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Perspectives on integrated retrofitting of existing reinforced concrete buildings

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Abstract

Buildings account for 40% of energy consumption and 38% of CO_2 emissions in the European Union (EU). This substantial impact is primarily due to the delayed implementation of initial energy codes. Additionally, about 40% of the EU's buildings are situated in seismic-prone areas, many of which were constructed without meeting current safety standards. An estimated 65% of these structures require both energy and seismic upgrades. Given these challenges, there is an urgent socio-economic and environmental need to renovate the existing building stock. It is crucial to adopt an integrated retrofitting strategy, enhancing both efficiency and resilience against extreme events. This study provides a detailed examination of the integrated retrofitting of existing Reinforced Concrete (RC) buildings. Additionally, a review of current international policies (or incentive programs) related to independent (i.e., structural or energy) and integrated retrofitting (i.e., seismic plus structural) is presented and discussed. From the ten incentive programs evaluated, 77% focused on energy retrofitting interventions, while only 33% addressed structural improvement interventions. As anticipated, there is an increasing emphasis on programs that also consider the sustainable impact of these buildings' interventions but the combination of energy plus structural interventions still has a minor relevance.

Keywords: Incentive programs; Integrated retrofitting; Energy efficiency; Structural safety; CO2 emissions.

1. Introduction

The construction sector in the European Union (EU) accounts for 36% of carbon dioxide (CO_2) emissions, 40% of energy consumption, and 55% of electricity consumption (Comission 2020). A significant portion of this energy

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consumption and CO_2 emission stems from the heating and cooling of buildings. This trend can be attributed to the delayed introduction of the EU's initial energy codes for buildings, which were only formally established in the 1970s. By that time, approximately 66% of the EU's existing building stock had already been constructed (Bournas 2018). Addressing energy consumption in the building sector is pivotal to meeting the United Nations' goal of achieving net-zero greenhouse gas emissions by 2050 (Comission 2021). Presently, policies are growing that aim to sustainably renovate existing building structures, primarily focusing on reducing operational energy consumption and incorporating low-carbon materials during refurbishment (Council 2019, Comission 2020). However, these policies often overlook structural vulnerabilities, potentially leaving buildings at risk, especially in seismic-sensitive areas. Structural retrofitting and rehabilitation are typically performed independently from the energy retrofitting interventions (and vice-versa), which can be changed by the implementation of new policies that promote integrated interventions (Masi, Chiauzzi et al. 2019).

Furthermore, it is important to note that 40% of these structures are located in earthquake-prone areas and were originally built without sufficient safety measures. Approximately 65% of them are in need of both energy efficiency improvements and seismic retrofitting.

The present work aims to provide an overview of the integrated retrofitting of existing Reinforced Concrete (RC) buildings. Additionally, it will be presented and discussed a review of existing international policies (or incentive programs) related to independent and integrated retrofitting.

Nomenclature

RC	Reinforced Concrete
EU	European Union
EEF	European Energy Efficiency Fund
JTF	Just Transition Fund
CF	Cohesion Fund
RRF	Recovery and Resilient Facility
PPEC	*Plano de Promoção da Eficiência no Consumo da Energia Elétrica*
FNRE	*Fundo Nacional de Reabilitação do Edificado*
IFRRU	*Instrumento Financeiro para a Reabilitação e Revitalização Urbanas*
RpA	*Reabilitar para Arrendar- habitação acessível*
ARU	Urban Rehabilitation Area
IVA	*Imposto de Valor Acrescentado*
IMT	*Imposto Municipal sobre as Transmissões Onerosas de Imóveis*
IRS	*Imposto de Rendimento das Pessoas Singulares*
IRC	*Imposto sobre o Rendimento das Pessoas Coletivas*
IMI	*Imposto Municipal sobre Imóveis*
AIMI	*Adicional Imposto Municipal sobre Imóveis*
IRPEF	Personal Income Tax
IRES	Corporate Income Tax

2. Methodology of review

A critical analysis was conducted on 10 incentive programs, encompassing both European and Portuguese levels, as well as 8 tax benefits—5 in Portugal and 3 in Italy—financed by the European Union. The creation of the database was made feasible solely through the examination and research of incentive programmes and tax benefit in official documents and websites of the European Union, the Portuguese government, and the Italian government.

2.1. Review of existing incentive programs for buildings' retrofitting

Each incentive program was studied based on impact assessment of their aim (i.e., improvement of their energy efficiency and/or structural integrity, and/or CO_2 emissions); technical information (construction period, and type of construction of the target constructions); eligible investments (investment range, debt maturity, explanation of the investment, investment instruments, and co-investments); beneficiaries and investors.

To prepare this preliminary report, an exhaustive analysis was carried out of both the incentive programs available in the EU and in Portugal, assessing the following variables: energy efficiency; structural integrity, and CO_2 emissions. After reviewing it in detail, it is possible to observe that in some cases some programs were not yet applied or were unknown, i.e., the target stakeholders were not well specified, or the date for starting its implementation was not yet defined.

2.2. *Tax Benefits*

In addition to studying different incentive programs relating to buildings' retrofitting, 8 active tax benefits in Portugal and Italy were also analysed. Of these, 63% are from Portugal while 38% are Italian and the connections between the different tax benefits were explored and drawn. These benefits were analysed based on several criteria: impact assessment (including energy efficiency, structural integrity, and CO_2 emissions), technical details (such as construction period and type of construction), financial contribution within the program, the specific tax benefits, beneficiaries, and investors.

3. **Review of existing strategies for independent and integrated retrofitting of existing RC buildings**

Retrofitting existing building structures is one of the most important tasks nowadays, since there is a significant number of buildings that are exceeding the service life or have serious energy inefficiency or structural vulnerabilities or both. Several research works were undertaken during the last few years showing different strategies for carrying out independent seismic or energy retrofitting, but few ones focus on integrated retrofitting. The review herein presented is only focused on the existing buildings' external envelopes since it is a critical part of the buildings that affect their energy efficiency and that can have serious consequences when subjected to earthquakes (Masi, Chiauzzi et al. 2019).

The masonry infill walls constitute a significant portion of a building's envelope. On one hand, they contribute to ensuring thermal and acoustic comfort inside a building without sacrificing its aesthetic appeal. On the other hand, the thermal resistance of the infill walls plays a pivotal role in a building's energy consumption. This is particularly pronounced in high-rise structures where the ratio of infill walls to the total envelope area is considerable.

Numerous strategies have been developed to enhance a building's energy efficiency, with a specific focus on upgrading the buildings' envelopes. These techniques include green walls, naturally ventilated façades, interior insulation cladding systems, thermal insulation of external wall air chambers, kit systems, prefabricated units, party wall external insulation, external thermal insulation composite systems, and cement panels.

In response to the structural and non-structural damages observed in recent earthquakes, mainly concentrated in the infill masonry walls, several structural retrofitting methods have been proposed to reduce the seismic vulnerability of masonry infill walls. The primary concerns within the scientific community deal with validating these techniques' efficacy under both in-plane and out-of-plane seismic loading demands (Koutas and Bournas 2019).

Given the pressing need to bolster buildings' energy efficiency while enhancing sustainability and minimizing seismic vulnerability in earthquake-prone areas, there is a rising demand for integrated energy and seismic retrofitting. Addressing the seismic vulnerability of masonry infill walls can lead to the preservation of human lives and substantial economic savings. By ensuring these walls are robust, the need for future replacements or repairs can be drastically reduced, directly contributing to sustainable construction. The most pragmatic approach to achieve these goals involves merging techniques that are traditionally used. An integrated strategy promises to simultaneously boost a building's energy efficiency and improve seismic resilience through a singular intervention.

3.1. *Energy retrofitting*

Efforts in the construction industry have centred on bolstering energy retrofitting solutions for masonry infill walls. Among the most prominent methods is external thermal insulation. While this approach is generally more efficient than internal insulation, emphasizing thermal and energy efficiency improvement and thermal bridge effects reduction, it is especially adequate for walls.

The external thermal insulation (Barreira and de Freitas 2014) offers several benefits. It is less disruptive for occupants compared to internal retrofitting and excels in reducing thermal bridges. Moreover, it shields the building's facade from weather elements and retains indoor space, unlike the interior approach, which can be inconvenient for occupants and diminish the building's heat storage capacity. However, external retrofitting has its downsides, such as difficulties in maintaining heritage RC building facades' original aesthetic and the added cost of scaffolding.

A renowned energy retrofitting technique is the External Thermal Insulation Composite System (ETICS). Designed for walls, ETICS combines insulation and sheathing into one system suitable for both new and existing structures. The continuous insulation perimeter of ETICS effectively eliminates thermal bridges. Various insulation materials, such as EPS, XPS, and cork, can be used in ETICS. The system employs non-structural meshes and plastic connectors, which can mitigate temperature fluctuations in walls, reducing potential damage due to temperature-driven material stresses (Barreira and de Freitas 2014, Michalak 2021).

A party wall is a structural divider between two neighbouring buildings, often composed of two walls built at separate times. External insulation is appropriate for shared exterior walls, instances of adjacent building demolition, or when significant facade flaws, like unsealed openings or inconsistent insulation, emerge (Lowe, Wingfield et al. 2007). Polyurethane foam can renovate these walls, enhancing sealing and insulation consistency. However, to shield against UV rays, this foam requires protection, either through paint or a dense polyurethane elastomer layer.

Prefabricated "kit systems" offer another solution, delivering a ready-to-install product with an external layer, insulation (made of materials like XPS, EPS, PF, or PUR), and fixing devices. Another strategy uses cement panels for façade refurbishment. If external modifications are unfeasible, interior thermal insulation is an alternative. Its main drawback is the reduction in living space, coupled with potential inconveniences during the retrofit for occupants. Another efficient technique involves injecting insulating materials, such as mineral fibres, into wall cavities. For a more sustainable approach, consider naturally ventilated façades or Green Walls.

3.2. *Seismic retrofitting*

Seismic retrofitting of masonry infill walls aims to prevent the wall from collapsing during earthquakes. Two main seismic loadings can damage or even cause the collapse of the walls: in-plane (along the wall plane) and out-of-plane (perpendicular to the wall). In-plane loadings can result in the wall detachment from the surrounding frame, diagonal cracking, shear failure, and corner crushing, all dependent on wall type and geometry (De Risi, Gaudio et al. 2018). Out-of-plane seismic accelerations can cause partial or complete wall collapses (Anić, Penava et al. 2020). One factor intensifying collapse risk is the interaction of in-plane and out-of-plane demands. Damage from in-plane loadings compromises wall boundaries and it increases the wall vulnerability against out-of-plane loading ones. Other factors, like wall support width reduction, slenderness, openings, and masonry type, also affect performance and vulnerability.

Priorities for structural retrofitting are: i) Preventing collapse from out-of-plane loadings, and ii) Enhancing wall resistance to combined in-plane and out-of-plane loadings. Based on that, two retrofit strategies can be assumed. First, disconnecting the wall from the structural system to counter the wall's seismic influence on building. However, this strategy increases the out-of-plane collapse vulnerability (Calvi and Bolognini 2001, Stathas, Karakasis et al. 2019). Disconnection can be done through sliding devices or energy dissipation devices. Some countries adopt a gap-based disconnection method. The second strategy, focuses on strengthening the wall and connecting it to the building superstructure using methods such as: Fiber Reinforced Polymers (FRP) (Valluzzi, da Porto et al. 2014); Engineered Cementitious Composites (ECC), Textile Reinforced Mortars (TRM) (Kariou, Triantafyllou et al. 2018); and Ferrocement. Considering these strategies and techniques it is fundamental for optimizing seismic resilience of masonry infill walls to perform detailed performance assessment studies.

3.3. *Integrated retrofitting*

Recent research has centred on evaluating the effectiveness of merging structural and energy retrofitting methods. The primary approach adopted in these studies involves enhancing textile-reinforced mortar using thermal insulation materials. This method integrates the textile-reinforced mortar with a thermal insulation composite system (Gkournelos, Triantafillou et al. 2020). Also, there is a possibility to combine thermal plasters with reinforcing meshes well fixed to the RC structural elements, tackling at the same time both energy and structural improvements (Furtado, Rodrigues et al. 2023).

Artino, Evola et al. (2019) introduced an innovative approach that concurrently addresses structural and energy retrofitting. Their proposed method involves substituting hollow brick external infill walls with high-performance autoclaved aerated concrete blocks. Using a four-storey building as a case study, they evaluated the efficacy of this technique. The findings indicated a significant enhancement in structural resilience, particularly at the damage limitation state. However, smaller improvements were observed at the life safety and near-collapse states. In terms of energy efficiency, substituting the building envelope walls resulted in a 10% and 4% reduction in energy demand for heating and cooling, respectively.

4. Review of existing incentive programs for buildings' retrofitting

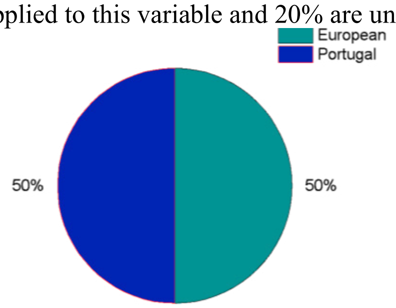
4.1. *General description*

A comprehensive review of the existing ten incentive programs in the scope of retrofitting/rehabilitation/renovation of existing buildings in Europe was performed. From these ten incentive programs, five of them are from Portugal and the remaining five are from other European countries. The preliminary observations are herein presented and discussed. The European programs presented below are the: i) European Energy Efficiency Fund (EEEF); ii) Just Transition Fund (JTF); iii) Cohesion Fund (CF); iv) InvestEU; and v) Recovery and Resilient Facility (RRF). Regarding the programs in force in Portugal that were considered in the database herein presented are: i) *Programa de Apoio ao Acesso à Habitação 1ºDireito; ii) Plano de Promoção da Eficiência no Consumo da Energia Elétrica* (PPEC); *iii) Fundo Nacional de Reabilitação do Edificado* (FNRE); iv) *Instrumento Financeiro para a Reabilitação e Revitalização Urbanas* (IFRRU); and v) *Reabilitar para Arrendar- habitação acessível* (RpA) promoted by Fundiestamo, Portal da Habitação and Entidade Reguladora dos Serviços Energéticos.

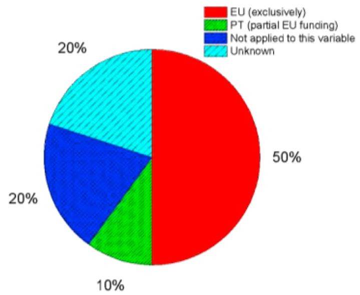
4.2. *Impact Assessment*

The introduction of incentive programs for building retrofitting carries significant consequences, including the delayed implementation of government measures and policies for renovating the building stock. Furthermore, it aims to promote comprehensive, integrated renovation efforts.

Regarding the programs under analysis in the present study that aim to promote energy efficiency improvement, Figure 1a shows that 50% are at the European level and 50% are at Portugal level. Currently, programs dedicated to improvement of the structural integrity/safety, particularly important in earthquake-prone regions, are applied differently in each European country, not having a common approach at the EU level. For example, in Portugal 40% of the programs under analysis were applied, with partial support from the European Union, but with a low rate of successful applications. Of the 10 programs under analysis, approximately 50% were provided exclusively by the European Union, 20% were applied in Portugal with partial funding from the European Union, 10% of the programs were not applied to this variable and 20% are unknown (Figure 1b).



a)



b)

Figure 1. Percentage of incentive programs by scope (a) energy efficiency; (b) CO2 emissions/ green impact.

Regarding the aim of all the programs under analysis (i.e., improvement of the energy efficiency, structural integrity, and reduction of CO_2 emission), it was observed that only 1 program was fully dedicated to only improving the energy efficiency (10%), 2 addressed in simultaneous improving structural integrity, reduction of CO2 emissions and improvement of energy efficiency (20%), 1 addressed structural integrity combined with energy efficiency (10%)

and 6 programs addressed energy efficiency combined with the CO2 emissions (60%). This becomes evident that the environmental and climate impact of the buildings is the priority of international policies nowadays mainly justified by climate change. Nevertheless, it should be strengthened that the resilience of the building stock has serious environmental consequences if, in the case of a post-earthquake scenario, it is necessary to demolish part of the existing building stock.

4.3. *Technical information on target building typologies*

In all the European Union programs explained above, it was not found restrictions regarding the period and type of construction. This aspect is particularly relevant since the buildings built before 1980 were designed before the implementation of the energy codes for construction and also without seismic designing.

Nevertheless, in Portugal, some incentive programs have minor specifications such as being part of urban rehabilitation areas. These areas are defined by the Municipalities and aim to restore buildings in urban areas.

4.4. *Eligible investments*

Eligible investments can differ significantly depending on the program. They encompass a broad spectrum, from direct investments and diverse investment instruments to debt maturities and co-investments. Typically, the investment amounts span from millions to billions of euros, with debt maturities ranging between 10 and 30 years.

For smaller-scale investments, details are often more favourable than prevailing market conditions. This is particularly the case for comprehensive building rehabilitations intended for housing or other activities. Such projects prioritize the integration of optimal energy efficiency solutions as part of the rehabilitation process. This strategy embodies a firm commitment to revitalizing urban areas. By doing so, it supports the repopulation of city centres, enhances the quality of life, and emphasizes greater energy efficiency tailored to the specific area.

Investment instruments available include senior debt, mezzanine instruments, leasing structures, and forfeiting loans, which are usually backed by budget commitments. Co-investments may or may not be part of the program but normally in the energy sector, there is equity participation with direct cooperation with municipalities and private entities.

4.5. *Beneficiaries*

Typically, the beneficiaries of these incentive programs are municipalities, local, and regional authorities as well as public and private entities acting on behalf of those authorities such as utilities, public transportation providers, social housing associations, energy service companies, and taxpayers.

4.6. *Investors*

The primary investors in the 10 incentive programs that were examined include the European Commission, Deutsche Bundesstiftung Umwelt, a major European insurance player, the Corporate Pension Fund, the European Bank for Reconstruction and Development, the Council of Europe Development Bank, the Nordic Investment Bank, the Republic of Portugal, the Housing and Urban Rehabilitation Institute, Compete 2020, Portugal 2020, and the Financial Instrument for Urban Revitalization.

5. **Review of existing tax benefits**

The following 3 Italian tax incentives, namely, i) Superbonus, ii) Sismabonus, and iii) Ecobonus, are jointly financed by the European Union and the Italian government, as of ISSAC (2023). Concerning the tax incentives in Portugal that will be discussed, they encompass i) Imposto de Valor Acrescentado (IVA), ii) Imposto Municipal sobre as Transmissões Onerosas de Imóveis (IMT), iii) Rendimento das Pessoas Singulares and Imposto sobre o

Rendimento das Pessoas Coletivas (IRS; IRC), iv) Imposto Municipal sobre Imóveis (IMI), and v) Adicional Imposto Municipal sobre Imóveis (AIMI).

5.1. *Impact assessment/ Tax benefits*

In examining the impact of tax benefits, the Italian government distinguishes between benefits targeting a single area of impact and those addressing a combination, notably energy efficiency and structural integrity. The Superbonus exemplifies this approach. The Superbonus offers tax deductions for expenses related to energy and seismic retrofitting of residential buildings starting from 1 July 2020 until 31 December 2022 and in some special cases in 2023. This initiative not only fosters economic growth and job creation but also reduces energy consumption, championing an environmentally friendly transition. Covered interventions include external insulation, efficient window installation, heating and air conditioning system replacements, and the addition of renewable energy systems.

Another tax incentive, "Sismabonus", encourages earthquake safety in Italy. Taxpayers can claim this deduction against either the IRPEF (Personal Income Tax) or IRES (Corporate Income Tax). For properties in seismic zones 1 and 2, described in the UNI EN 1998-1, the deduction, enhanced by the Relaunch Decree (Decree-Law 19/05/2020 n.34), reaches 110% for certain seismic safety improvements. This includes work transitioning buildings to a lower-risk seismic category and investments in earthquake-resistant structures built after demolition and reconstruction (known as Sismabonus purchases) in seismic zones 1, 2, and 3, with expenses made between July 1, 2020, and December 31, 2021. The "Ecobonus" serves as Italy's energy-saving tax incentive guide. Depending on the nature of the work, claimants may receive an IRPEF refund ranging from 50% to 65% of the cost. For projects in condominiums, especially those enhancing both energy efficiency and seismic resistance, the Ecobonus can reach up to 85%.

In Portugal, there are five distinct tax benefits: i) IVA: This offers a 6% rate reduction on urban rehabilitation projects; ii) IMT: It provides tax exemptions on property purchases intended for rehabilitation and on the first transfer post-rehabilitation; iii) IMI: Municipalities can apply up to a 25% reduction for five years on energy-efficient urban buildings, along with a three-year exemption following urban rehabilitation; iv) AIMI: This permits deductions on taxable income equivalent to a portion of the IVA paid on environmental costs. Additionally, there's a 5% tax on capital gains for residents on the first sale post-intervention and a 5% tax on rental income for rehabilitated properties.

4. Conclusion, limitations, and future research opportunities

Buildings account for 40% of the EU's energy consumption and 38% of its CO_2 emissions, largely due to delayed implementation of early energy codes. Moreover, 40% of these buildings are situated in seismic regions but were constructed with inadequate safety standards. Roughly 65% require both energy and seismic retrofitting. A notable fraction of the EU population also faces heating challenges in their homes, posing health and energy poverty risks. Existing RC building envelopes play a pivotal role in energy efficiency and seismic performance. Unfortunately, these two parameters are often studied separately. While the European Green Deal has spurred energy retrofitting, it has not adequately addressed structural deficits, leaving many buildings vulnerable, especially in seismic areas.

This research work undertook a comprehensive review of existing energy, structural and integrated retrofitting approaches for envelopes of existing buildings. From this review, it was found that the combination of TRM-based solutions with the ETIC system can be a promising and effective strategy for integrated interventions of envelopes. Most of these programs prioritize energy retrofitting: 10% focus on only energy retrofitting, 10% focus on energy retrofitting combined with improvement of the structural integrity, 20% focus on energy efficiency combined with structural integrity and reduction of CO2 emissions. Finally, 60% focus on the combination of energy retrofitting and reduction of CO2 emissions. Owners have the opportunity to combine different incentive programs, enhancing RC buildings both structurally and thermally, while also contributing to environmental conservation by reducing CO_2 emissions. Notably, while EU programs have broad eligibility, some Portuguese initiatives are specifically tailored for urban rehabilitation areas. These programs typically benefit municipalities, regional governments, public and private entities, including utilities, public transportation providers, social housing associations, energy service companies, and taxpayers. Key investors include the European Commission, Deutsche Bundesstiftung Umwelt, European Bank for Reconstruction and Development, Nordic Investment Bank, Portuguese Republic, and several others. In Italy, tax benefits, like the Superbonus, support energy and seismic upgrades in the wider class of residential buildings. The Sismabonus allows for tax deductions on seismic safety initiatives, incentivizing the move to lower-risk building categories. Meanwhile, the Ecobonus facilitates deductions of up to 85% on energy conservation measures that also improve earthquake resilience. Portugal offers five main tax benefits. These include a 6% reduction in the IVA rate for urban rehabilitation, IMT exemptions for properties undergoing or completed rehabilitation, and IMI reductions for energy-efficient urban buildings with a lower percentage of refunding.

Finally, another important limitation is that the programs and benefits discussed are subject to frequent updates. For this reason, future research will require continual database refreshing, including the integration of new countries, programs, and tax benefits, ensuring comprehensive and up-to-date comparative analysis.

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