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INTEGRATED SUSTAINABLE BUILDING RENOVATION: TOWARDS A POSITION PAPER BY AN EAEE WORKING GROUP

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Abstract: *An estimated 35% of European buildings are over 50 years old, which makes renovation activities urgent to achieve European and international goals. Existing buildings are indeed inefficient in energy consumption, and renovating them will save energy and improve the inhabitants' quality of life. Renovation of existing buildings and urban spaces provides an opportunity to enhance not only energy but also structural performance. As part of building requalification for energy efficiency, structural safety should also be considered. Additionally, building renovations provide an excellent opportunity to create a safe, sustainable, and resilient built environment, as supported by the New European Bauhaus initiative. Hence, implementing sustainable and life cycle thinking-based retrofitting interventions can minimise costs and impacts associated with production, construction and other life cycle phases (such as maintenance and end-of-life stage) and simultaneously ensure adaptability to climate change and future occupant demands. Thus, under the mandate of the European Association of Earthquake Engineering, a Working Group focused on "Combined seismic and environmental upgrading of existing buildings" organised a workshop as a forum for an ad hoc assembly of knowledge on this topic. As part of this workshop, state-of-the-art combined methods and techniques were presented, and visions have been discussed based on information from European scientific community experts*

in the Working Group regarding promising integrated techniques for environmental refurbishment and seismic retrofitting from their countries. The final objective of such an activity is to draft a position paper that aims to disseminate technical information about integrated techniques, solutions and methods for retrofitting European building stock that can increase energy efficiency and decrease structural vulnerability while significantly reducing environmental impact and lowering maintenance costs, and increasing adaptability and resilience for future climate changes and needs.

1. Introduction

In the European Union (EU), 50% of material depletion and 40% of energy consumption is attributed to the existing building stock, which results in 36% of the EU's greenhouse gas emissions (GHG) and 35% of waste production (Bean et al., 2018). The existing built environment is energy inefficient in 75% of cases. Although outdated construction is an issue in Europe, it is not the only one. Buildings built before 1970 often did not consider either seismic vulnerability or energy efficiency (Lamperti Tornaghi, Loli and Negro, 2018). Residential EU buildings consume annually more than 1900 TWh for heating at a cost of 180 billion euro (Gkatzogias et al., 2022a). Accordingly reducing the energy consumption of existing buildings to achieve the EU targets through low carbon footprint technologies remains a challenge. Several buildings have been in service for 50-60 years now that have exhibited severe energy and structural deficiencies, particularly when compared with the current EU and national legislation. On average, 35% of European buildings are over 50 years old (in some countries, even more), and 75%-80% of these buildings will still be in use by 2050 (Fabbri, Groote and Rapf, 2016; Li *et al.*, 2019). Additionally, their maintenance and retrofitting are economically unsustainable (Menna *et al.*, 2022).

Sustainability has progressively become a fundamental objective for several sectors of the economy, including the construction industry. The effects of climate change, overconsumption of natural resources, and population growth are already evident, making it one of the major challenges of this century. For the first time, the Brundtland Report (1987) (Brundtland Commission, 1987) considered the concept of sustainable development as one that meets the needs of present generations without compromising the ability of future generations to meet their own needs. Sustainable construction involves constructing structures in a manner that does not harm the environment, allowing for ongoing building activities.

Engineering frameworks typically treat sustainability as multi-criteria decision-making support, which can be applied to various activities such as building renovation, waste management, and transportation, defining different objectives, such as reducing embodied energy, reducing waste generation, or reducing carbon footprints. When applied to buildings, sustainability is commonly defined as the result of the interaction between (i) environmental aspects, usually expressed in terms of exploitation of resources, energy consumption or GHG emissions, and estimated through the Life Cycle Assessment (LCA) methodology (Gervasio and Dimova, 2018); (ii) economic aspects, typically referring to costs of building construction, repair and maintenance; and (iii) social aspects, mainly related to the impact on the community, such as human health, indoor environmental quality, social inclusion, the standard of living, safety against risks (Passoni et al., 2021). All three aspects have the same importance and mutually cross-link with sustainable development at the centre of this interaction.

2. Towards the development of a position paper

Renovating the existing EU building stock would reduce energy consumption and improve the quality of life for the inhabitants. In addition to improving energy efficiency, renovations of existing buildings and urban spaces can also improve structural performance (Feroldi et al. 2013; Marini et al. 2017; Bournas, 2018; Gkatzogias et al. 2023). Additionally, renovations provide the opportunity to create a sustainable, beautiful, and inclusive built environment in line with the values of the New European Bauhaus initiative (European Commission, 2021). It is, therefore, possible to minimise costs and impacts associated with production, construction, and other life cycle phases (such as maintenance and end-of-life stages) and to ensure that climate change and future occupant demands can be adapted simultaneously by implementing sustainable and life cycle thinking-based retrofitting interventions (Passoni et al., 2022).

Indeed, based on the current situation, a gap remains in the integrated retrofitting of buildings that takes into account the principles of sustainability, including life cycle thinking. This gap needs to be addressed to ensure the sustainability of existing buildings. Additionally, retrofitting costs should be considered to ensure its feasibility over the whole life cycle.

1.1. Working group

Under the mandate of the European Association of Earthquake Engineering (EAEE), a working group was established with a specific focus on “combined seismic and environmental upgrading of existing buildings” (Felicioni *et al.*, 2022). The Working Group 15 (WG15) objectives include promoting the dissemination of technical solutions and methods aimed at reducing seismic vulnerability and improving energy efficiency, which will significantly impact the economic, environmental, and social health of buildings. The Working Group does not engage in research as such but drafts state-of-the-art papers, organises workshops, and holds special sessions at conferences.

1.2. WG15 Workshop 2023

In June 2023, WG15 organised a workshop as a forum for an ad hoc assembly of knowledge on this topic. The main goal of the workshop was to present state-of-the-art combined methods and techniques, as well as ongoing European, national and international projects. Such a step was fundamental to discuss future visions, based on information provided by experts in the field from the European scientific community, regarding promising integrated methodologies and measures for the sustainable renovation of the building stock in their respective countries. Ultimately, this activity was intended to develop a position paper aimed at disseminating technical information regarding integrated technologies, solutions, and methods for retrofitting European building stock. This will result in increased energy efficiency, decreased structural vulnerability, and a significant reduction in environmental impact and maintenance costs.

The workshop was open to WG members and their collaborators and consisted of presentations (30 minutes each) given by members of the WG15 grouped according to their geographical location. The sub-groups were required to present their research to better understand current developments regarding integrated methodologies and techniques for existing buildings across Europe. Table 1 provides a summary of the main topics discussed at the workshop. Topics ranged from the international to the national level.

Table 1. Overview of topics discussed at the EAEE WG15 2023 workshop.

n.	Topic	Context
1	State-of-the-art on integrated retrofitting of existing buildings considering a life cycle thinking approach	International
2	Sustainability and resilience of the built environment	International
3	Integrated techniques for the seismic strengthening and energy efficiency of existing buildings (REEBUILD)	European
4	Innovative seismic and energy retrofitting of the existing building stock (iRESIST+)	European
5	Methodology for combined seismic and energy assessment of buildings	Greek
6	The Greek Legislative framework for pre-earthquake evaluation of buildings, and their connection with energy efficiency programs.	Greek
7	ReLuis project: the Italian experience on integrated interventions	Italian
8	Integrated technologies and multi-criteria performance-based design methods for seismic safety and environmental sustainability of buildings	Dutch/International

This workshop aimed to present updated state-of-the-art of the published results as well as to complement them with recent and ongoing relevant activities taking place in the EU. The discussion investigated the possibility of aligning the current European efforts for the integrated renovation of buildings with the increasing seismic and other climate-related hazards that may impact the vulnerability of structures.

State of the art on integrated retrofitting of existing buildings considering a life cycle thinking approach

An analysis of the literature on sustainable retrofitting was conducted to map the publications that address this topic. Figure 1 shows the workflow of the literature research; different steps were undertaken to reach the topic of interest – energy and seismic retrofit following Life Cycle Thinking (LCT) principles (Passoni et al., 2022). According to the results, the concept of integrated retrofitting is finally receiving attention from the scientific community. Still, there is only a limited amount of literature that addresses retrofit intervention based on a life-cycle approach. This could be one of the reasons for the limited means of sustainably retrofitting the building stock, even though the New European Bauhaus (European Commission, 2021) and other international projects aim to achieve this goal.

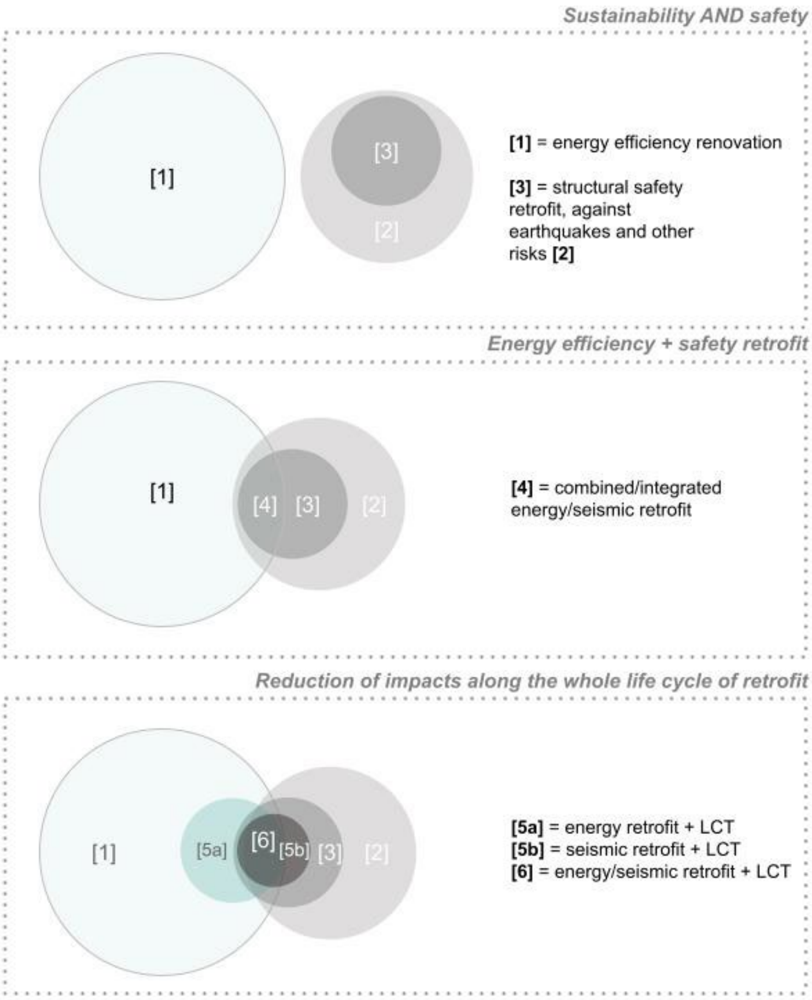

Figure 1 Literature research diagram.

Sustainability and resilience of the built environment

Exceptional natural or man-made actions and disasters affect the entire system and its performance, and thus resilience is interrelated with all three pillars of sustainability. As part of the discussion of this topic, it was noted that the changing environment, social, and economic conditions necessitate an increase in resilience of the built environment using advanced technical solutions for the design, construction, reconstruction, and modernization of existing buildings (Hajek, 2023). These solutions should be tailored to the specific needs and conditions of each building and should be based on the principles of sustainability, efficiency, and cost-effectiveness. Further, they should fully consider the environmental, social, and economic impacts of the building throughout its life cycle using a comprehensive life cycle assessment and life cycle cost assessment considering regional specifics, including expected future changes in climatic conditions.

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

The pilot project 'Integrated techniques for the seismic strengthening and energy efficiency of existing buildings' was carried out by the Joint Research Centre of the European Commission (Figure 2). The project aims at a safe, sustainable and inclusive built environment by promoting a holistic view of renovation, providing scientific support to building renovation policies in the EU and encouraging their further development (Gkatzogias et al., 2023). Existing seismic, energy and combined/integrated renovation technologies were reviewed (Pohoryles et al. 2022a, Pohoryles et al. 2022b, Romano et al., 2023a). A simplified method for assessing the benefit of combined renovation was proposed and applied to representative buildings (Romano et al., 2023b). An integrated framework was developed for regional impact analysis. By employing this framework across the EU, seismic risk, energy performance and socioeconomic aspects were assessed to identify priority regions and investigate renovation scenarios (Gkatzogias et al., 2022a, b). Project results showed that Integrated renovation can save lives, energy and investments while reducing the environmental burden. Policy makers, EU, national and regional authorities together with practitioners and the public are the beneficiaries of this project. Dissemination and outreach were further supported by the 'Building renovation makerspace' platform and by science-for-policy and technical reports (European Commission, n.d.a).

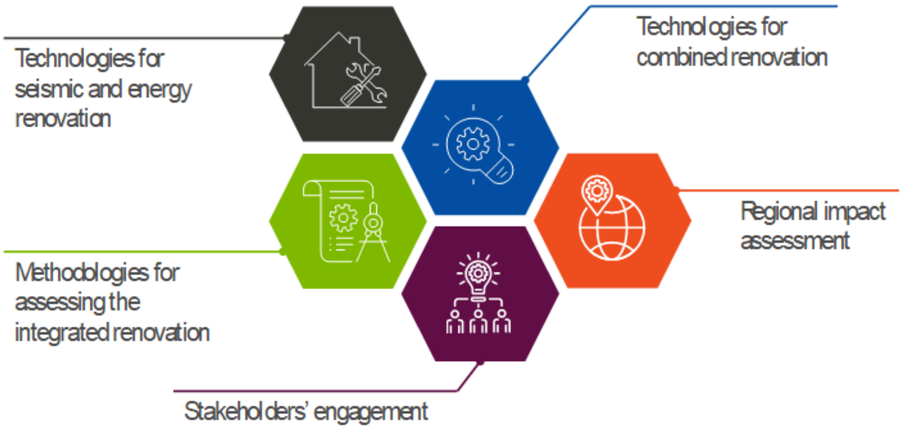

Figure 2 Pilot project actions (Gkatzogias et al., 2023).

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

iRESIST+ was an exploratory research project whose primary objective was to evaluate a novel seismic-plus-energy retrofitting scheme (European Commission, n.d.b). Research conducted as part of this project has considerable relevance to policy areas such as energy savings in buildings, circular economy, and resilience in the built environment. A prototype structure at the JRC was used to evaluate the validity of the proposed approach (Kallioras et al. 2023). During the project, a new macro-modelling approach was developed for textile-reinforced mortar (TRM)-strengthened infilled reinforced concrete (RC) buildings (Pohoryles and Bournas 2020). This was then used to quantify the effectiveness of the retrofit in increasing the in-plane capacity of a prototype structure. The results of incremental dynamic analyses were expanded, demonstrating improved dynamic behaviour of mid-rise RC buildings with reduced damage at higher earthquake intensities (Pohoryles and Bournas, 2021). Using the same combined retrofitting strategy, a study was conducted across twenty European cities in five seismic zones and four climate zones to assess the retrofit for all possible combinations of seismic hazard and climatic conditions, demonstrating that combined or integrated retrofitting can be more cost-effective compared to seismic or energy retrofitting alone for locations of medium to high seismic hazard (Pohoryles et al. 2020).

SURE methodology for combined seismic and energy assessment of buildings

Several methodologies for combined seismic and energy assessment have been identified in the literature, e.g., Romano, Negro and Taucer, 2014; Lamperti Tornaghi, Loli and Negro, 2018 (Romano, Negro and Taucer, 2014; Lamperti Tornaghi, Loli and Negro, 2018), but their application is limited to pilot studies and selected inventories. In response to the increased scientific interest in this topic and the EU's 2030 goals, a new methodology has been developed and adopted within SURE (Competence Center for a Sustainable and

Resilient Built Environment) (Greece). This methodology is based on the fragility curves of buildings and the correlation between the hazard (return periods) and the performance levels (limit states) to develop a seismic performance index for various earthquake intensity levels and damage probability factors, along with a weighting factor. Afterwards, the safety index is combined with an energy efficiency index to provide a holistic assessment of seismic and energy assessment. This methodology has been validated by implementing a case study with a minimal set of parameters (Stefanidou *et al.*, 2023).

The Greek Legislative framework for pre-earthquake evaluation of buildings, and their connection with energy efficiency program

The problem of pre-earthquake assessment of buildings is complex for earthquake-prone countries since detailed assessment of building structural capacity is costly and time-consuming. In Greece, for example, the Earthquake Protection and Planning Organization (OASP) assigned a working group to prepare a proposal for such an assessment, which was delivered in 2000. The proposed methodology is influenced by the American system, FEMA 154, which includes three levels of assessment, namely visual screening, simplified calculation for seismic evaluation, and detailed evaluation. Despite this, there are no dedicated policies or actions devoted to improving the energy efficiency of buildings to enforce the assessment of seismic capacity according to the national Greek codes before energy upgrades and major renovations are undertaken.

ReLuis project: the Italian experience on integrated interventions

In Italy, the Consortium Reluis - an interuniversity consortium that aims to coordinate the activities of the Italian Network of Laboratories of Seismic and Structural Engineering as one of the main Centres of Competence of the Department of Civil Protection - is working on Fast and Integrated Retrofit Interventions (Work Package 5 of the national project ReLUIS-DPC 2022-2024). WP5 of the ReLUIS project engages approximately 40 research units dedicated to the innovative exploration and development of integrated seismic-energy retrofit techniques and methods. This critical phase of the project is characterised by an intensive, multidisciplinary study aimed at enhancing the safety, resilience, and energy efficiency of existing buildings, including residential structures and public interest buildings made of reinforced concrete and masonry. Utilising a collaborative approach, the research units are collectively investigating and analysing innovative retrofit strategies, ensuring that the techniques are adaptable, efficient, and applicable to a diverse range of building typologies and structural materials. Through in-depth case studies, WP5 strives to push the boundaries of conventional retrofit methodologies, aspiring to integrate seismic and energy retrofitting to promote sustainable, safe, and energy-efficient building ecosystems.

Integrated technologies and multi-criteria performance-based design methods for seismic safety and environmental sustainability of buildings (SAFE-FACE)

There is a significant risk of façade performance and serviceability being severely affected by earthquakes in seismic hazard zones. Even at low seismic intensities, the damage to a façade may pose a risk to life and property, resulting in substantial economic losses and market disruptions. For this reason, the EU project 'Seismic SAFety and Energy Efficiency: Integrated technologies and Multi-criteria Performance-Based Design for Building FACadEs' (SAFE-FACE), led by the TUDelf (Netherlands), addresses this issue (TUDelft, no date). The project aims to develop earthquake-proof sustainable façades for mid-rise residential and office buildings by using damage-control construction details and energy-efficient techniques combined. The design of façade systems is supported by multi-criteria performance-based tools and frameworks, including seismic safety as a decisive criterion (Bianchi, 2023; D’Amore et al., 2023).

3. The way to go

The material presented at the workshop (Felicioni and Negro, 2023) has demonstrated that methods have been developed to address the assessment and re-design of existing structures to improve at the same time the seismic safety and the environmental performances of the existing buildings. It has also been shown that many techniques, both traditional and innovative, can be mobilised to achieve such goals, and ongoing research actions are expected to introduce new ones.

Within the earthquake engineering community, awareness has grown about the need for improving the energy efficiency of existing buildings as a crucial necessity in meeting climate change objectives.

At the same time, a general consensus has been achieved about the fact that failing to seize the opportunity of the energy renovation of buildings without simultaneously enhancing their seismic safety would be a waste of valuable resources.

On the other hand, there is much more than energy efficiency in environmental performance. Embodied energy should also be considered, as well as all the processes which are associated with the whole life span of buildings. Life Cycle Analysis is a mature discipline, and it is time to adopt such a framework for the design of buildings. A thorough life cycle analysis approach, which addresses both energy efficiency and safety, would lead to the environmental rehabilitation of the European building stock.

By also incorporating ideals of inclusion and aesthetics into this holistic approach, this would result in a unique and proud European strategy for building rehabilitation.

It becomes clear that the process for the re-design of buildings will become multi-faceted, and different expertise has to be mobilised and possibly developed, with an urgent need for enforcing an appropriate strategy for the interaction of those expertise.

4. Conclusions

Sustainable renovation of buildings has evolved over the past few decades progressively, leading to the latest interpretation as the necessity to simultaneously minimise a building's structural vulnerability to natural hazards and its energy and resource consumption, as well as addressing the embodied carbon and energy in the construction materials themselves.

Participants in the workshop presented several activities that are currently underway in different regions of Europe. The Netherlands, for example, has undertaken a research project to assess the performance of glazed façades under seismic activity, and Italy has begun a project called ReLuis to develop innovative and integrated retrofit technologies that will be more efficient and cost-effective.

Methods have been developed to address the re-design of buildings to simultaneously improve their seismic safety and their environmental performance, such as the SAFESUST approach and the technique developed for the pilot project ‘Integrated techniques for the seismic strengthening and energy efficiency of existing buildings.

Future efforts of the WG15 will include the development of a vision paper on integrated retrofitting of buildings that would go beyond the current state of the art in the field and propose guidelines and perspectives for the future renovation of the building stock, as well as improved dissemination activities to foster an effective collaboration of different expertise around the goal of the integrated rehabilitation of buildings.

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