo Masi
Professor, University of Basilicata

13:10–13:30 **Discussion**

13:30–13:50 **Complementary projects**

Novel integrated approach for seismic and energy upgrading of existing buildings
Christis Chrysostomou
Professor, Cyprus University of Technology

Earthquake-resilient school projects in the territory of Algarve and Huelva
Beatriz Zapico
Researcher, University of Seville

13:50–14:00 **Closure**

Georgios Tsionis
Project officer, Joint Research Centre, European Commission

17 November 2020 (9:00–13:00 CET)

Overview and classification of technologies for seismic strengthening and energy upgrading of existing buildings

09:00–09:30	Virtual waiting lobby
09:30–09:40	**Opening and introduction** Paolo Negro Project officer, Joint Research Centre, European Commission
09:40–10:10	**Presentations of complementary background activities** *The SAFESUST approach* Paolo Negro Project officer, Joint Research Centre, European Commission *SAFESUST Workshop: A roadmap for the improvement of earthquake resistance and eco-efficiency of existing buildings and cities* Alessandra Marini Associate Professor, University of Bergamo *SAFESUST 2 – SURECON Workshop: A roadmap for a SUstainable integrated REtrofit of CONcrete buildings* Ornella Iuorio Associate Professor, University of Leeds
10:10–10:20	**Progress on Action 1** Elvira Romano Project officer, Joint Research Centre, European Commission
10:20–10:40	**Building typologies most needing upgrading** Christopher Butenweg SDA Engineering
10:40–11:10	**Focus on Italian masonry and RC buildings most needing upgrading** Angelo Masi Professor, University of Basilicata Giuseppe Santarsiero Assistant Professor, University of Basilicata
11:10–11:20	Break

11:20–11:40	**Technology options for seismic upgrading**
	Andrea Belleri Associate Professor, University of Bergamo
11:40–12:10	**Technology options for energy upgrading**
	Ivan Jankovic Building Performance Institute Europe (BPIE)
12:10–12:55	**Discussion**
12:55–13:00	**Conclusions and closure**

18 November 2020 (9:00–13:00 CET)

Analysis of technologies for combined upgrading of existing buildings

09:00–09:30	Virtual waiting lobby
09:30–09:40	**Opening and introduction** Dionysios Bournas Project Officer, Joint Research Centre, European Commission
09:40–10:20	**Complementary background activities: the iRESIST+ project** Dionysios Bournas and Daniel Pohoryles Project Officers, Joint Research Centre, European Commission
10:20–10:25	**Progress on Action 2: Introduction** Daniel Pohoryles Project Officer, Joint Research Centre, European Commission
10:25–10:50	**Advanced and novel seismic retrofitting technologies** Thanasis Triantafillou Professor, University of Patras
10:50–11:05	**Advanced and novel energy upgrading technologies** Bjørn Petter Jelle Professor, Norwegian University of Science and Technology; Chief Scientist, SINTEF
11:05–11:20	Break
11:20–11:35	**Overview of technology options for integrated upgrading** Francesca da Porto Professor, University of Padua
11:35–11:50	**Analysis of technologies for combined upgrading** Giuseppe Santarsiero Assistant Professor, University of Basilicata
11:50–12:05	**Technologies for the improvement of cultural heritage buildings** Daniel Oliveira Associate Professor, University of Minho
12:05–12:15	Break
12:15–13:00	**Discussion: Progress and future challenges**

19 November 2020 (9:00–13:00 CET)

Methodologies for assessing the combined effect of upgrading (09:00–12:15 CET)

09:00–09:30 Virtual waiting lobby

09:30–09:40 **Opening and introduction**

Paolo Negro
Project officer, Joint Research Centre, European Commission

09:40–09:50 **Progress on Action 3**

Elvira Romano
Project officer, Joint Research Centre, European Commission

09:50–10:10 **Existing assessment methods of combined upgrading**

Petr Hájek
Professor, Czech Technical University in Prague

10:10–10:30 **Proposal of a simplified method for combined assessment of building upgrading**

Costantino Menna
Assistant Professor, University of Naples Federico II

Andrea Prota
Professor, University of Naples Federico II

10:30–10:50 **Case studies identification and simplified method application to retrofitted buildings**

Antonello Formisano
Assistant Professor, University of Naples Federico II

10:50–11:00 Break

11:00–11:30 **Presentation of complementary ongoing research projects: Italian DPC–ReLUIS project (2019–2021)**

Rapid and integrated interventions of low impact for both seismic vulnerability and energy consumption reduction of existing buildings
Andrea Prota
Professor, University of Naples Federico II
Francesca da Porto
Professor, University of Padua

11:30–11:55 **Discussion**

11:55–12:00 **Conclusions and closure**

12:00–12:15 Break

Closing session (12:15–13:00 CET)

12:15–12:55 **Conclusions, recommendations, and further steps**

Action 1
Paolo Negro
Project Officer, Joint Research Centre, European Commission

Action 2
Dionysios Bournas
Project Officer, Joint Research Centre, European Commission

Action 3
Paolo Negro
Project Officer, Joint Research Centre, European Commission

Action 4
Georgios Tsionis
Project Officer, Joint Research Centre, European Commission

12:55–13:00 **Closure**

Silvia Dimova
Deputy Head of Unit, Joint Research Centre, European Commission

Connection details:
Meeting ID: 560 637 3884
Password: ##Explore2

https://europa.zoom.us/j/5606373884?pwd=c0YrRy9GTG1tT2FmYlA5VjVkRGpBZz09
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Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

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EU Science, Research and Innovation

EU Science Hub

Annex 2. Midterm workshop JRC presentations

Presentations delivered by JRC Pilot Project team members during the midterm workshop are provided below. Presentations are ordered by workshop day (see Annex 1).

Seismic and energy retrofit of buildings

Overview of the pilot project

Georgios Tsionis, Silvia Dimova

Workshop "Integrated techniques for seismic strengthening and energy efficiency of existing buildings

16 -19 November 2020

Joint Research Centre

European Pilot Project

Integrated techniques for the seismic strengthening and energy efficiency of existing buildings

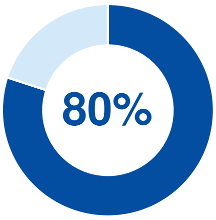
2018: proposed by the European Parliament

2019: financed by EU with Decision C(2019) 3874

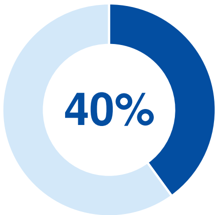
2019 - 2022: led by the JRC

European Commission

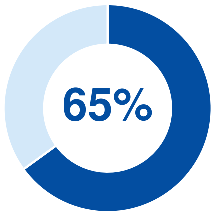
European building stock



Buildings in EU constructed before 1990



Buildings in EU located in seismic regions and designed with inferior safety requirements



Buildings in seismic regions need both energy and seismic retrofit

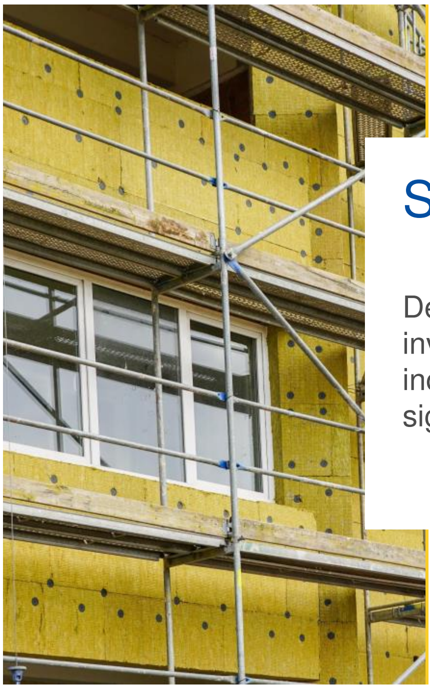
Policy goals

Green Deal
Renovation wave
New European Bauhaus
Energy Performance of Buildings

New Industrial Strategy for Europe
New Circular Economy Action Plan

Action Plan on the Sendai Framework
Sustainable Development Goal 11

European Framework for Action on Cultural Heritage
European Agenda for Culture



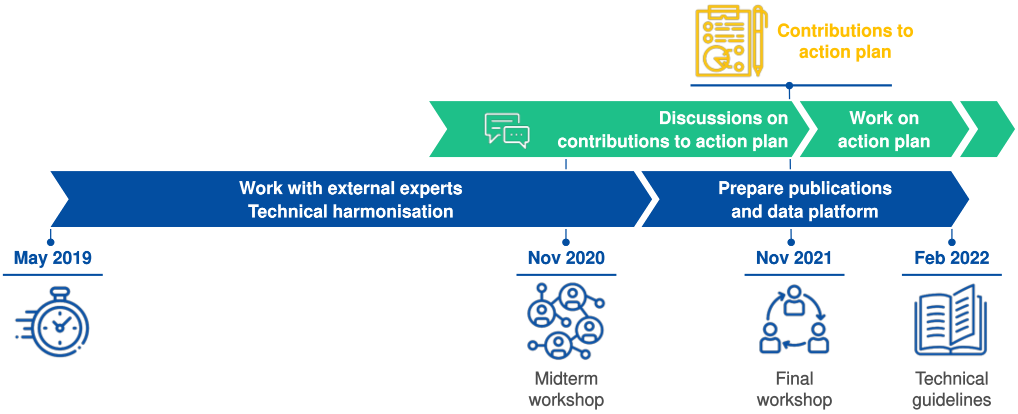
Scope

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.

Objectives

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

Timeline



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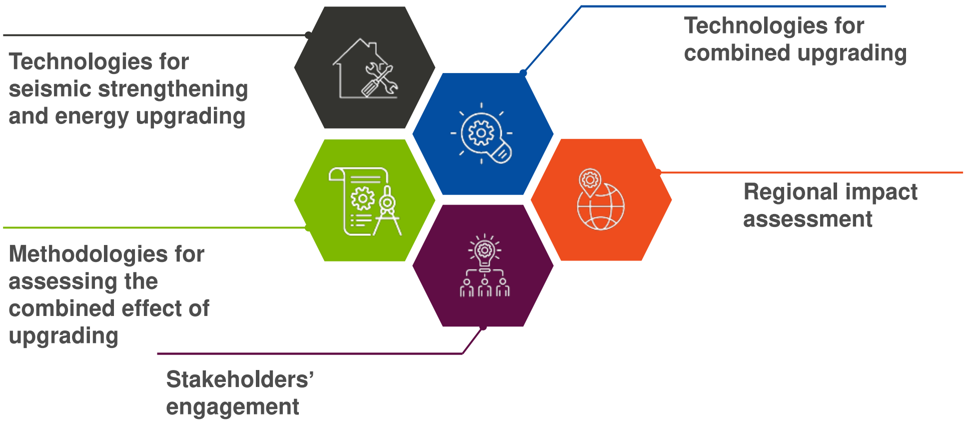
Pilot project actions



8

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Action 1

Overview and classification of technologies for seismic strengthening and energy upgrading of existing buildings

- Identification of **building typologies** that require renovation
- Review of technology options for the **seismic upgrading** of existing buildings
- Review of technology options for the **energy upgrading** of existing buildings

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Action 2

Analysis of technologies for combined upgrading of existing buildings

- Review of **technology options** for combined seismic and energy upgrading
- Analysis of **novel technologies** for combined seismic and energy upgrading

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Action 3

Methodologies for assessing the combined effect of upgrading

- Review of **methods to assess improvement** of seismic safety and energy efficiency
- **Definition of a method** for a combined assessment of the upgrading
- Implementation of methods on **case studies**

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Action 4

Regional impact assessment and proposals in support of an action plan

- Identify **priority regions for renovation** based on risk and socio-economic indicators
- Review **implementing measures**
- Identify and compare **scenarios for intervention**

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Action 5

Stakeholders' engagement

Involvement during the project through workshops on technical and policy issues

Dissemination and outreach

Open and free data to support regional policies

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Output

- Building typologies most needing upgrading
- Classification of technologies
- Selection of best combined renovation technique
- Method to assess the benefits gained from integrated retrofit

14

Output

- Regions where renovation can achieve highest impact
- Retrofit scenarios and impact analysis
- Web platform for sharing data, knowledge and best practices

15

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The JRC Pilot Project team

Silvia Dimova
Paolo Negro
Georgios Tsionis
Dionysios Bournas
Konstantinos Gkatzogias
Daniel Pohoryles
Elvira Romano
Maria Luisa Sousa
Desislava Strezova
Martin Poljansek
Maria Fabregat
our 22 experts

16

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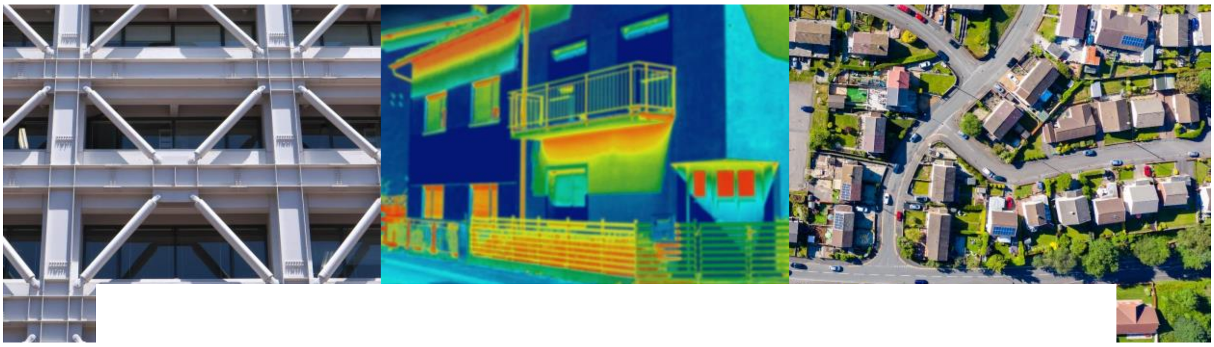

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Thank you

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

Overview of the Pilot Project and work in Actions 4 and 5

Konstantinos Gkatzogias

16 November 2020

Layout

- Pilot Project – Overview
- Action 4 – Regional impact assessment & contributions to an action plan
- Action 5 – Stakeholders' engagement

2

Pilot Project

Overview

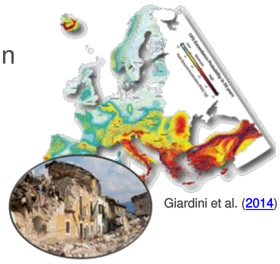
Introduction

Pilot Project scope

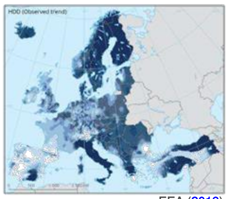
Define solutions that, at the same time and in the least invasive way, can both reduce seismic vulnerability and increase energy efficiency in such a way to produce a significant positive environmental impact

Main objectives

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



Giardini et al. (2014)



EEA (2019)

Buildings: 38.1% of energy consumption in EU

Future EU Action Plan

4

Policy goals

Green Deal
Renovation wave
New European Bauhaus
Energy Performance of Buildings

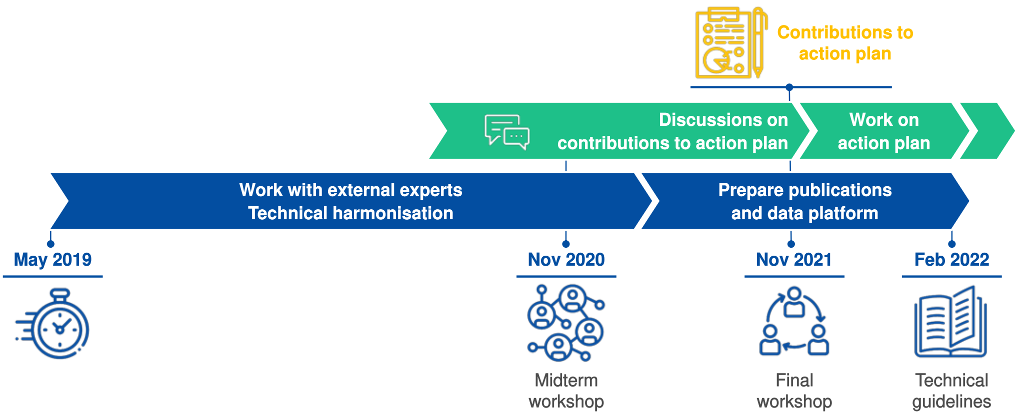
New Industrial Strategy for Europe
New Circular Economy Action Plan

Action Plan on the Sendai Framework
Sustainable Development Goal 11

European Framework for Action on Cultural Heritage
European Agenda for Culture

5

Timeline



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Regional impact assessment & contributions to an action plan

Priority regions
Rank EU regions based on:
seismic risk, energy performance of buildings, socio-economic indicators

Implementing measures
Review legislation, incentives, guidance and standards prescribed in EU Member States

Scenarios for interventions
Define concurrent and non-concurrent scenarios (considering also replacement)
Assess scenarios at regional level in terms of seismic safety & energy efficiency

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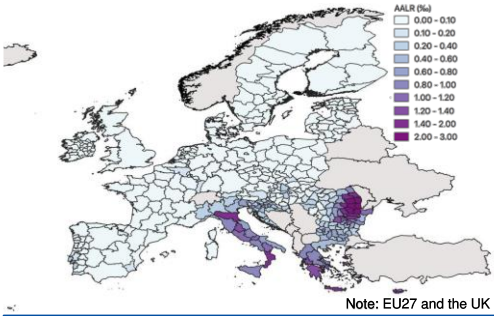
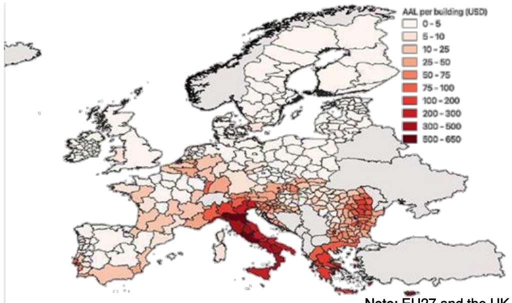
Seismic risk assessment



Note: EU27 and the UK



Note: EU27 and the UK

AALR
absolute loss normalised to exposure value

AAL per building
absolute loss normalised to exposure size

Socio-economic indicators

Regional socio-economic indicators

- Sources: Eurostat; EU-SILC; Gallup World Poll

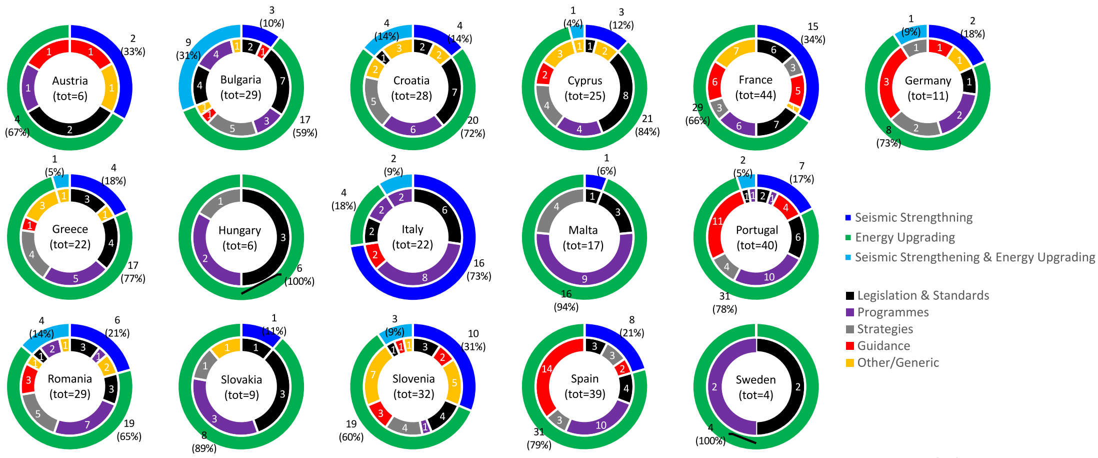
Regional composite indicators

- EU-Human Development Index (EU-HDI): socio-economic development
- Europe 2020 Index: progress in line with Europe 2020 Strategy
- Social Progress Index: social and environmental performance (non-economic)

Regional groups based on GDP per capita

- Less-developed (LD) regions: GDP < 75 % of EU average
- Transition regions: 75 % ≤ GDP ≤ 90 % of EU average
- More-developed (MD) regions: GDP > 90 % of EU average

Implementing measures



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Implementing measures

- Various “energy” strategies and programmes with elevating demands
- Lack of “seismic” and “combined” measures
  - Less public awareness
  - Engagement of hard-to-reach groups: building as a whole, service interruption, consent
  - Cost issues (e.g. non-regulated prices)
  - Scarce data
- Seismic insurance schemes in France, Spain, Portugal

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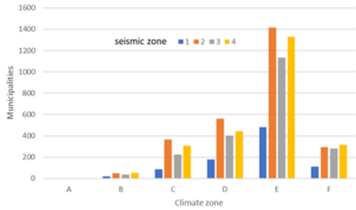
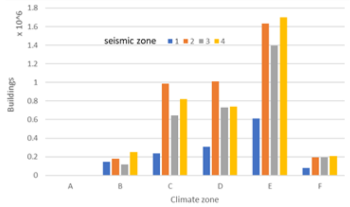
Scenarios for intervention in Italy

Seismic zones (ZS): 1–4 (by decreasing seismic demand; PGAs)

Climatic zones (ZC): A–F (by increasing energy demand; HDDs)

Italian exposure data
total number of buildings and population aggregated at municipality level & distributed among ZS, ZC → → →





Distribution of buildings & population by combined ZSC ↓ ↓

SCZ	Seismic Zone	Climate Zone	No. of buildings (x10^6)	No. of buildings (%)	Population (x10^6)	Population (%)
SCZ1	1-2	D-E-F	3.84	31.47%	19.13	31.64%
SCZ2a	1-2	A-B-C	1.55	12.74%	8.00	13.23%
SCZ2b	3-4	D-E-F	4.96	40.70%	25.18	41.66%
SCZ3	3-4	A-B-C	1.84	15.09%	8.14	13.47%
		Total	12.19	100.00%	60.45	100.00%

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Scenarios for intervention in Italy

Definition of intervention scenarios →

- based on seismic and energy demand
- potential extent of field of application
- buildings/population imply similar trends
- largest share of buildings/population

SCZ	Intervention Scenario
SCZ1	Comprehensive concurrent seismic and energy upgrading; possible demolition/reconstruction
SCZ2a	Seismic upgrading with minor energy efficiency upgrading
SCZ2b	Energy upgrading with minor seismic upgrading
SCZ3	Minor (or none) seismic and energy upgrading

SCZ	Seismic Zone	Climate Zone	No. of buildings (x10^6)	No. of buildings (%)	Population (x10^6)	Population (%)
SCZ1	1-2	D-E-F	3.84	31.47%	19.13	31.64%
SCZ2a	1-2	A-B-C	1.55	12.74%	8.00	13.23%
SCZ2b	3-4	D-E-F	4.96	40.70%	25.18	41.66%
SCZ3	3-4	A-B-C	1.84	15.09%	8.14	13.47%
		Total	12.19	100.00%	60.45	100.00%

Vulnerability: based on age

- $I_v = \frac{A_{c,m}}{A_{class}} \rightarrow R_s$ municipality level

Seismic risk zones (ZR)
(i) moderate-to-high: $R_s \geq$ medianR_s
(ii) low-to-moderate: $R_s <$ medianR_s

Distribution of buildings & population by combined Z(R)SC → → →

S(R)CZ	Seismic (risk) zone	Climatic zone	No. of buildings (x10^6)	No. of buildings (%)	Population (x10^6)	Population %
R1	medium-high	D-E-F	3.95	32.40	20.78	34.38
R2a	medium-high	A-B-C	2.60	21.33	11.46	18.96
R2b	low-medium	D-E-F	4.85	39.76	23.53	38.92
R3	low-medium	A-B-C	0.79	6.50	4.68	7.74
		Total	12.19	100	60.45	100

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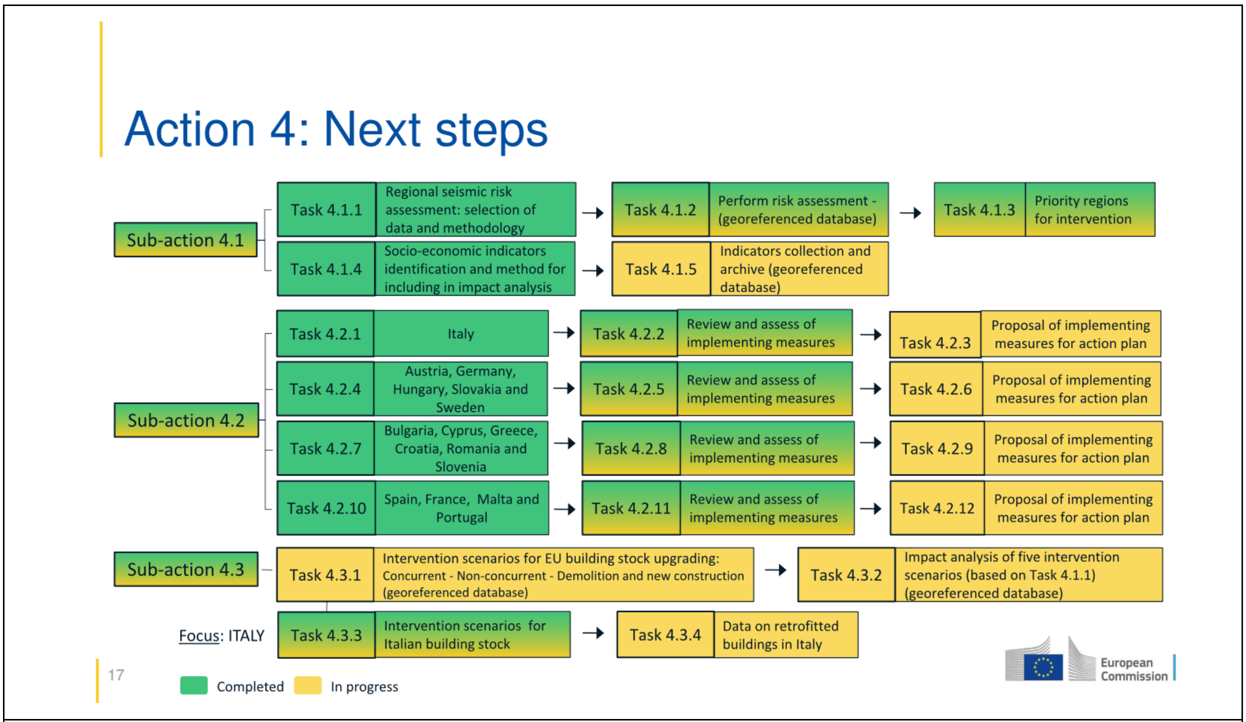

Action 4: Next steps
Sub-action 4.1
Task 4.1.1
Regional seismic risk assessment: selection of data and methodology
Task 4.1.2
Perform risk assessment - (georeferenced database)
Task 4.1.3
Priority regions for intervention
Task 4.1.4
Socio-economic indicators identification and method for including in impact analysis
Task 4.1.5
Indicators collection and archive (georeferenced database)
Sub-action 4.2
Task 4.2.1
Italy
Task 4.2.2
Review and assess of implementing measures
Task 4.2.3
Proposal of implementing measures for action plan
Task 4.2.4
Austria, Germany, Hungary, Slovakia and Sweden
Task 4.2.5
Review and assess of implementing measures
Task 4.2.6
Proposal of implementing measures for action plan
Task 4.2.7
Bulgaria, Cyprus, Greece, Croatia, Romania and Slovenia
Task 4.2.8
Review and assess of implementing measures
Task 4.2.9
Proposal of implementing measures for action plan
Task 4.2.10
Spain, France, Malta and Portugal
Task 4.2.11
Review and assess of implementing measures
Task 4.2.12
Proposal of implementing measures for action plan
Sub-action 4.3
Task 4.3.1
Intervention scenarios for EU building stock upgrading: Concurrent - Non-concurrent - Demolition and new construction (georeferenced database)
Task 4.3.2
Impact analysis of five intervention scenarios (based on Task 4.1.1) (georeferenced database)
Focus: ITALY
Task 4.3.3
Intervention scenarios for Italian building stock
Task 4.3.4
Data on retrofitted buildings in Italy
17
Completed
In progress
European Commission


Action 5
Stakeholders' engagement
European Commission

Stakeholders’ engagement

Involvement of stakeholders during the project

- Involve stakeholders in enquires on relevant measures, technologies & methodologies
- Organise workshops

Dissemination and outreach

Achieve visibility of project results, awareness of the need for further measures at European level, and support the follow-up action plan by means of:

a) public communication material

b) a web platform (including a technical area/repository)

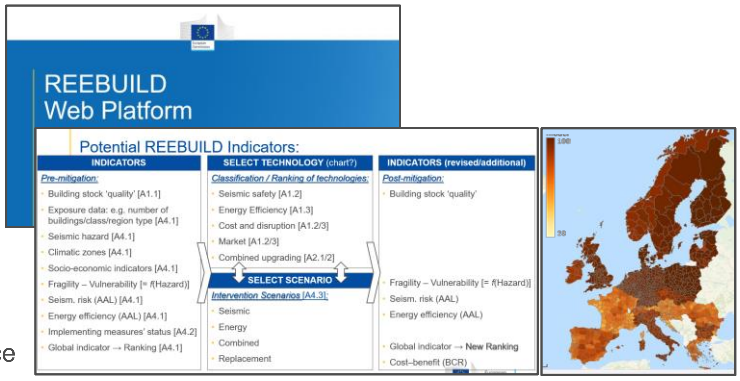
c) technical and science for policy reports

Dissemination material & activities

Web platform

Sections

- Home
- About
- Actions
- Policy
- News & Events
- Library / Repository
- Software & Tools
- Community of Practice
- Contact



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Web platform

Which of the following web-platform sections are you keen to use?
(please select up to three)

- About the pilot project
- Policy context
- Library
- Community of practice
- Data repository and visualisation
- Tools for data processing
- News and events

European Commission

Acknowledgments

Unit E4: Safety and Security of Buildings
Dir E: Space Security and Migration
Joint Research Centre, European Commission

Artur Pinto
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Dionysios Bournas
Georgios Tsionis
Martin Poljansek
Elvira Romano
Daniel Pohoryles
Maria Luisa Sousa
Desislava Strezova
Maria Fabregat

European Commission

References

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European Environment Agency (EEA) (2019) 'Heating and cooling degree days', *EEA*, Indicators

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

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Thank you

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

Previous/associated work: the SAFESUST project

Paolo Negro , Elvira Romano et al.
17 November 2020

Joint Research Centre

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

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

2

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Life Cycle Analysis (LCA, from cradle to grave…)

3

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Life Cycle Analysis (LCA, from cradle to grave)

Many LCA assessment procedures….

- Different criteria
- Lack interoperability
- Long and difficult

- Only a posteriori….

BREEAM
greenstar
SBTool
LEED
HQE CASBEE DGNB

4

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How to match safety with sustainability?

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

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How to optimize all performances?

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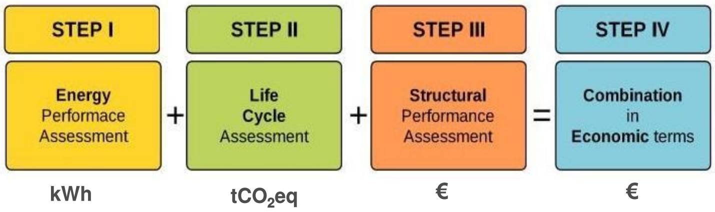
How to optimize all performances?

Sustainable Structural Design (SSD)
methodology



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

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Can we define a cost for safety?

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

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

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

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A Simplified Performance Based Assessment

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

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

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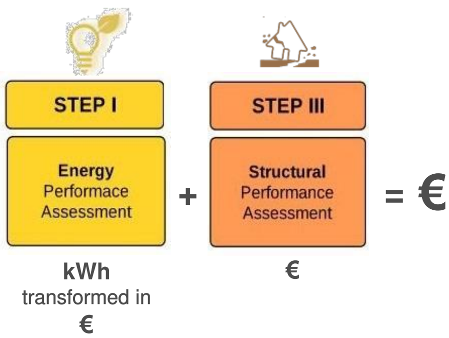
A total cost for the building



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

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

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How about sustainability?

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

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Back to Life Cycle Analysis

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

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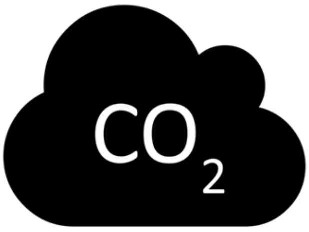
A global performance indicator



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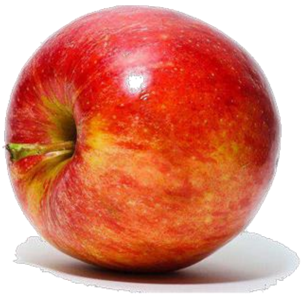
A global performance indicator



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

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The *price* of Carbon

“Carbon must have its price – because Nature cannot pay the price anymore”

(President von der Leyen, State of the Union Address)

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The *price* of Carbon

Cost of equivalent CO_2 emissions:

European Union Emission Trading System

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

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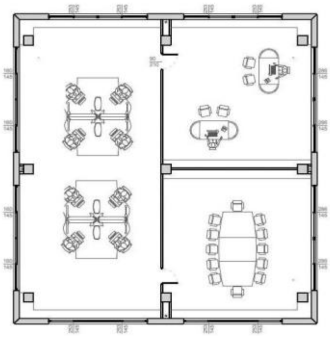
Application to a building



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

Location: ***Barcis (PN)***
PGA = 0.25 g
Zone F → U = 0.26 W/m²K
Office occupancy
Service life 50 years

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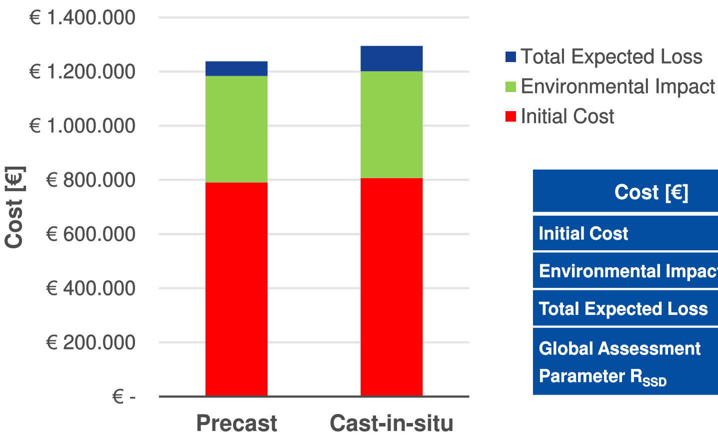
Application to a building



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

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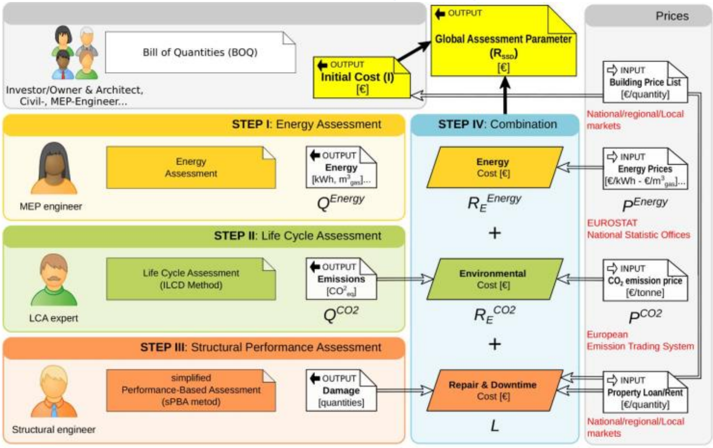
Costs as a common language….



(Lamperti et al, 2018)

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

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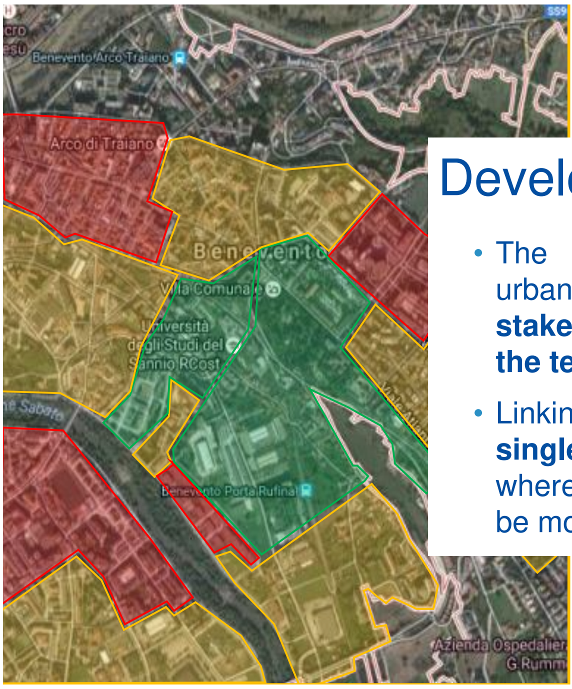

Developments of the methodology

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

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

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Not only earthquakes

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

SURECON:

A ROADMAP FOR A SUSTAINABLE INTEGRATED RETROFIT OF CONCRETE BUILDINGS

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

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Thank you

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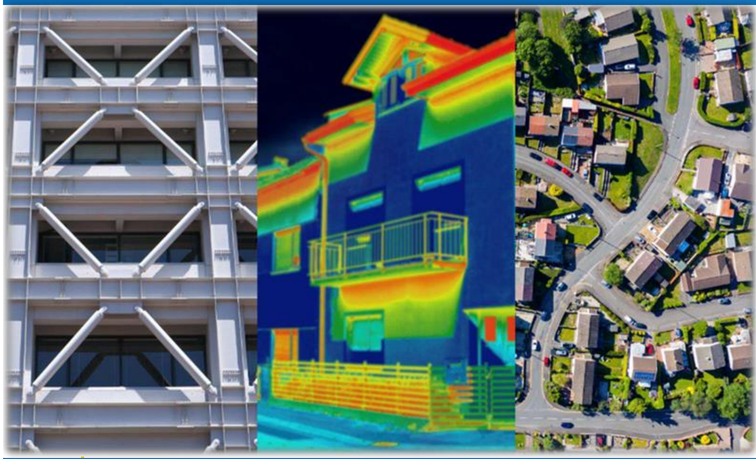
MIDTERM WORKSHOP

16 - 19 November 2020

PILOT PROJECT

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



ACTION 1

17 November 2020

OVERVIEW AND CLASSIFICATION OF TECHNOLOGIES FOR SEISMIC STRENGTHENING AND ENERGY UPGRADING OF EXISTING BUILDINGS

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

Work Progress in Action 1

Elvira Romano, Paolo Negro

17 November 2020

Contents

- Introduction
- Sub-action 1.1 – Work progress
- Sub-action 1.2 – Work progress
- Sub-action 1.3 – Work progress

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Introduction

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Action 1: Sub-actions

1 - TECHNOLOGIES FOR SEISMIC STRENGTHENING AND ENERGY UPGRADING

SUB-ACTION 1.1 - Building typologies needing upgrading

Identify representative classes of buildings regarding both seismic & energy performance

SUB-ACTION 1.2 - Technology options for seismic upgrading

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

SUB-ACTION 1.3 - Technology options for energy upgrading

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

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Action 1: Tasks

1 - TECHNOLOGIES FOR SEISMIC STRENGTHENING AND ENERGY UPGRADING

SUB-ACTION 1.1
- Task 1.1.1 — • Age distribution • Structural typologies
- Task 1.1.2 — • Climatic zones • Seismic exposure
- → EU: Task 1.1.3 — Building typologies most needing upgrading
- Focus: ITALY
  - Task 1.1.4 — Masonry buildings
  - Task 1.1.5 — RC buildings

SUB-ACTION 1.2
- Task 1.2.1 — Technology options for seismic upgrading → Task 1.2.2 — Classification of seismic upgrading technologies by cost, disruption, compatibility with energy measures

SUB-ACTION 1.3
- Task 1.3.1 — Technology options for energy upgrading → Task 1.3.2 — Classification of energy upgrading technologies by cost, disruption, compatibility with seismic measures

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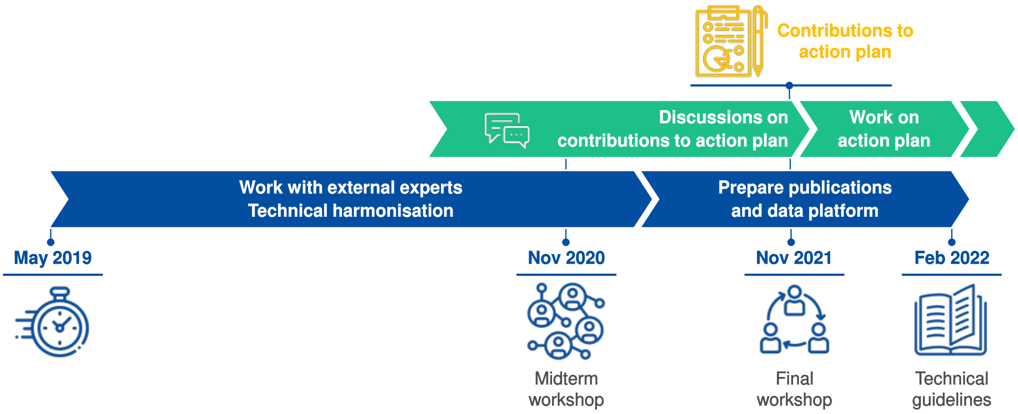
Timeline



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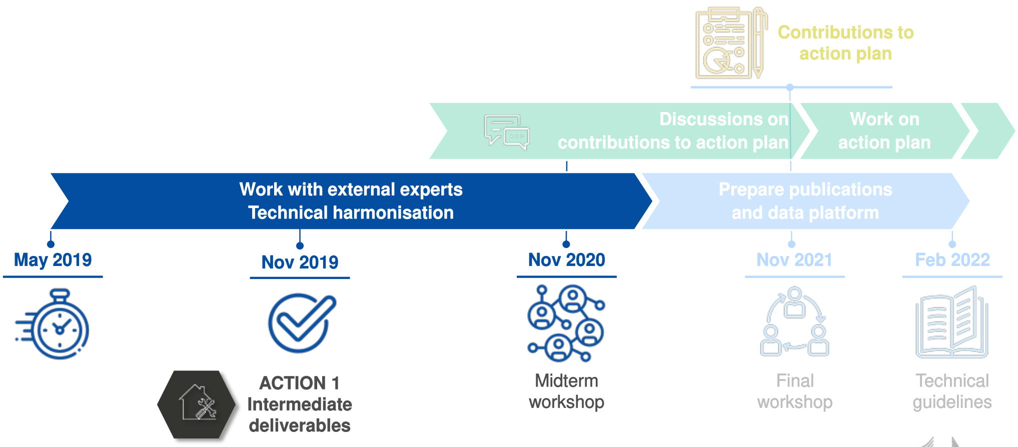
Timeline



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Sub-action 1.1

Work Progress

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Building typologies needing upgrading

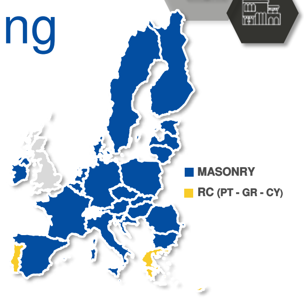
Distribution of building typologies by year of construction

- Analysis of EU dwellings distribution by ***year of construction***, ***building typologies*** (based on number of dwellings), ***surface area***
- Classification of EU buildings by **construction technology** (EU projects: TABULA/EPISCOPE; NERA)
- Analysis of buildings share by year of construction at regional/province level per each EU country

22% Buildings before 1945

79% Buildings before 1991

Data source:
European Statistical System (EES), *2011 Population and Housing Census* data - EUROSTAT, Census Hub



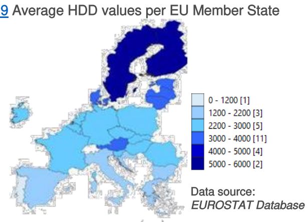
European climatic zones & seismicity

- Maps of Europe in terms of **seismic hazard** (ESHM13) and **climatic zones** (in terms of HDD)
- Specific analysis of seismic hazard and climatic zones per EU Member State
- Identification of EU regions with high seismic and climatic exposure: (1) **Bulgaria**, (2) **Croatia**, (3) **Greece**, (4) **Italy**, and (5) **Romania**

European Seismic Hazard Map

Giardini et al. (2014)

2019 Average HDD values per EU Member State



Data source:
EUROSTAT Database

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Building typologies needing upgrading

Prioritization of building typologies needing upgrading

- EU regions with moderate to high seismic exposure and high HDD climatic exposure (e.g. from Zone 3 to Zone 5)
- Correlation of seismic hazard-climatic zones with building distribution in terms of age of construction and construction technologies

Correlation matrix for the five selected EU Member States

HDD	SEISMIC HAZARD LEVEL Low	Moderate	High	EU Country
Zone 1		X (Andros)	X (Athens)	GR
Zone 1	X (Sassari)	X (Salerno)	X (Naples)	IT
Zone 2		X (Pleven)	X (Plovdiv)	BG
Zone 2	X (Zadar)	X (Split)	X (Dubrovnik)	HR
Zone 2		X (Kozani)	X (Thessaloniki)	GR
Zone 2	X (Bari)	X (Pisa)	X (Perugia)	IT
Zone 2		X (Bucharest)		RO
Zone 3		X (Sofia)	X (Blagovgrad)	BG
Zone 3	X (Osijek)	X (Primorje-Gorski kotar)	X (Zagreb)	HR
Zone 3		X (Dykiti Makedonia)		GR
Zone 3	X (Como)	X (Vicenza)	X (Bergamo)	IT
Zone 3	X (Cluj)	X (Satu Mare)	X (Vrancea)	RO
Zone 4	X (Verbano-Cusio-Ossola)			IT
Zone 4	X (Bistrita)	X (Hargita)	X (Covasna)	RO
Zone 5	X (Aosta)	X (Bolzano)	X (Trento)	IT

- **Masonry** constructions for the majority of buildings in **Bulgaria**, **Croatia**, **Italy**, and **Romania**
- Same fractions of **masonry** and **RC** constructions in **Greece**

Focus on building typologies needing upgrading within the Italian context

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

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Sub-action 1.2

Work Progress

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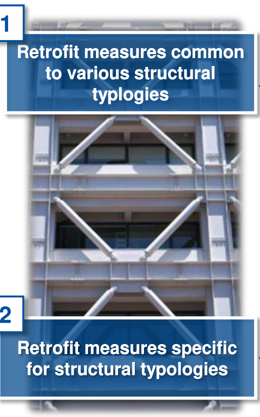
Technology options for seismic upgrading

Overview of seismic strengthening technologies for existing buildings



1 Retrofit measures common to various structural typlogies

- **Reduction of seismic demand**
  - **Additional damping**
  - **Seismic isolation**
- Provision of an effective **diaphragm floor**
  - **Intrados** solutions
  - **Overlay for RC - brick and block systems**
  - **Technology** for **wood floors**
  - **Technology** for **precast floors**
  - **Roof-box structure**
- **Global retrofit measures**
  - **New bracing system**
    - **Rocking walls e PreWEC system**
    - **Hinged walls**
    - **RC infills**
    - **Steel bracing (CBF - EBF - BRB)**
    - **RC walls**
  - **External exoskeleton**
    - **Diagrid systems**
    - **Cross laminated timber panels**
    - **Proprietary systems**

2 Retrofit measures specific for structural typologies

- **Reinforced concrete structures**
- **Masonry structures**
- **Steel structures**
- **Precast structures**

→ **Local retrofit measures**

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Classification of technologies for seismic upgrading

Classification by Life Cycle Thinking (LCT) criteria: 17 criteria and definition of grade (1–5)

	LIFE CYCLE THINKING (LCT) CRITERIA	SCORE 1–5			
A	**Holistic - integrated compatible**	1	No compatible with holistic	5	Fully compatible
B	**Incremental Rehabilitation**	1	No compatible with Incr. Rehab	5	Fully compatible
C	**Disruption of the occupants / relocation**	1	Relocation of occupants	5	Minimum disruption/short-no downtime
D	**Disruption to the building, such as to the electrical/plumbing distribution systems**	1	No disruption to electrical/plumbing systems	5	No disruption to electrical/plumbing systems

Classification by cost of intervention, disruption time, compatibility with energy upgrading

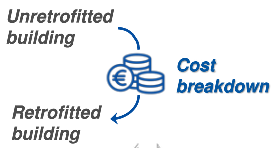
- Construction cost breakdowns of masonry and RC retrofitted buildings for a total of **25 case studies**
- Average **range of construction costs**
- Cost-effectiveness analysis exploring 3 iso-performance retrofit solutions on a selected RC building

Masonry buildings: 4 case studies

Case study	Improvement in the quality of the masonry	Perimeter ties	Roof/floor diaphragm	Improving in-plane res. of the walls	Retrofit of foundation system	Retrofit for static actions
Historic palace - Mantova province, Italy (Table2)	✓ (Local retrofit of masonry walls)	✓	✓			✓
Historical Palace, Garda lake, Italy (Table 3)	✓ (Local retrofit of masonry walls)	✓	✓	✓	✓	✓
Historical Church, Mantova province, Italy (Table 4)	✓ (Local retrofit of masonry walls)	✓	✓	✓ (diaphragm arches)		✓
Residential Building, Bergamo province, Italy (Table 5)		✓	✓	✓	✓	

RC buildings: 4 case studies

Case study	Strength. of frame joints	Exoskel. with shear walls	Shell exoskel.	Floor/roof diaphragm	Seismic base isolation	Retrofit for static loads	Energy efficiency retrofit
Gym Hall, Brescia, IT (Table7)			✓	✓			✓
School, Varese, IT (Table 8)		✓					
School, Lecco, IT (Table 9)		✓					
Residential Building, Garda lake, IT (Table 10)		✓		✓			✓



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Sub-action 1.3

Work Progress

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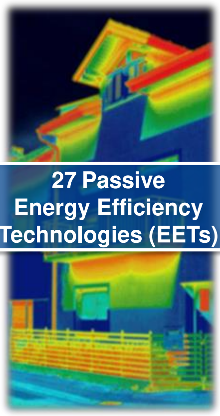
Technologies options for energy upgrading

Overview of energy upgrading technologies for existing buildings



- **27 Passive Energy Efficiency Technologies (EETs)**
  - **Category:** ENVELOPE
    - **Sub-categories:**
      - WALL
      - FLOOR
      - ROOF
      - WINDOW
      - DOOR

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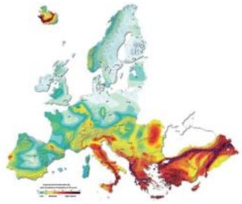
Classification of technologies for energy upgrading

Classification by building typologies

- Building typologies in **11 target countries**
  - *Single family house, Multi family house, Apartment Block, and non-residential buildings*
- Correlation of EETs with building typologies
- Impact of EETs on targeted building stock



Giardini et al. (2014)

HIGH	MODERATE
1. Bulgaria	1. Austria
2. Croatia	2. France
3. Cyprus	3. Portugal
4. Greece	4. Spain
5. Italy	
6. Romania	
7. Slovenia	

Classification by cost of intervention, disruption time, compatibility with seismic upgrading

	CRITERIA AND INDICATORS	MEASURE UNIT
1	Unitary cost of implementation	€/m² or €/unit
2	Unitary energy saved	kWh/m² or kWh/unit
3	Unitary cost-effectivity	kWh saved/€ invested
4	(Unitary) Disruption time	hours/m² or hours/unit
5	Unitary environmental impact	$KgCO_2/m^2$ or $KgCO_2$/unit
6	Users' comfort achieved	PPD/m² or PPD/unit
7	Life span	Years
8	Recycling possibility	Totally/Partial/Not applicable
9	Potential health risks in case of fire	High/Moderate/Low
10	Degree of compatibility with seismic retrofit measures	Totally/Restricted/Non compatible
11	Degree of relevance	Points

- ***Indicator 10*** – 20 Seismic Retrofit Technologies (SRT) (global and local)
- **Classification** by selected indicators
- Ranking of EETs through **multi-criteria decision making** analysis

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Classification of technologies for energy upgrading

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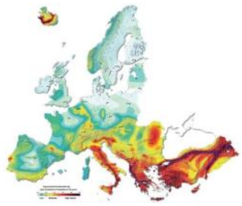

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10	Degree of compatibility with seismic retrofit measures	Totally/Restricted/Non compatible
11	Degree of relevance	Points

→

Example: ENV-WA-01
External Thermal Insulation Composite system (ETICS)

	Description	Value
1	Preparation of the supporting wall Application of ETICS (Lower bound) Application of ETICS (Higher bound)	30 €/m² 65 €/m² 110 €/m²
4	Preparation of the supporting wall Application of ETICS (Lower bound) Application of ETICS (Higher bound)	1 h/m² 0.75 h/m² 1.5 h/m²
7	Lower bound Higher bound Average	16 years 35 years 30 years
10	EET – SRTs compatibility	77.5 points

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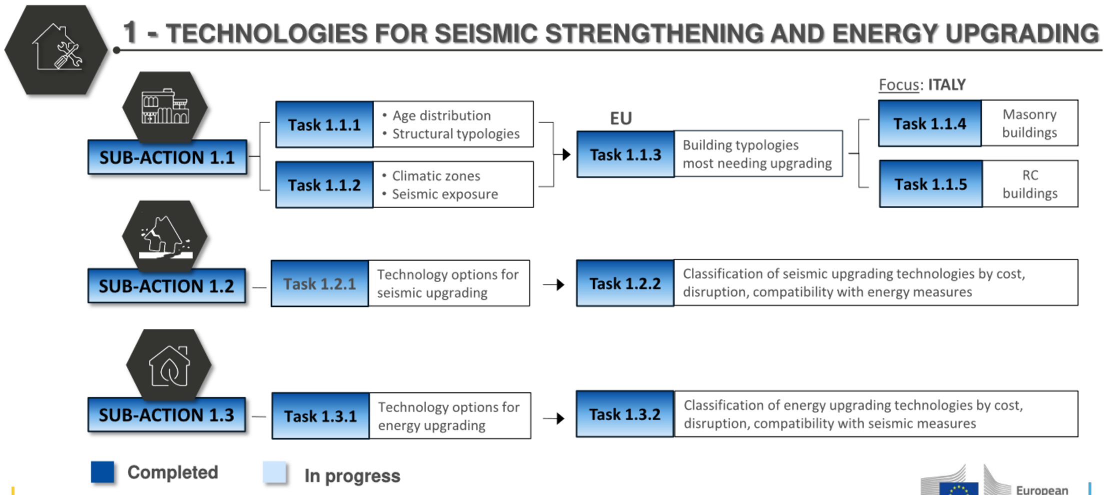
Action 1: Next steps



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Eurostat Database. Environment and Energy - Energy Statistics, Cooling and heating degree days by country - annual data.

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

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Thank you

Contact us:

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

16–19 November 2020

We will start soon
Please stay online
The Pilot Project team

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

Action 2: Technologies for combined upgrading
Opening and introduction

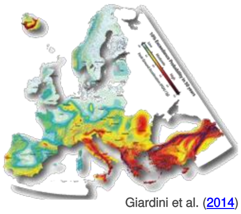
Dionysios Bournas

18/11/2020

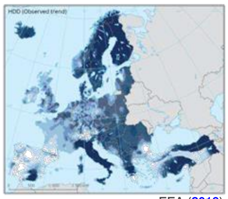
Introduction

Pilot Project scope

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



Giardini et al. (2014)



EEA (2019)

Buildings: 38.1% of energy consumption in EU

Main objectives

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

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Policy goals

Green Deal
Renovation wave
New European Bauhaus
Energy Performance of Buildings

New Industrial Strategy for Europe
New Circular Economy Action Plan

Action Plan on the Sendai Framework
Sustainable Development Goal 11

European Framework for Action on Cultural Heritage
European Agenda for Culture

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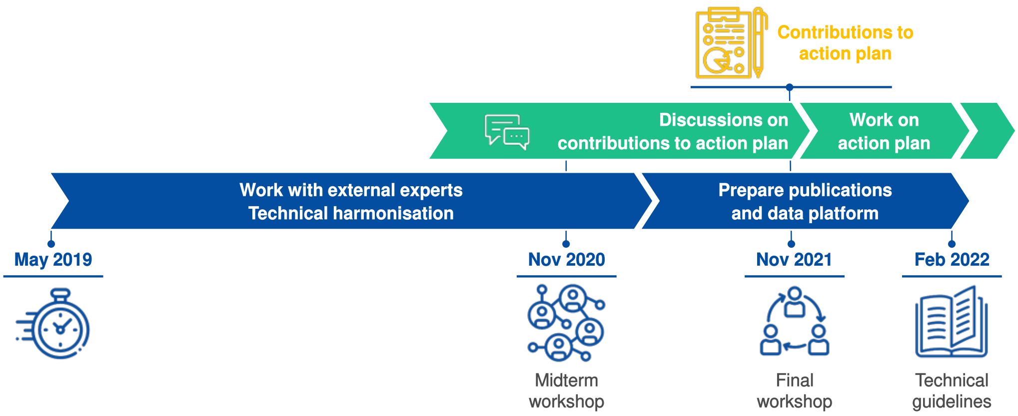
Pilot project actions

Timeline



Action 2: Aims and objectives

Sub-action 2.1: Review of technology options for combined seismic and energy upgrading of existing buildings

- Overview of combined technologies currently proposed
- Analysis and review of these technologies

Sub-action 2.2: Analysis of novel technologies for combined seismic and energy upgrading of existing buildings

- Outlook of the possibilities offered by novel technologies in seismic and energy retrofitting
- Analysis of possibilities of identified novel technologies for integrated retrofitting

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Technologies for combined upgrading (18/11)

09:30–09:40 Introduction
Dionysios Bournas
Project Officer, Joint Research Centre (JRC), European Commission (EC)

09:40–10:20 Complementary background activities: the iRESIST+ project
Dionysios Bournas and Daniel Pohoryles
Project Officers, JRC, EC

10:20–10:25 Work in Action 2: introduction
Daniel Pohoryles
Project Officer, JRC, EC

10:25–10:50 Advanced and novel seismic retrofitting technologies
Thanasis Triantafillou
Professor, University of Patras

10:50–11:05 Novel thermal insulation materials for energy upgrading
Bjørn Petter Jelle
Professor, Norwegian University of Science and Technology; Chief scientist, SINTEF

11:05–11:20 Coffee break

11:20–11:35 Overview of technology options for integrated upgrading
Francesca da Porto
Professor, University of Padua

11:35–11:50 Analysis of technologies for combined upgrading
Giuseppe Santarsiero
Assistant Professor, University of Basilicata

11:50–12:05 Technologies for the improvement of cultural heritage buildings
Daniel Oliveira
Associate Professor, University of Minho

12:05–12:15 Coffee break

12:15–12:55 Discussion: progress and future challenges

12:55–13:00 Closure
Dionysios Bournas
Project Officer, JRC, EC

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European Commission

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

Complementary background activities: the iRESIST+ project

Dionysios Bournas, Daniel Pohoryles

18/11/2020

Joint Research Centre

Exploratory Research

iRESIST+ Project : Innovative Seismic plus Energy Retrofitting of the ExiSting BuIlding STock

- Explore advanced materials (Textile Reinforced Mortar & thermal insulation) for the combined seismic and energy retrofitting of the existing buildings' envelopes
- Provide a common approach for the classification of existing EU buildings performance considering energy efficiency & seismic resilience
- Experimental investigation in a full-scale building

https://ec.europa.eu/jrc/en/research-topic/improving-safety-construction/i-resist-plus

European Commission

Marie Skłodowska-Curie - IF (2018-2020)

SPEctRUM project

Seismic Plus Energy Upgrading of Masonry Buildings using Advanced Materials

European Commission

Advanced materials for combined retrofitting of buildings' envelopes

European Commission

Masonry-infilled RC buildings

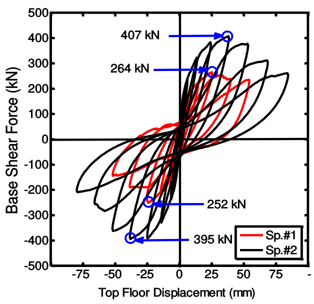
Masonry infill walls

- Contribute to strength of RC buildings
- BUT fail at early stages of seismic load
- Failure of masonry results in severe damage/failure of load-carrying elements, possibly triggering global collapse

European Commission

Seismic Retrofitting of masonry-infilled RC frames with Textile-Reinforced Mortars (TRM)

In-plane response

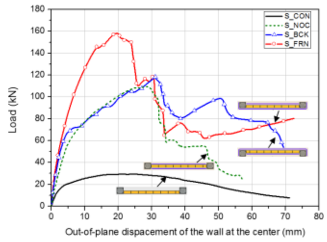


- Increase lateral load capacity by 55%
- Increase deformation capacity
- Convert infill into more reliable load-carrying element

Source: provided by L. Koutas.

Koutas L., Bousias S., and Triantafillou T. (2015). "Seismic Strengthening of Masonry-Infilled RC Frames with TRM: Experimental Study", ASCE, Journal of Composites for Construction, 19(2), 04014048.

Out-of-plane response



- Out-of-plane strength increase up to 5.5 times
- Initial stiffness increase and higher energy absorption

Source: Koutas L., and Bournas, D.A., (2019), "Out-of-Plane Strengthening of Masonry-Infilled RC Frames with Textile-Reinforced Mortar Jackets", ASCE Journal of Composites for Construction, (23)1.

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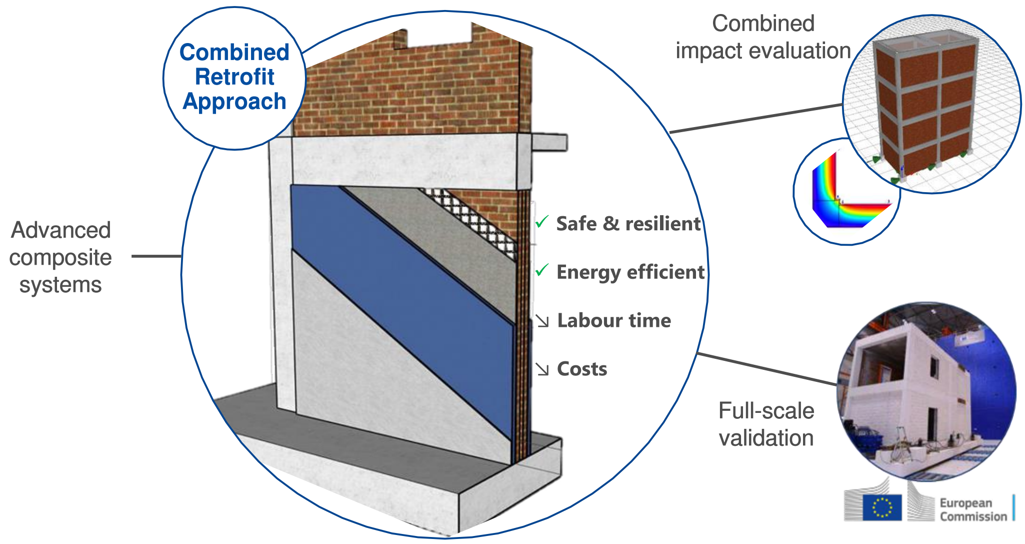
Experimental testing (ongoing)

iRESIST+ Combined retrofit scheme



Experimental prototype to be tested at ELSA

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

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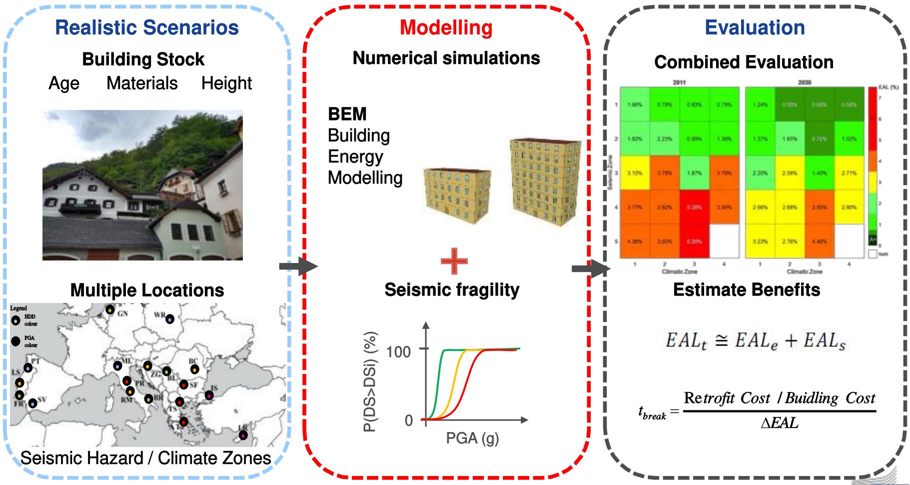
Combined impact evaluation

European Commission

Combined impact evaluation

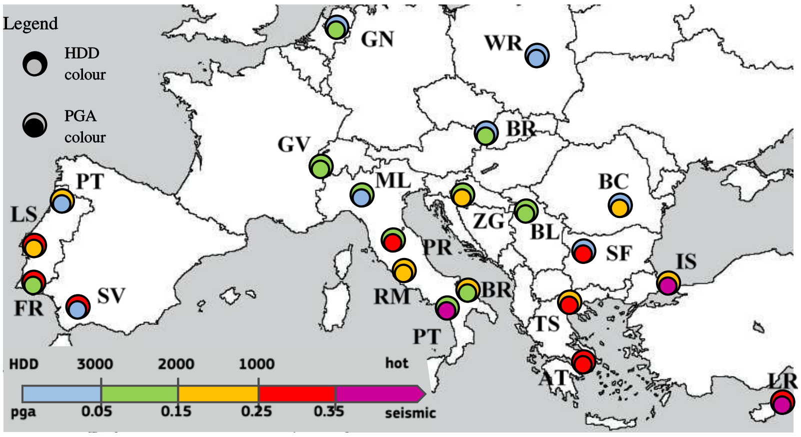


European Commission

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)

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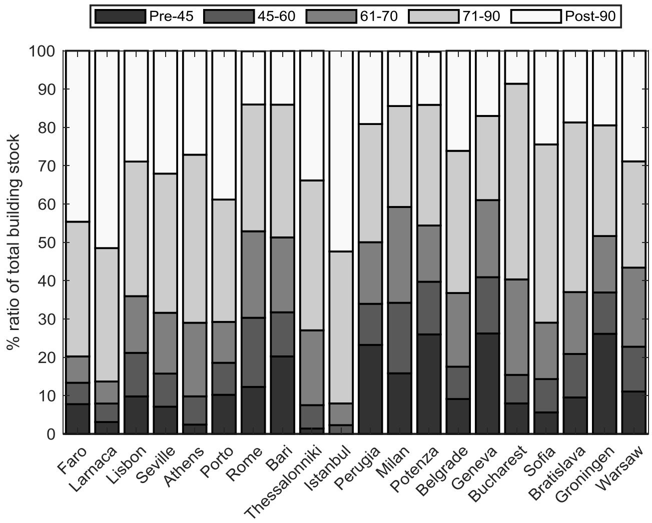
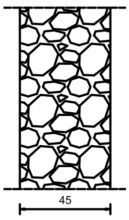
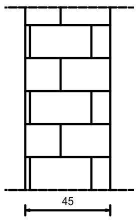
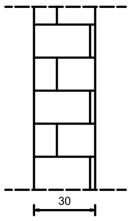
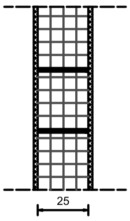
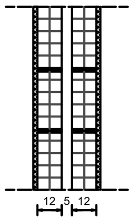
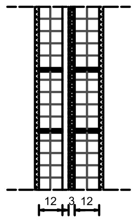
Building stock: Relative distribution

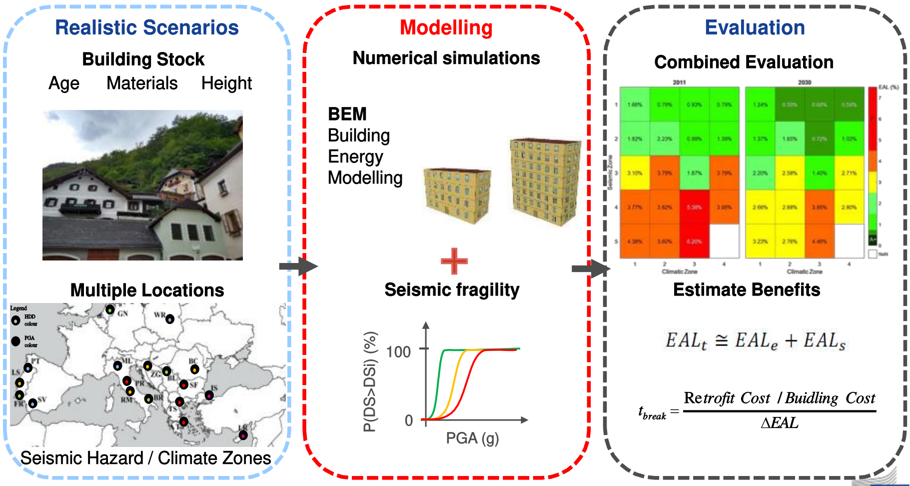
By Age - Census 2011
[EUROSTAT]



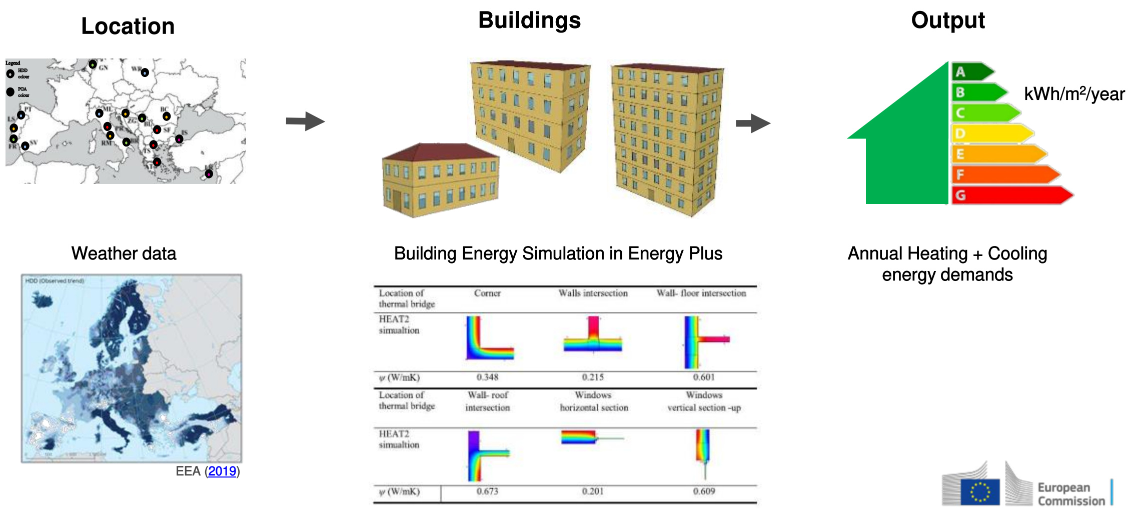
Energy and seismic characteristics

	Pre - 1945 Stone masonry	**Pre - 1945** Brick masonry	**1945 - 1959** Single leaf wall solid clay bricks	**1960 - 1969** Single leaf wall hollow clay bricks	**1970 – 1989** Cavity wall hollow clay bricks	**Post - 1990** 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**

Combined impact evaluation

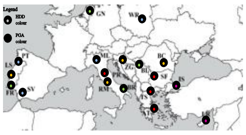


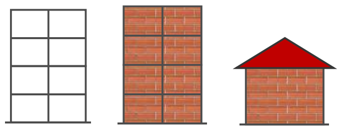
Building Energy Demand Modelling



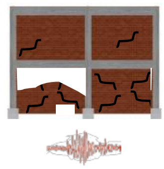
Seismic modelling

Location → **Buildings** → **Output**

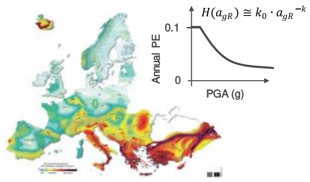




RC - Kappos et al. 2006 Masonry - Ahmad et al. 2010

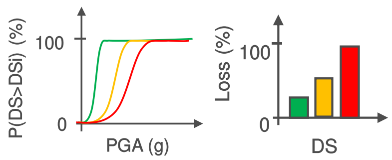


Seismic Hazard Data

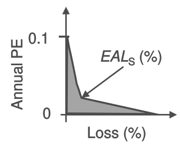


2013 European seismic hazard model
Giardini et al. (2014)

Fragility Curves + Damage Functions



Seismic Losses



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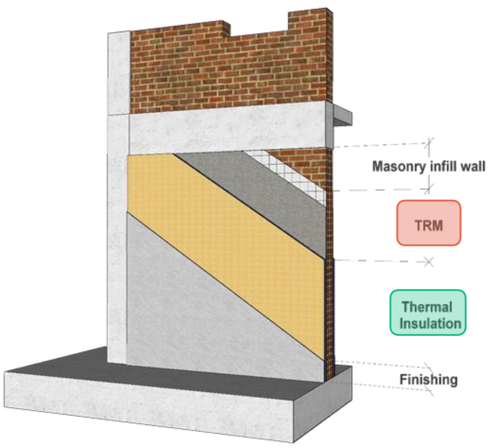
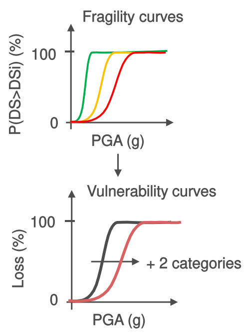
Retrofit levels



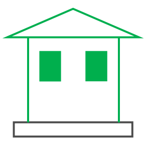


+ 2 categories

Age	Material	Current	Target
Pre-1945	Stone	URM	RBM
Pre-1945	Brick	URM	RBM
1945-59	RC	No code	Medium
1960-69	RC	Low	High
1970-89	RC	Medium	High
Post-90	RC	High	N/A

Masonry - Ahmad et al. 2010
RC - Kappos et al. 2006

Average of national legislations



Retrofit Measures		Zone 1	Zone 2	Zone 3	Zone 4
Walls	U -	0.75	0.50	0.40	0.35
Roof	value	0.60	0.40	0.33	0.25
Windows	W/m²K	2.80	2.50	1.90	1.30
Solar gains	g - value	0.55			
Air Changes	h^{-1}	0.60			

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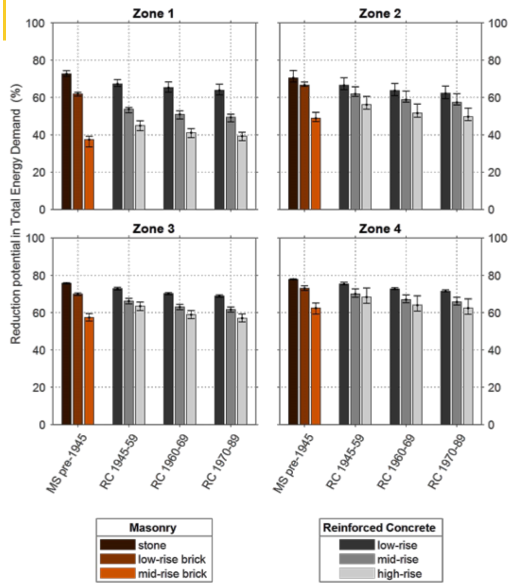
Energy savings by building type

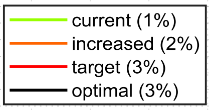


- Highest reduction potential for oldest structures and low - rise buildings
- Reduction potential up to 78% in Zone 4
- Reduction potential up to 74% in Zone 1

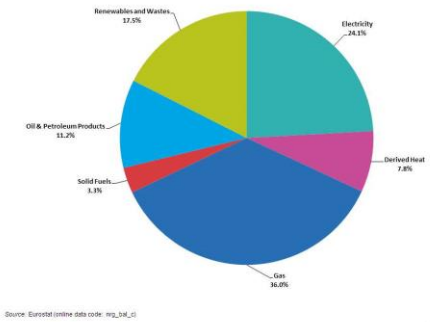
European Commission

Influence of renovation rates 2020 - 2030

- **Three renovation scenarios**
  - 1% annual renovation (current)
  - 2% annual renovation (increased)
  - 3% annual renovation (target – EPBD)
  - 3% annual renovation (optimised by typology)



- **Primary Energy** + **$CO_{2,eq}$ - emissions** based on current [EUROSTAT] and future **energy mix** [DG ENER]



eurostat

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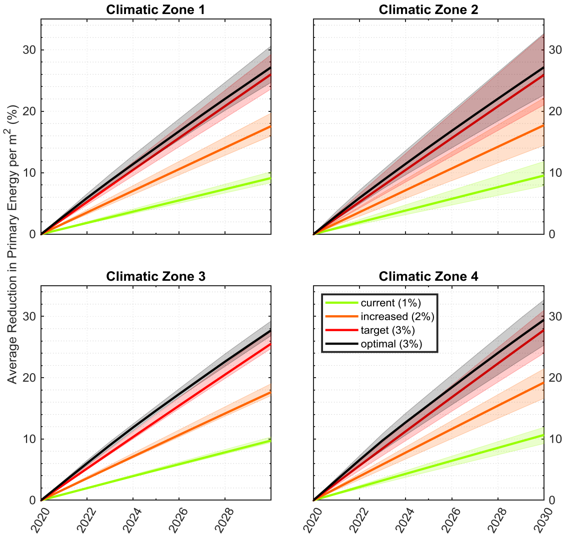
Energy performance improvements

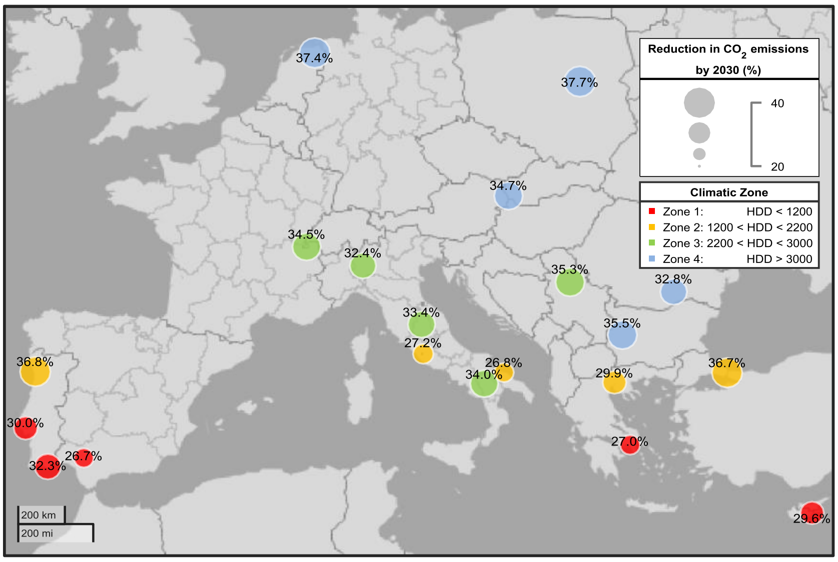


- Looking at the entire building stock of the case study cities
- Impact of increasing annual building renovation rate to 3%
- Effect of targeting the buildings with highest renovation potential (optimal) first

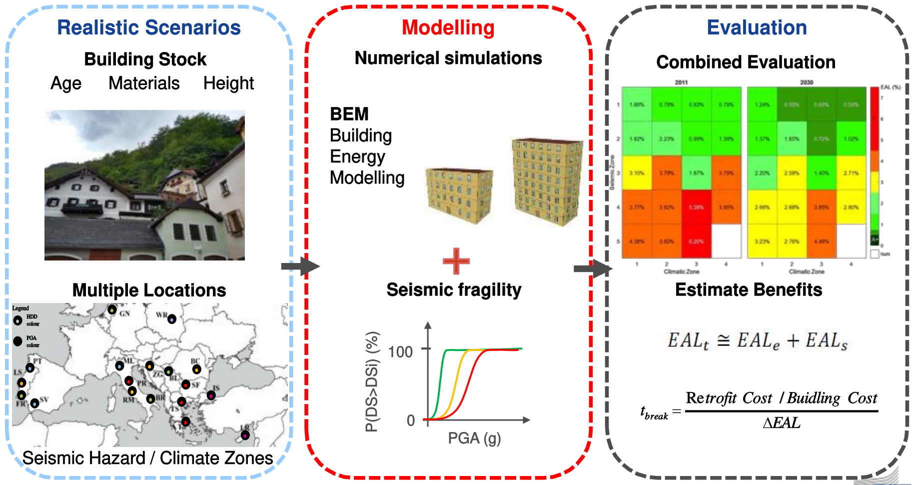
Annual Renovation Rate

- current (1%)
- increased (2%)
- target (3%)
- optimal (3%)

Renovation 2020 - 2030: $CO_{2,eq}$ emissions

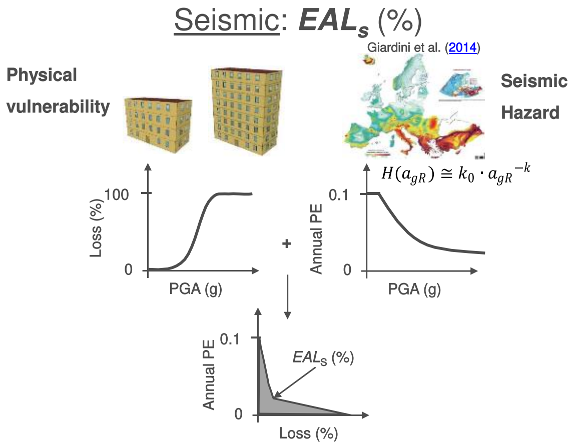


Combined impact evaluation



Combined evaluation metric

- ***EAL*(%): Expected annual loss** – as a fraction of building value $EAL_t \cong EAL_e + EAL_s$

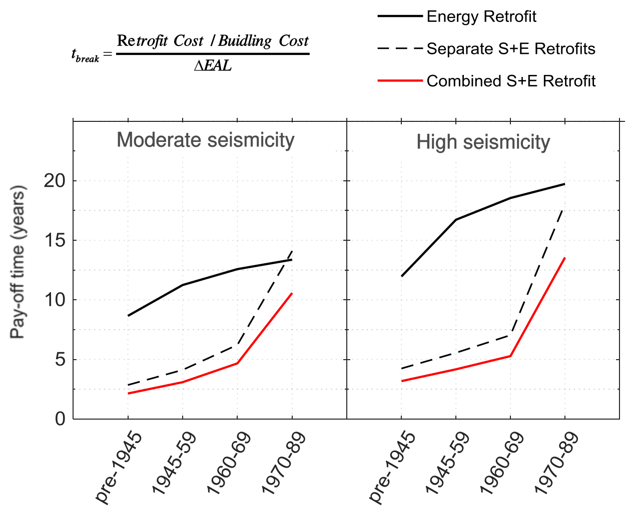


Energy: EAL_E (%)

- BEM - Building Energy Modelling

- Heating + Cooling Energy → Local Energy costs (€/m²) [Eurostat]
- Local variability: property price (€/m²) [Real estate costs]

Benefits of combined retrofitting



- Combined retrofitting can be more cost-effective than energy retrofitting alone
- For moderate to high seismic hazard, pay-off times are significantly lower for combined retrofitting
- Incentivises the renovation of buildings further

Summary

- The use of textile-based composites for combined seismic and energy retrofitting is investigated in the iRESIST+ project
- Proposed approach feasibility will be evaluated experimentally at JRC ELSA with seismic and energy testing on a full-scale building
- The numerical study showed that retrofitting 3% of the building stock annually can lead to reductions in Primary Energy use up to 35% and up to 38% in CO_2 emissions
- A combined seismic and energy evaluation shows cost benefits in moderate to high seismic zones

Acknowledgements

We would like to kindly acknowledge the contributions of

- Panagiotis Gkournelos
- Carmen Maduta
- Leonidas Kouris
- Lampros Koutas
- ELSA Laboratory staff

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Pohoryles, D.A., and D.A. Bournas, 2020. **A Unified Macro-Modelling Approach for Masonry-Infilled RC Frames Strengthened with Composite Materials**, *Engineering Structures*, Vol. 223, 2020, 111161.

https://ec.europa.eu/jrc/en/research-topic/improving-safety-construction/i-resist-plus

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

Progress on Action 2: Introduction

Daniel Pohoryles
18/11/2020

Joint Research Centre

Action 2: Aims and objectives

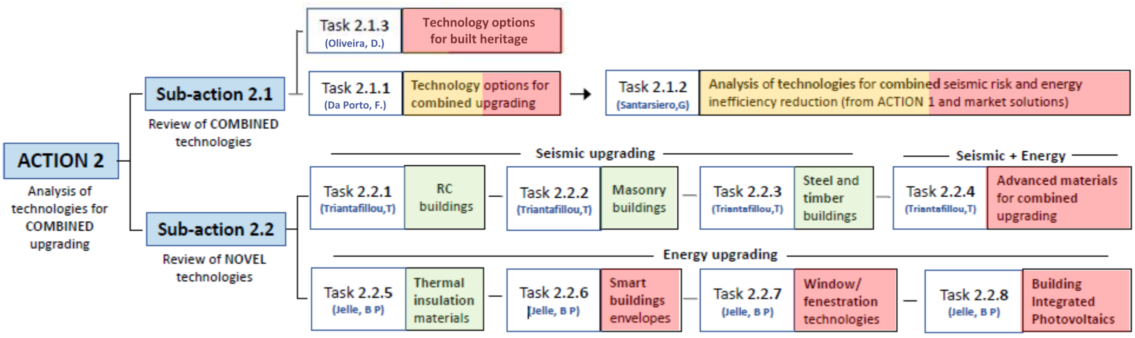
Sub-action 2.1: Review of technology options for combined seismic and energy upgrading of existing buildings

- Overview of combined technologies currently proposed
- Analysis and review of these technologies

Sub-action 2.2: Analysis of novel technologies for combined seismic and energy upgrading of existing buildings

- Outlook of the possibilities offered by novel technologies in seismic and energy retrofitting
- Analysis of possibilities of identified novel technologies for integrated retrofitting

Action 2: Progress to-date



Completed	Partial	Future deliverable

Novel retrofit technologies

10:25 - T. C. Triantafillou, University of Patras

- Advanced and novel seismic retrofitting technologies

10:50 - H.B. Jelle, Norwegian University of Science and Technology

- Novel thermal insulation materials for energy upgrading

Technologies for combined retrofitting

11:20 - F. Da Porto, University of Padua

- Overview of technology options for integrated upgrading

11:35 - G. Santarsiero, University of Basilicata

- Analysis of technologies for combined upgrading

11:50 - D. Oliveira, University of Minho

- Technologies for the improvement of cultural heritage buildings

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Technologies for combined upgrading (18/11)

09:30–09:40	Introduction Dionysios Bournas Project Officer, Joint Research Centre (JRC), European Commission (EC)
09:40–10:20	Complementary background activities: the iRESIST+ project Dionysios Bournas and Daniel Pohoryles Project Officers, JRC, EC
10:20–10:25	Work in Action 2: introduction Daniel Pohoryles Project Officer, JRC, EC
10:25–10:50	Advanced and novel seismic retrofitting technologies Thanasis Triantafillou Professor, University of Patras
10:50–11:05	Novel thermal insulation materials for energy upgrading Bjørn Petter Jelle Professor, Norwegian University of Science and Technology; Chief scientist, SINTEF
11:05–11:20	Coffee break
11:20–11:35	Overview of technology options for integrated upgrading Francesca da Porto Professor, University of Padua
11:35–11:50	Analysis of technologies for combined upgrading Giuseppe Santarsiero Assistant Professor, University of Basilicata
11:50–12:05	Technologies for the improvement of cultural heritage buildings Daniel Oliveira Associate Professor, University of Minho
12:05–12:15	Coffee break
12:15–12:55	Discussion: progress and future challenges
12:55–13:00	Closure Dionysios Bournas Project Officers, JRC, EC

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Thank you for attending

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JRC-REEBUILD@ec.europa.eu

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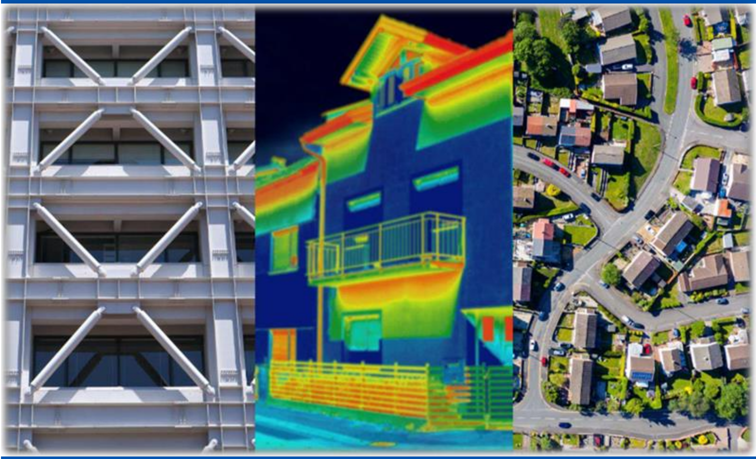
MIDTERM WORKSHOP

16 - 19 November 2020

PILOT PROJECT

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



ACTION 3

19 November 2020

METHDOLOGIES FOR ASSESSING THE COMBINED EFFECT OF UPGRADING

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

Work Progress in Action 3

Elvira Romano, Paolo Negro

19 November 2020

Contents

- Introduction
- Sub-action 3.1 – Work progress
- Sub-action 3.2 – Work progress
- Sub-action 3.3 – Work progress

Introduction

Action 3: Sub-actions

3 - METHODOLOGIES FOR ASSESSING THE COMBINED EFFECT OF UPGRADING

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

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

SUB-ACTION 3.2 - Proposal of a simplified assessment method

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

SUB-ACTION 3.3 - Case studies

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

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Action 3: Tasks

3 - METHODOLOGIES FOR ASSESSING THE COMBINED EFFECT OF UPGRADING

SUB-ACTION 3.1 — Task 3.1.1: Existing assessment methods of combined upgrading → Task 3.1.2: Classification of assessment methods by effectiveness, speed in implementation, ability to account for costs and disruption

SUB-ACTION 3.2 — Task 3.2.1: Requirements for a novel/simplified method → Task 3.2.2: Proposal of a simplified method for combined assessment of building upgrading

SUB-ACTION 3.3 — Task 3.3.1: Case-studies identification
- → Task 3.3.2: Standard methods application for independent assessment of seismic and energy upgrading
- → Task 3.3.3: Proposed simplified method application for combined assessment of retrofitted buildings

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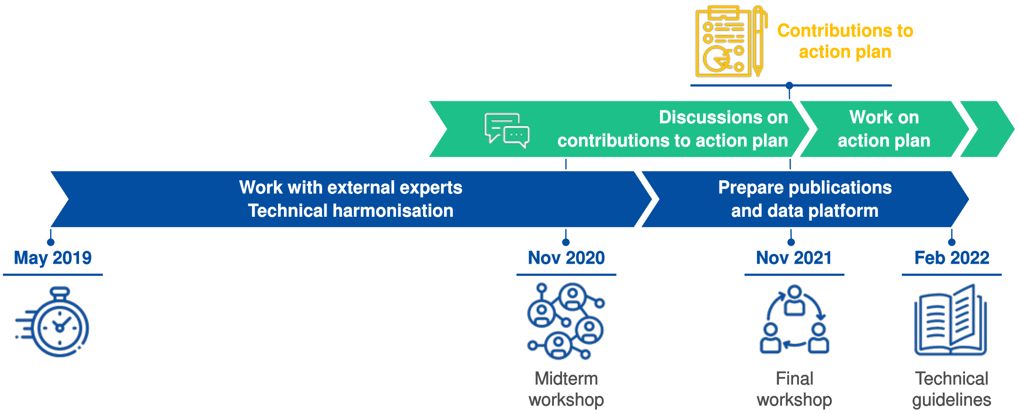
Timeline



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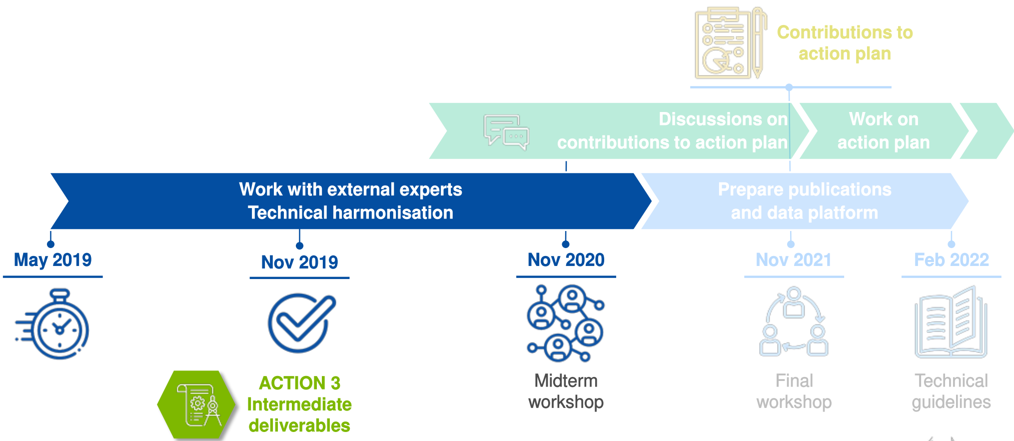
Timeline



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Sub-action 3.1

Work Progress

State-of-the-art assessment methodologies

Review of existing methods for the assessment of combined upgrading and their corresponding classification

Method categories

SEISMIC VULNERABILITY

- Seismic loss estimation methods
  (PBEE; HAZUS; AEBM)
- Method and tools for seismic vulnerability assessment
  (REDi™; RELi™2.0; Envision v3)

ENERGY/ENVIRONMENTAL ASSESSMENT

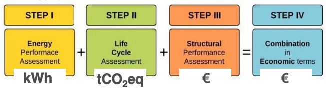
- Life Cycle Assessment (LCA)
  (ISO 14040/4:2006) – Tool review: (SimaPro; GaBi; etc.)
- Life Cycle Energy Analysis (LCEA)
  Tool review: (EnergyPlus)

SUSTAINABILITY

- **Qualitative assessment** - European and non-European rating system tools: e.g. BNB; BREEAM; Level(s); etc.

COMBINED SEISMIC AND ENERGY ASSESSMENT

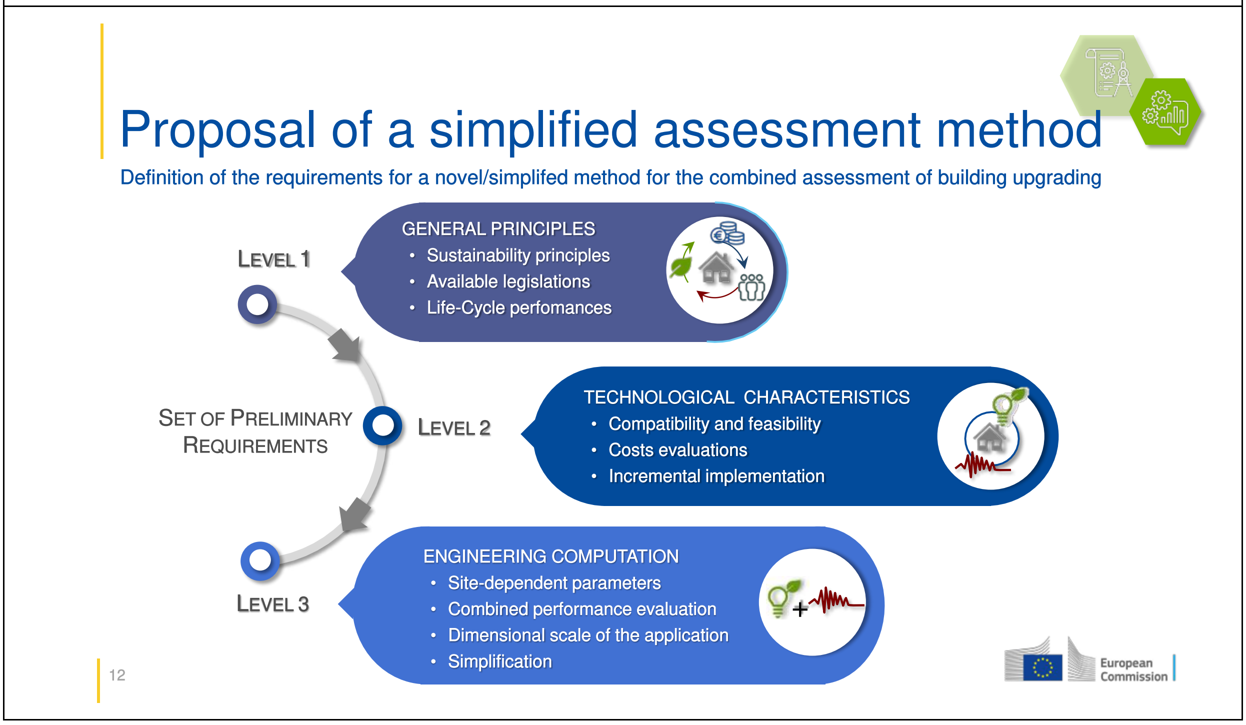
- **Quantitative assessment** – Sustainable Structural Design - SSD methodology (JRC - SAFESUST)



Methods classification

- Scope of assessment
  (New or existing building)
- Considering essential indicators and relative importance
  (Energy use; Climate change; Natural disaster/seismicity)
- Country where method or tool is used
- Method effectiveness
- Readiness
- Ability to consider costs and disruption in use


Sub-action 3.2
Work Progress
European Commission


Proposal of a simplified assessment method
Definition of the requirements for a novel/simplifed method for the combined assessment of building upgrading
LEVEL 1
GENERAL PRINCIPLES
• Sustainability principles
• Available legislations
• Life-Cycle perfomances
SET OF PRELIMINARY REQUIREMENTS
LEVEL 2
TECHNOLOGICAL CHARACTERISTICS
• Compatibility and feasibility
• Costs evaluations
• Incremental implementation
LEVEL 3
ENGINEERING COMPUTATION
• Site-dependent parameters
• Combined performance evaluation
• Dimensional scale of the application
• Simplification
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Proposal of a simplified assessment method

Definition of a simplified assessment method for combined upgrading: main steps

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

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Sub-action 3.3

Work Progress

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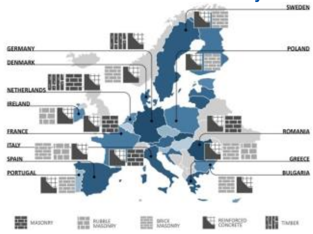
Case studies

Case studies identification by construction technologies



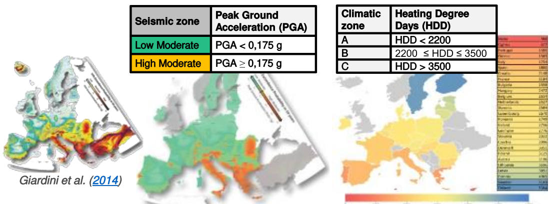
MASONRY BUILDINGS
1. CULTURAL MONUMENTAL RUBBLE MASONRY BUILDING
2. RESIDENTIAL BRICK MASONRY BUILDING

REINFORCED CONCRETE BUILDINGS
3. RESIDENTIAL REINFORCED CONCRETE BUILDING
4. PUBLIC REINFORCED CONCRETE BUILDING

Hazard matrix characterized by different combinations of seismic and climatic zones and case studies location

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

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



Giardini et al. (2014)

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

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

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Case studies

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

'Pietro Santini' RC building school

Loro Piceno (MC)

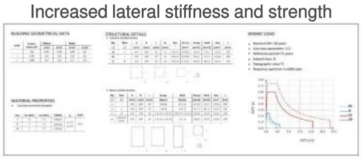
PGA = 0.202g at Life Safety limit state
HDD = 2150

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

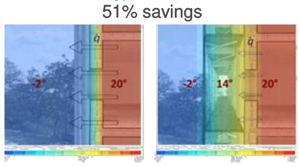
Retrofit technology (global)
- Exoskeleton: X-shaped concentric bracing frames (X-CBF)
- Double-skin envelope

Standard independent methods

Seismic assessment
Increased lateral stiffness and strength

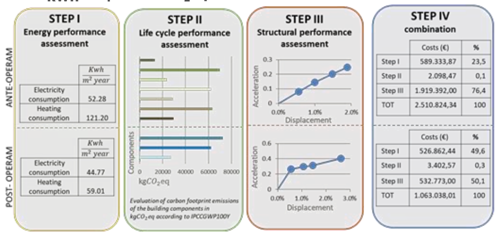


Energy assessment
51% savings



Standard combined method: SSD methodology

kWh + tCO_2eq + € = €



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

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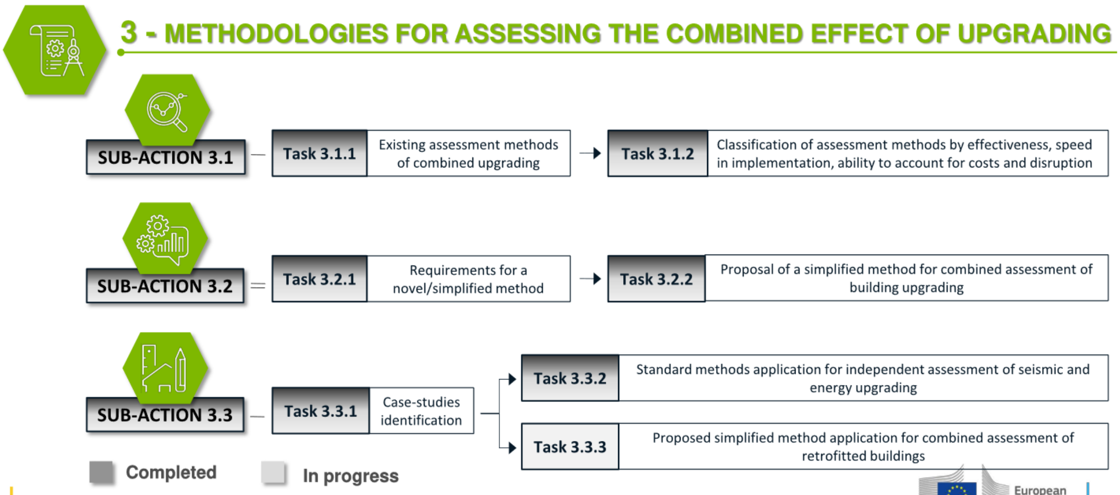
Action 3: Next steps



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Thank you

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