



INTEGRATED TECHNIQUES FOR THE SEISMIC STRENGTHENING AND ENERGY EFFICIENCY OF EXISTING BUILDINGS: A PILOT PROJECT

P. Negro⁽¹⁾, S. Dimova⁽²⁾, D. Bournas⁽³⁾, G. Tsionis⁽⁴⁾, D. Strezova⁽⁵⁾

⁽¹⁾ Project Officer, European Commission, Joint Research Centre, paolo.negro@ec.europa.eu

⁽²⁾ Deputy Unit Head, European Commission, Joint Research Centre, silvia.dimova@ec.europa.eu

⁽³⁾ Project Officer, European Commission, Joint Research Centre, dionysios.bournas@ec.europa.eu

⁽⁴⁾ Project Officer, European Commission, Joint Research Centre, georgios.tsionis@ec.europa.eu

⁽⁵⁾ Project Assistant, European Commission, Joint Research Centre, desislava.strezova@ec.europa.eu

Abstract

Under mandate of the European Parliament, a European Pilot Project named “Integrated techniques for the seismic strengthening and energy efficiency of existing buildings” has been activated.

Construction industry produces 9% of EU’s GDPs and it provides 18 million direct jobs. In the EU there are about 25 billion square meters of built-up area, of which about 10 billion built before 1960 require substantial maintenance because of their structural condition, changes in environmental conditions and building sector regulations. Particularly relevant is the seismic vulnerability that characterises the building heritage of Member States with medium to high seismic hazard such as Italy and Greece, where the seismic events of recent decades have claimed thousands of victims and caused extensive economic damage, but also in some areas of Member States at lower risk, such as Germany, France and Spain.

At the same time, the energy performance of European buildings is unsatisfactory: in fact, the energy consumed in buildings is one of the biggest sources of CO₂ emissions in Europe. Hence, reducing buildings vulnerability and increasing at the same time their energy efficiency is of paramount importance for the European economy. Therefore, an organic Action Plan is a primary objective for the EU in order to redevelop and modernise the existing building stock. In view of the huge number of constructions involved, the plan must be based on criteria of high efficiency and economic and environmental sustainability.

The pilot project defines, including by examining specifically identified case studies, 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 environmental impact (reduction of CO₂ emissions, reduction of the waste that could be generated through widespread building replacement action, or future earthquake disasters, etc.).

The organic actions have the following main objectives:

- Define the tools and guidelines to reduce all at once building’s vulnerability and energy inefficiency.
- Stimulate the use of integrated solutions.
- Create awareness about the topic in the aim of prevention.

The Pilot Project is being conducted by the Joint Research Centre of the European Commission, involving a number of experts from the scientific community. This paper presents the research programme, highlighting the interactions with the previously conducted work.

Keywords: Seismic rehabilitation; energy efficiency; combined seismic and energy upgrading, existing buildings



1. Introduction

In the European Union there are about 25 billion square meters of built-up area, of which about 10 billion built before 1960 require substantial maintenance because of their structural condition, changes in environmental conditions and building sector regulations.

Particularly relevant is the seismic vulnerability that characterises the building heritage of Member States with medium/high seismic hazard such as Italy and Greece, where the seismic events of recent decades have claimed thousands of victims and caused extensive economic damage, but also in some areas of Member States at low rest, such as Germany, France and Spain. Likewise, the energy performance of European buildings is unsatisfactory: in fact, the energy consumed in buildings is one of the biggest sources of CO₂ emissions in Europe. Therefore, an organic action plan is a primary objective for the Union in order to redevelop and modernise the existing building stock. In view of the huge number of constructions involved, the plan must be based on criteria of high efficiency and economic and environmental sustainability.

From this starting point, a specific Pilot Project has been proposed by the European Parliament and activated by the European Commission [1, 2]. This pilot project will define, including by examining specifically identified case studies, 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 environmental impact (reduction of CO₂ emissions, reduction of the waste that would be generated through widespread building replacement action, etc.)

The activities planned will be directly integrated into, and complementary with, those already under way within the Joint Research Centre, in particular under the SAFESUST project [3] (impact of sustainability and energy efficiency requirements on building design and retrofit) the RESURBAN project (seismic risk assessment for current conditions and different retrofit scenarios for seismic and energy performance) and the iRESIST+ project [4-7] (development of new materials and methods for the energy retrofitting of existing buildings taking into consideration the opportunity for simultaneous seismic upgrading for the buildings in seismic areas across Europe).

2. General objectives

Construction industry produces 9% of European Union's GDP and it provides 18 million direct jobs. In the European Union there are about 25 billion square meters of built-up area, of which about 10 billion built before 1960 require substantial maintenance because of their structural condition, changes in environmental conditions and building sector regulations. Particularly relevant is the seismic vulnerability that characterises the building heritage of Member States with medium/high seismic hazard such as Italy and Greece, where the seismic events of recent decades have claimed thousands of victims and caused extensive economic damage, but also in some areas of Member States at low rest, such as Germany, France and Spain.

At the same time, the energy performance of European buildings is unsatisfactory: in fact, the energy consumed in buildings is one of the biggest sources of CO₂ emissions in Europe. Hence, reducing buildings vulnerability and increasing at the same time their energy efficiency is of paramount importance for European economy.

Organic actions should have the following main objectives:

- Define the tools and guidelines to reduce all at once building's vulnerability and energy inefficiency.
- Stimulate the use of integrated solutions.
- Create awareness about the topic in the aim of prevention.



3. Actions

Five main actions are foreseen:

1. Overview and classification of technologies for seismic strengthening and energy/environmental upgrading of existing buildings
2. Overview of technologies for combined upgrading of existing buildings
3. Methodologies for assessing the combined effect of upgrading
4. Regional impact assessment and proposals for the Action Plan
5. Stakeholders' involvement.

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

On the basis of existing studies and databases, the age distribution and structural typologies in Europe will be analysed, to identify the classes of building corresponding to the most representative typologies. The analysis will take into account the number of buildings in each class, as well as the economic/societal importance, the climatic zone and the seismic exposure.

3.1.1 Identification of typologies most badly needing upgrading

A preliminary assessment of the existing (RC and masonry) building deficiencies was done in the framework of iRESIST+ project [6-7]. When it comes to the seismic performance of existing reinforced concrete (RC) buildings, there are many common deficiencies compromising their structural integrity. Design standards before the '80s were considering seismic actions less than 50% compared to modern ones (e.g. Eurocode 8 2004); reinforcement detailing measures were poor, and structural analyses were conducted using over-simplified and approximate models.

A number of deficiencies can also be observed if one examines an existing structure from its energy efficiency point of view. The first regulations date back to the late 1950s and the early 1960s in Scandinavian countries. Later, more countries followed after the oil supply crisis in the 1970s, but the actual implementation of energy-related regulations in construction was in most cases delayed. In Greece, for instance, according to the Greek Statistics Agency (ELSTAT), 45.6% of the residencies do not have any kind of thermal insulation at all [8]. Therefore, the lack of insulation, the energy deficient fenestration surfaces used, but also the old and inefficient mechanical equipment used for heating, cooling and domestic hot water needs, result in high energy consumptions, hence high economic losses and increased CO₂ emissions [7].

In the Pilot Project, on the basis of existing studies and databases, the age distribution and structural typologies in Europe will be analysed, to identify the classes of building corresponding to the most representative typologies. The analysis will take into account the number of buildings in each class, as well as the economic/societal importance, the climatic zone and the seismic exposure.

3.1.2 Review of technology options for the seismic upgrading of existing buildings

This is one of the activities in which the Joint Research Centre has been active in the framework of its institutional research programmes. A general classification of the existing technologies for seismic strengthening has been released, and will form the basis for further work [9]. With reference to the typologies previously identified as the most representative, the set of existing technology options for their seismic strengthening will be reviewed. Each technology option will be classified in terms of expected seismic safety improvement, cost and disruption in use, use of raw material and effects in terms of Life



Cycle Analysis for the whole expected remaining lifetime. Moreover, the general potential of combining each technology option with measures for energy/environmental amelioration will be assessed.

3.1.3 Review of technology options for the energy/environmental upgrading of existing buildings

With reference to the typologies previously identified as the most representative, the set of technology options for their energy improvement will be reviewed. Each technology option will be classified in terms of expected energy improvement, cost, disruption in use, use of raw material and effects in terms of Life Cycle Analysis for the whole expected remaining lifetime. Moreover, the general potential of combining each technology option with measures for seismic upgrading will be assessed.

3.2 Overview of technologies for combined upgrading of existing buildings

Options are commercially available to increase the energy efficiency of existing buildings, and data about the “return of investment” is generally available. However, data is generally poorly consistent, and does not take into account important issues such as disruption of use, waste of resources and environmental effects in a life cycle perspective. Moreover, there are not technologies available for the combined seismic and energy upgrading of the existing buildings.

The concept of the combined seismic and energy retrofitting was introduced very recently [4, 10]. At the JRC, the iRESIST+ (Innovative Seismic and Energy Retrofitting of the Existing Building Stock) project aims to develop innovative techniques integrating advanced materials for the simultaneous seismic and energy retrofitting of the European building stock.

3.2.1 Review of technology options for combined seismic and energy/environmental upgrading of existing buildings

A preliminary state-of-the-art review on the materials and techniques used in upgrading existing buildings have been recently presented. For what concerns seismic retrofitting, numerous techniques have been developed aiming at increasing the strength, stiffness or the deformation capacity of masonry buildings and/or masonry infills in RC buildings. These techniques could be divided in two categories: (a) the traditional techniques making use of conventional construction materials (i.e. concrete and steel) and (b) new techniques based on advanced composite materials i.e. textile-reinforced mortar (TRM) [11, 12]. For what concerns energy retrofitting, the most commonly used insulation building materials today could be classified in three categories: (a) Conventional insulation materials; (b) State-of-the-art insulation materials including nano insulation materials and (c) Smart insulation materials such as Phase change materials (PCM) [4].

In this pilot project, the technological options for combining the improvement of seismic safety and energy performance will be extensively reviewed. Both the combination of technologies identified in Action 1 and the combined solutions already available in the market will be analysed.

3.2.2 Analysis of novel technologies for combined seismic and energy/environmental upgrading of existing buildings

Since replacing existing buildings is prohibitively expensive and would have a huge environmental impact, their lifetime extension requires considering both seismic and energy retrofitting which is very costly. To achieve cost effectiveness, iRESIST+ explores a novel approach, proposing a hybrid structural-plus-energy retrofitting solution which combines inorganic textile-based composites with thermal insulation systems for reinforced concrete and masonry building envelopes, as illustrated in Fig. 1.

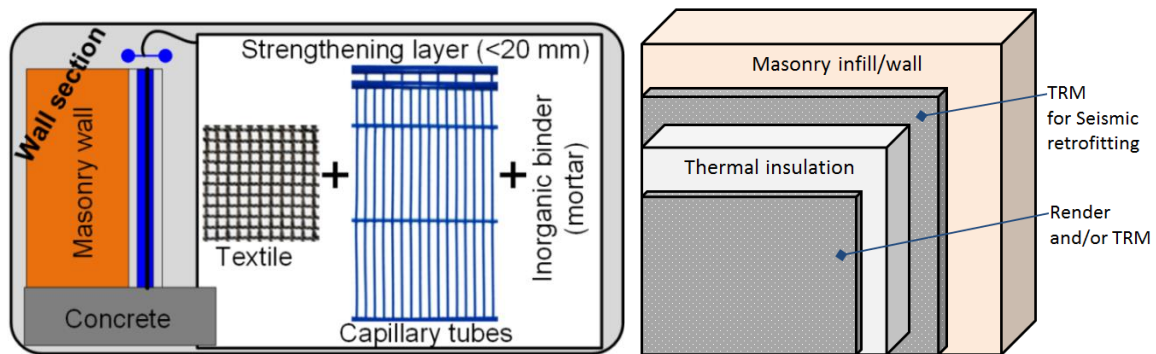


Fig. 1 – The iRESIST+ novel concept explored for the combined seismic and energy upgrading of the existing building envelopes [4].

The effectiveness of the proposed retrofitting system will be validated experimentally in a full-scale building using the ELSA reaction wall facility. Moreover, in the Pilot Project, the outlook of the possibilities offered by novel technologies being currently proposed for the combined amelioration of existing buildings will be analysed in depth.

3.3 Methodologies for assessing the combined effect of upgrading

Methodologies to assess the solutions for the combined improvement of seismic safety and energy/environmental performance will be defined. Whereas practical methods to assess the possible improvement in terms of energy performance exist, codified procedures to quantify the improvement in terms of seismic safety are scarce, and no method is available for the combined assessment.

3.3.1 State of the art of methodologies for the improvement of seismic safety and energy/environmental performance

Simplified methodologies have been developed to assess the expected improvement in terms of energy saving (to justify the possible obtainment of economic incentives, as well as the reduction of expected losses for seismic actions (e.g. *sismabonus* [13] in Italy).

3.3.2 Definition of a method for a combined assessment of the upgrading

Based on the study of the existing procedures, and on the possibility of their combined use, a simplified method for the combined assessment of the economic advantage of each solution will be proposed, along the objectives of the SAFESUST approach. The SAFESUST approach [3], or Sustainable Structural Design (SSD) method [14], considers both structural and environmental parameters in a life cycle perspective. The original framework of the method is based on three main pillars, corresponding to the three evaluation steps: Structural Performance Assessment, Energy Performance Assessment; Life Cycle Assessment. Structural performances are considered in a probabilistic approach, through the introduction of a simplified performance-based assessment method [15] to evaluate the expected damages throughout the lifetime of the building (including repair and downtime costs). The energy performance assessment corresponds to the evaluation of the total expected cost for the operation of the building. The method can also consider the environmental impacts: equivalent CO₂ emissions resulting from a Life Cycle Analysis can be converted into costs by multiplying by the carbon prices corresponding to the European Union Emissions Trading System.



The SAFESUST approach allows for the involvement of all experts and stakeholders in the design or rehabilitation of buildings (Figure 2), and all quantities are expressed in monetary units. The SAFESUST approach has also shown to be a viable tool for decisions at urban or regional level [16]. The idea of measuring all performance parameters (energy, structural, and eventually environmental) in monetary terms, and to sum them up to obtain a global economic performance indicator is the key issue of the SAFESUST approach, and this will most probably be retained in the work for the Pilot Project.

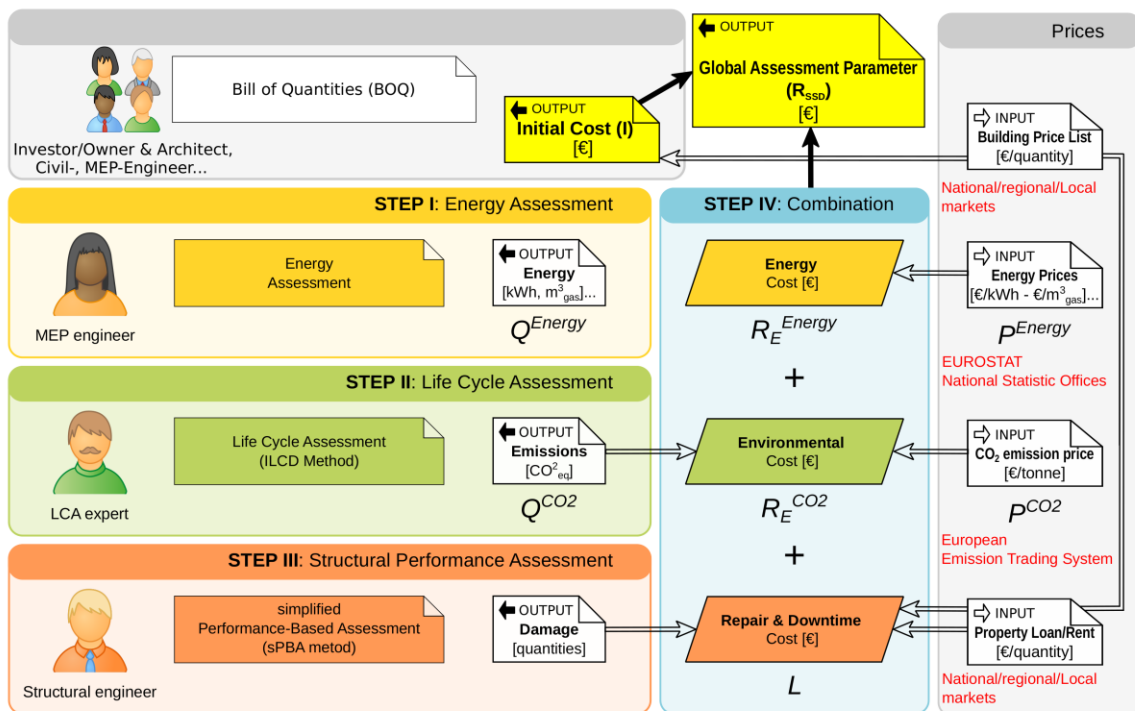


Fig. 2 – Scheme of the SAFESUST approach, showing the interactions among all experts and stakeholders

Moreover, an evaluation method of the integrated seismic and energy retrofitting has been proposed in the iRESIST+ project. Similarly, monetary terms are implemented by defining the Expected Annual Loss (EAL) which allows evaluating the buildings' seismic risk and energy performance in a combined manner. To achieve this integration, the building performance related to earthquake resilience is assessed in accordance with the predicted value of seismic expected annual loss (EAL_S). The index of the EAL_S , provides the average value of loss that a building will sustain annually over its (remaining) life span due to seismic action. On the other hand, the well-known practice used in evaluating the energy performance of buildings based on their total annual energy consumption (i.e. classes A to G) is adopted, evaluating the energy efficiency via the mean annual energy cost (annual energy consumptions multiplied by their relevant energy unit costs). Therefore, by considering the building total value, the corresponding seismic and energy expected annual loss, namely EAL_S and EAL_E , can be expressed by the ratio of the average annual cost (of consumed energy or expected seismic loss) to the building total value, providing two analogous indexes that can be compared directly [4, 6].

3.3.3 Case studies

Case studies of representative types of buildings being retrofitted with the identified technological options for combing the improvement of seismic safety and energy performance will be performed. Along with the



evaluation of the impact on seismic safety, energy and environmental performance in Life Cycle perspective, the case studies will demonstrate the application of the method for combined assessment of the upgrading.

It worth's noting that the overall effectiveness of the combining energy efficiency and seismic retrofitting was demonstrated for old-type RC and masonry buildings in different preliminary case studies [4, 6, 7]. Particularly, for high seismicity areas, it was shown that the payback of the retrofitting intervention can be significantly reduced when seismic is applied concurrently with energy retrofitting by combining advanced construction materials, thanks to large savings related to the labour costs.

3.4 Regional impact assessment and proposals for the Action Plan

The objective of this action is to draw lessons, identify gaps and propose good practices in support of the organic Action Plan for the redevelopment and modernisation of the European building stock. Firstly, proposals will be formulated for efficient policy measures and tools to successfully implement the seismic and energy upgrading of existing buildings in Europe. Secondly, the action will inform the Action Plan regarding the areas where a higher impact can be achieved and will assess the impact of alternative intervention scenarios. This is in line with the third priority of the Action Plan on the Sendai Framework for Disaster Risk Reduction that calls for risk-proofed investments in disaster risk reduction and linked construction policies. The action will operate at the regional level, thus extending the building-specific case studies, and will integrate technical and socio-economic aspects.

3.4.1 Priority regions

Using the data on the European building stock, the seismic risk and the energy performance of buildings will be assessed at regional level throughout Europe with the aim to identify those regions where interventions are of higher priority. Previous work at the Joint Research Centre reviewed models for seismic vulnerability of buildings [17], examined the effect of the detail of exposure models on regional seismic risk assessment [18] and created an inventory of the housing stock at a regional level across European countries and performed a classification of seismic vulnerability [19]. The outcome of the analysis shows that the majority of existing buildings was designed with moderate-level seismic codes or without provisions for earthquake resistance at all and are therefore vulnerable to earthquakes (Figure 3).

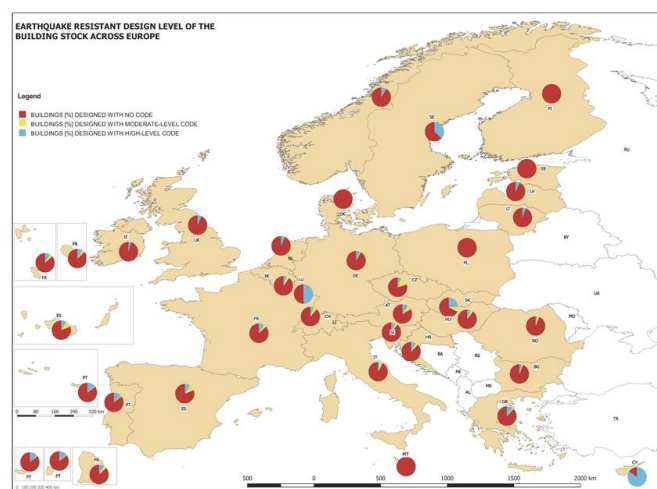


Fig. 3 – Percentage of buildings designed without provisions for earthquake resistance (no code – red), moderate level (yellow) and high-level (blue) seismic code [19]



This is particularly relevant in the regions of moderate and high seismicity (Figure 4), where old buildings may have a significant impact on a large part of the population. Interventions are needed to improve the safety of vulnerable buildings and consequently reduce the risk of socio-economic losses.

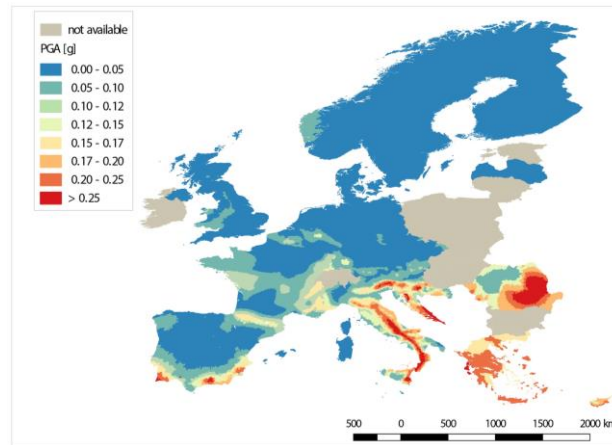


Fig. 4 – Seismic zones in Europe: peak ground acceleration for the reference return period of seismic action for the no-collapse requirement in Eurocode 8 [19]

The priority ranking will be complemented with socio-economic indicators referring to the total population and the fractions belonging to more vulnerable groups, as well as to the economic activity in each region.

3.4.2 Implementing measures

This activity will collect and examine all measures - legislation, incentives, guidance and standards - that exist in EU Member States regarding the retrofit of buildings aiming at an improved energy and seismic performance. Following the European legislation on energy efficiency and energy performance of buildings, various types of implementing measures have been put in place in different European countries. They depend on financial, business and social conditions, e.g. energy efficiency checks facilitated for low-income households. Regarding the improvement of seismic safety, advanced technical guidelines and standards are in use [19], but there is lack of legislative measures and incentives. A notable example is the *sismabonus* scheme in Italy that provides tax return when improving the seismic safety of buildings. Even less measures exist that target a combined intervention. The municipality of Lisbon is studying a programme to improve the safety of buildings against natural hazards, their energy efficiency and the accessibility for disabled persons [22].

The activity will also examine insurance schemes to incentivise risk reduction measures and shorten the recovery time. Insurance schemes for residential buildings were introduced and re-designed in earthquake-prone countries after major disasters. Insurance policies are now available from governments, private insurers and public-private partnerships, but despite being affordable, they are not widely used.

3.4.3 Scenarios for interventions

The activity will first define a set of plausible intervention scenarios such as concurrent, i.e. aiming to improve at the same time the earthquake safety and energy efficiency of existing buildings, and non-concurrent interventions, as well as demolition and new construction. Subsequently, the impact of these alternative scenarios will be assessed at the regional level with a view to providing insight on the benefits associated to each of them.



3.5 Stakeholders' involvement

The action is aimed to support the awareness, dissemination and outreach of the results of the pilot project with a look at the sustainability of the initiative in a medium/long term perspective. The involved stakeholders will be representatives of European Institutions, EU Member States, Regional Authorities, CEN, industrial associations, experts and communities of practice.

4. Conclusions

A Pilot Project on the integrated techniques for the seismic strengthening and energy efficiency of existing buildings has been launched under the mandate of the European Parliament. The economic and societal significance of devising measures for improving at the same time the seismic safety and the energy performance of the European building stock have been illustrated. The research programme will be conducted with the participation of a number of European experts. At the same time, the Pilot project's future activities will be directly integrated into, and complementary with, those under way within the Joint Research Centre, in particular under the SAFESUST, RESURBAN and iRESIST+ projects.

In particular, the so called SAFESUST approach, aiming at defining the global performance (structural, energy and environmental) in monetary terms has been described. This approach, combined with the findings of the other research actions conducted at the JRC will form the basis of the novel simplified assessment method which will be defined as a part of the project.

For what concerns the technologies for combined upgrading of existing buildings, the results obtained so far from the iRESIST+ are very promising. A novel approach proposing a hybrid seismic-plus-energy retrofitting solution which combines inorganic textile-based composites with thermal insulation systems tailored for RC and masonry building envelopes was explored. The overall effectiveness of the combining energy efficiency and seismic retrofitting has been demonstrated via case studies of masonry and RC building. Moreover by proposing a common approach based on the expected annual loss (of consumed energy or expected seismic loss), it was possible to evaluate the financial feasibility and benefits of the combined approach. It was shown that the payback of the retrofitting intervention can be significantly reduced when seismic is applied concurrently with energy retrofitting by combining advanced construction materials, thanks to large savings related to the labour costs. The effectiveness of the proposed retrofitting system will be validated experimentally in a full-scale RC building using the ELSA reaction wall facility.

5. References

- [1] European Parliament (2019), Definitive adoption of the European Union's general budget for the financial year 2019, L 67/1096, *Official Journal of the European Union*, 7.3.2019, 1094-1095.
- [2] European Commission (2019), Decision C(2019) 3874 final on the adoption of a financing decision and a work programme for 2019 for the implementation of the Pilot Project "Integrated techniques for the seismic strengthening and energy efficiency of existing buildings" to be financed under budget line 13 03 77 26, 28.05.2019, 1-2.
- [3] Caverzan A, Lamperti Tornaghi M, Negro P (2019): Matching safety and sustainability: the SAFESUST approach. IOP Conf. Series: Materials Science and Engineering, **442** (2018) 012019 doi: [10.1088/1757-899X/442/1/012019](https://doi.org/10.1088/1757-899X/442/1/012019).
- [4] Bournas, D.A. (2018a): Concurrent seismic and energy retrofitting of RC and masonry building envelopes using inorganic textile-based composites with insulation materials: A new Concept, *Composites Part B: Engineering*, **148**, 166-179. <https://doi.org/10.1016/j.compositesb.2018.04.002>.
- [5] Bournas, D.A. (2018b): "Innovative materials for seismic and energy retrofitting of the existing EU buildings", Research Report, No. EUR 29184 EN; Joint Research Centre, Ispra, Italy, DOI: 10.2760/091621.



- [6] Gkournelos PD, Bournas DA, Triantafillou TC. (2019): Combined seismic and energy upgrading of existing reinforced concrete buildings using TRM jacketing and thermal insulation. *Earthq Struct* 2019;16:625–39. <https://doi.org/10.12989/EAS.2019.16.5.625>.
- [7] Pohoryles D. A. Maduta C., Bournas D. A. and Kouris L. A. (2020): Energy Performance of Existing Residential Buildings in Europe: A Novel Approach Combining Energy with Seismic Retrofitting. *Energy and Buildings*.
- [8] Daskalaki, E.G., Droutsa, K., Balaras, K.A. and Kontogiannidis, S. (2016): Typology of Greek residency buildings” (in Greek), Research Report, Institute of Environmental Research, Sustainable Development and National Observatory of Athens, Athens. Marini A, Passoni C, Riva P, Negro P, Romano E, Taucer F (2014): Technology options for earthquake resistant, eco-efficient buildings in Europe: Research needs, Joint Research Centre, *Scientific and Policy Reports*, JRC87425, doi [10.2788/68902](https://doi.org/10.2788/68902).
- [9] Marini A, Passoni C, Riva P, Negro P, Romano E, Taucer F (2014): Technology options for earthquake resistant, eco-efficient buildings in Europe: Research needs, Joint Research Centre, *Scientific and Policy Reports*, JRC87425, doi [10.2788/68902](https://doi.org/10.2788/68902).
- [10] Triantafillou TC, Karlos K, Kapsalis P, Georgiou L. (2018): Innovative Structural and Energy Retrofitting System for Masonry Walls Using Textile Reinforced Mortars Combined with Thermal Insulation: In-Plane Mechanical Behavior. *J Compos Constr*;22:04018029. [https://doi.org/10.1061/\(ASCE\)CC.1943-5614.0000869](https://doi.org/10.1061/(ASCE)CC.1943-5614.0000869).
- [11] Koutas LN, Tetta Z, Bournas DA, Triantafillou TC. (2019): Strengthening of Concrete Structures with Textile Reinforced Mortars: State-of-the-Art Review, *J Compos Constr*; 23:03118001. [https://doi.org/10.1061/\(ASCE\)CC.1943-5614.0000882](https://doi.org/10.1061/(ASCE)CC.1943-5614.0000882).
- [12] Pohoryles DA, Bournas DA. (2020): Seismic retrofit of infilled RC frames with textile reinforced mortars: State-of-the-art review and analytical modelling. *Composites Part B: Engineering*, **183**; <https://doi.org/10.1016/j.compositesb.2019.107702>.
- [13] Italian Ministry for Infrastructures and Transports (2017): Ministerial Decree n. 58 of February 2nd, 2017, Sisma Bonus – Linee guida per la classificazione del rischio sismico delle costruzioni nonchè le modalità per l’attestazione, da parte di professionisti abilitati, dell’efficacia degli interventi adottati.
- [14] Lamperti M, Loli A, Negro P (2018): Balanced Evaluation of Structural and Environmental Performances in Building Design, *Buildings* **2018**, 8(4), 52; <https://doi.org/10.3390/buildings8040052>.
- [15] Negro P, Mola E (2017): A performance based approach for the seismic assessment and rehabilitation of existing RC buildings, *Bulletin of Earthquake Engineering*, **volume 15**, pages3349–3364 (2017) <https://doi.org/10.1007/s10518-015-9845-8>.
- [16] Caruso MC, Lamperti M, Negro P (2018): Applicability of the Sustainable Structural Design (SSD) Method at urban/regional/national level, *16th European Conference on Earthquake Engineering*, Thessaloniki, Greece.
- [17] Maio R, Tsionis G, Sousa ML, Dimova S (2017): Review of fragility curves for seismic risk assessment of buildings in Europe. *16th World Conference on Earthquake*, Santiago, Chile.
- [18] Sousa ML, Tsionis G, Dimova S (2017): Effect of the detail of exposure data in large-scale seismic risk assessment. *16th World Conference on Earthquake*, Santiago, Chile.
- [19] Palermo V, Tsionis G, Sousa ML (2018): Building stock inventory to assess seismic vulnerability across Europe. *16th European conference on Earthquake Engineering*, Thessaloniki, Greece.
- [20] CEN (2004): *Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings*. European Committee for Standardization.
- [21] CEN (2005): *Eurocode 8: Design of structures for earthquake resistance - Part 3: Assessment and retrofitting of buildings*. European Committee for Standardization.
- [22] RER- Programa de Segurança Sísmica e Aumento da Eficiência Energética. <http://www.cm-lisboa.pt/viver/urbanismo/reabilitacao-urbana/programas-municipais-de-incentivo-a-reabilitacao/rer-programa-de-seguranca-sismica-e-aumento-da-eficiencia-energetica-em-estudo>.