Peer-reviewed version available at *Sustainability* **2018**, *10*, 1561; doi:10.3390/su10051561

Review

Seismic and energy renovation. A review of the design approach in Italy and in Romania.

Emil-Sever Georgescu [1], Mihaela Stela Georgescu [2], Zina Macri [2], Edoardo Michele Marino [3], Giuseppe Margani [3], Vasile Meita [1], Radu Pana [1], Horia Petran [1], Pier Paolo Rossi [3], Vincenzo Sapienza [3]* and Marius Voica [2]

[1] NIRD URBAN - INCERC, Soseaua Pantelimon, nr. 266, 021652, Sector 2, Bucharest, Romania;
[2] University of Architecture and Urbanism "Ion Mincu", Bucharest 010014, Romania; [3] Department of Civil Engineering and Architecture - University of Catania, via Santa Sofia, 64, 95125 Catania
* Correspondence: vsapienza@unict.it; Tel.: +39-0957382531

Abstract: Most European cities are characterized by very large areas, often formed by buildings with low quality, from a series of point of view. The possibility of renovating them is strategic to improve both the quality of life and to the possibility of economic recovery for building companies. In the last decades, the attention of the scientific community has been addressed to the energy renovation, thanks to the strong activities of the European Community in this field. However, since a relevant part of the EC territory is at risk of earthquake, the possibility to combine both energy and seismic renovation actions may be strategic for many countries. In particular, Italy and Romania are linked by a common social tradition that springs from the Roman Empire. Nowadays, this link is stronger, thanks to common interests in social, cultural and business fields. Therefore, the investigation of possible synergies for seismic and energy renovation strategies may be really interesting for both countries. This paper represents the first step in this direction. After an overview of regulations and common practices for buildings with reinforced concrete structures, in both states, some key combined renovation interventions will be described and discussed, as well as advantages and perspectives of integrated renovation approaches.

Keywords: Building rehabilitation; energy efficiency; seismic reinforcement.

1. Introduction

Most European cities are characterized by large urban areas, built after the II World War and formed by edifices that often show low standards of quality. The renovation of these districts represents a strategic issue to improve the quality of life and to foster the recovery of the building sector.

In the last decades, the attention of the scientific community has been driven mainly to energy retrofitting, thanks to the strong activities of the European Community in this field. However, a significant number of EU regions is earthquake-prone, as it has been unfortunately shown in recent time. So, the opportunity to combine energy and seismic renovation turns out to be crucial for many countries.

Italy and Romania, whose real estate is highly energy-consuming and seismically vulnerable, may play a breakthrough role.

This paper will review both traditional and innovative renovation interventions devoted in Italy and Romania to enhance the seismic and energy performance of recent buildings, i.e. erected from the 1950s through the 1980s, which are generally characterized by reinforced concrete (RC) or steel load bearing structures. Historic edifices, i.e. built before 1950, need specific measures [1-3] and are not considered in this paper.

2. State of art

2.1. Overview of technical regulations in Italy in relationship with earthquake vulnerability

The classification of the Italian territory in areas with different levels of seismic hazard started in 1909, after the devastating earthquake that hit the cities of Messina and Reggio Calabria in 1908. The district of Messina and the whole Calabria region were classified as earthquake prone areas and the explicit consideration of the seismic excitation in the design of buildings located in these areas became mandatory [4]. The effect of the earthquake was simulated by equivalent horizontal forces. The level of seismic resistance to be provided to the structure was set to avoid the collapse on the occurrence strong ground motions, but damage of structural members caused by such extreme events was admitted. The classification of new seismic areas generally followed the catastrophic events that struck the country over time; for instance, after the Avezzano earthquake in 1915 a portion of the central area in Italy was classified as earthquake prone. Other important seismic events that anticipated the classification of new seismic areas are those occurred in Abruzzo and the southern area of Marche (1943), central area of Calabria (1947), Carnia (1959), Velina valley (1961), Irpinia (1962), Monti Nebrodi (1967), Belice valley (1968), Tuscania (1971), Friuli (1976), southern area of Calabria, Patti gulf (1978), Valnerina (1979) and Irpinia-Basilicata (1980). Today, the whole country is considered earthquake prone and the expected level of seismic excitation is given based on the geographic location of the site (Figure 1). Unfortunately, the most considerable growth of the building stock in Italy took place in seventies when the application of seismic provisions was not mandatory in most of the country. As a consequence, most of the existing buildings supported by a RC frame, which represents the most common technology in Italy, have been designed without considering seismic provisions and are affected by important structural deficiencies. The seismic upgrading of these buildings is of paramount importance for the safety of the population and the resilience against earthquakes [5].

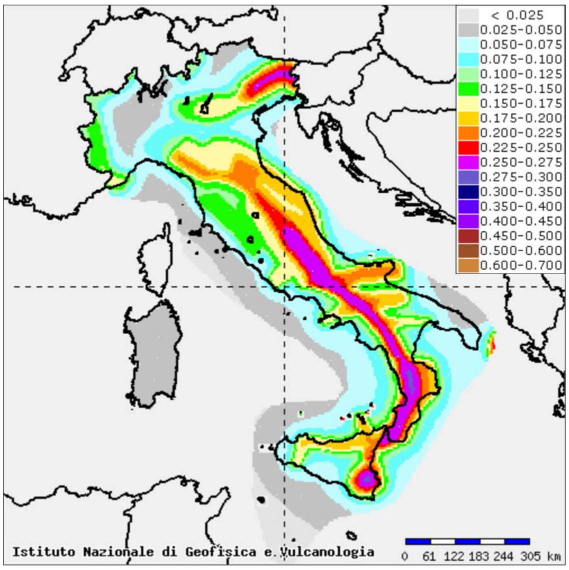


Figure 1. Italian seismic hazard map, PGAs (g) for probability of exceedance of 10% in 50 years.

The Italian Building code provides specific sections for existing buildings. More in detail, provisions for seismic assessment and retrofitting of existing buildings are reported in Section 8 of the “Norme Tecniche per le Costruzioni” (Technical rules for constructions, NTC08) enforced in 2008 [6] and in the relevant section of the associated Commentary [7]. In addition, Section 11 of the Ordinance n. 3431 [8] emanated in 2005 still applies when not in contrast with NTC08. The Italian code is fully consistent with the European building code, which provides the regulations on existing buildings in Eurocode 8 (EC8) part 3 [9]. Finally, Eurocode 8 as implemented by means of the relevant National Annexes [10] is also applicable in Italy. The code provisions for existing buildings in force in Italy (i) regulate the procedure for the identification of the structural system and its geometric/mechanical features, (ii) define the methods of analysis and their limits of application, and (iii) provide instructions for the execution of the safety verifications.

2.2. Overview of technical regulations in Italy in relationship with energy performance requirements

In Italy, the firs regulation for the reduction of the energy consumption in buildings was issued in 1976 (Law 373/1976) [11], but it was low-restrictive an often unattended, due to inadequate controls. The first effective code addressing thermal performance criteria was issued only in 1991 (Law 10/1991) [12], when over 80% of the current residential stock had been already built [13]. Consequently, most of the Italian real estate is highly energy-consuming.

Today, a recent directive regulates the energy efficiency of new and existing buildings: the Interministerial Decree 26/6/2015 [14].

With particular reference to renovation actions, this directive classifies three levels of interventions:

1. *relevant renovations of first level*, which involves more than 50% of the building envelope, as well as the upgrade of the heating and/or cooling system;
2. *relevant renovations of second level,* which involves 25÷50% of the building envelope;
3. *energy requalification*, which involves less than 25% of the building envelope and/or the upgrade of the heating and/or cooling system.

In case of interventions (1), the renovated building must have the same energy performance of a new building. For (2) and (3) the energy performance requirements to be verified regard mainly the thermal characteristics of the portion of building envelope interested by the renovation works and/or the efficiency of the upgraded systems.

Moreover, according to the Legislative Decree 28/2011 [15], if the energy renovation involves the entire envelope (external walls, windows, roof and ground slab) of buildings with a net floor area over 1000 m^2, at least 50% of the energy demand for heating, cooling, domestic hot water (DHW) and electricity must be covered by renewable energy sources (RES).

Finally, according to Law 90/2013 [16], from 2019 all new public buildings and from 2021 all new buildings must reach the nearly zero energy building (nZEB) standard. Of course, this applies also to relevant renovations of first level.

According with its geographic characteristics, Italy has a large variety of climatic conditions (Figure 2) and so, the approach to the energy renovation problems, is very different, along the peninsula. As a simplification, in the northern regions, where the heating demand is prevailing, it is necessary to highly insulate the building envelope, while in the southern ones, where conversely the cooling demand is predominant, it is important to take advantage of natural ventilation, external sun-shading devices and massive walls [17].

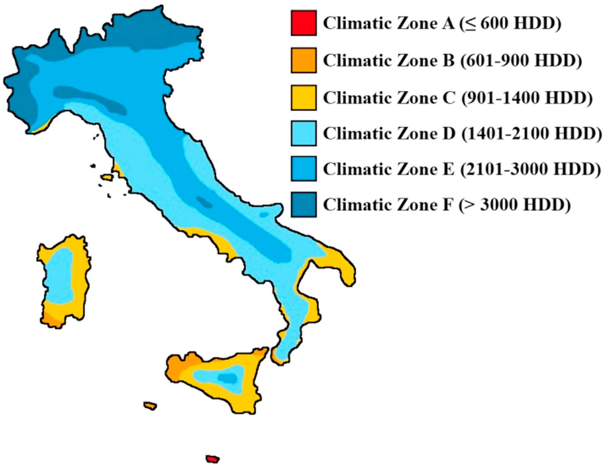


Figure 2. Italian climatic zones, according to the heating degree-days (HDD).

Peer-reviewed version available at Sustainability 2018, 10, 1561; doi:10.3390/su10051561

2.3. Overview of technical regulations in Romania in relationship with earthquake vulnerability

The seismic hazard of Romania (Figure 3) is dominated by the Vrancea intermediate depth earthquakes in south-east of the country. This source affects with high intensities ca. 50% of the territory and is felt with quite important damaging effect on very large areas in neighboring countries, at each strong event. Romania is a country that is periodically subject to such destructive Vrancea earthquakes, as most recently in 1940 and 1977 [18]. Other crustal (shallow) earthquakes can generate locally very high intensities, with a strong tendency of concentration in west and north.

The November 10, 1940 Vrancea earthquake had a magnitude $M_{G\text{-}R}$ = 7.4 (converted at present at M_w = 7.6-7.7) with an epicentral intensity assessed as 10 MCS. In 1940, the damage was heavier in counties and towns near the epicentral area, largely to masonry buildings. In Bucharest, the 12-storey Carlton block, the tallest RC building in the city, collapsed entirely. After the 1940 Vrancea earthquake, earthquake resistant design codes were enacted as MLP Provisional Instructions of 1942 and 1945 [19].

In 1963, the Code P.13/1963 was endorsed as compulsory regulation; it was revised in 1970. The design spectrum was based on a Californian-type spectrum and seismic motions. From 1952 to 1977, seismic zones and K_s factors corresponded at that time to 0.025 values in 7 grade on MSK Scale, 0.05 in 8 grade and 0.1 in 9 grade. Microzonation maps have been indicated as an alternative to the soil conditions characterization [19].

The March 4, 1977 Vrancea earthquake had a magnitude $M_{G\text{-}R}$=7.2 (converted at present at M_w=7.5) and caused damage to a large area and to a variety of buildings. The neglected damages to many buildings affected in 1940 led to collapses of 28 high-rise buildings in 1977. There was a partial collapse of 3 buildings erected after 1960 and damages to others. The earthquake caused the collapse or serious damage of 156,000 apartments in urban areas and 21,500 apartments in rural zones; other 366,000 urban apartments and 117,000 rural houses had to be repaired [18-21]. According to data at hand, out of the over US $ 2 billion losses, about US $ 1.42 billion were in construction field (buildings, water supply system), out of which buildings valued US $ 1.03 billion.

The INCERC seismic record of March 4, 1977 pointed out, for the first time, the spectral content of long period seismic motions of Vrancea earthquakes, the duration, cycle number and higher values of actual accelerations vs. code ones, with important effects of overloading upon flexible structures [18-20]. As a consequence of the INCERC record, the spectral curve (the dynamic coefficient β_r), from the P13-1970 Code (which became P100-78), as well as the seismic zonation map of Romanian Standard STAS 2923-63 have been radically changed, with increase of base shear forces. Since then, all areas are seismic.

The new seismic design codes P100 - 1991, revised 1992, introduced a seismic zonation with two maps, one in terms of seismic coefficient (related to PGA) and another in terms of corner period of the design spectrum, with 3 values. The return period of the map was different in function of the source type.

The procedures for the harmonization between national and European regulations in the field of civil engineering started in Romania in the mid-1990s. Prior to its accession to the European Union (on January 1, 2007), Romania has also followed tightly the programme for the adoption of Eurocodes as national standards [22-24]. The Romanian Seismic Design Code P100-1/2006 has prepared the adoption, starting from 2011, of the homologous Eurocode, EN 1998-1, as the Romanian standard SR EN 1998-1, together with its National Annex for Romania, and has represented an essential factor in the transition to European norms. The P100-1/2006 Code implements important elements of progress with respect to its previous version, P100-92. The zoning map was set with a return periods of 100 years [22]. The P100-1/2013 Code, introduced a map with 225 years return period. Currently PGA from 0.10 g to 0.40 g are compulsory by the zonation map [22]. A zonation map with 475 years return period map (EC 8 level) was not yet endorsed, being considered necessary an interval for stakeholders' adaptation.

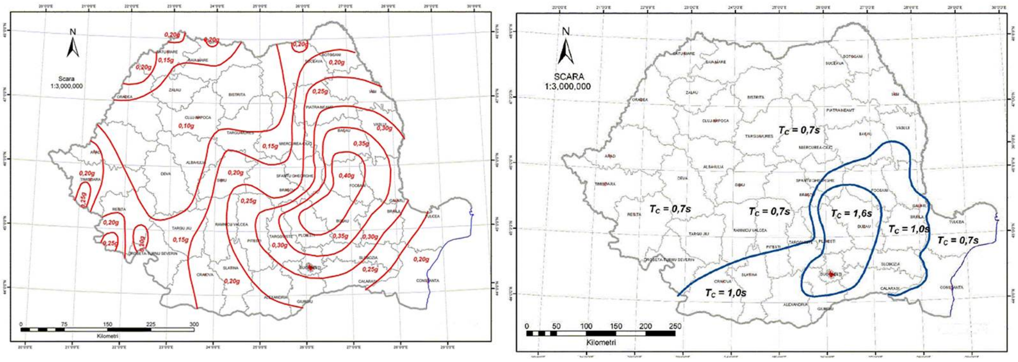


Figure 3. Left: The seismic zoning map of Romania (PGA) for a mean recurrence interval of 225 years and 20% exceedance probability in 50 years. Right: The seismic zoning map of Romania in terms of Tc - corner periods of the response spectrum (Code P100 – 1 /2013, UTCB [25]).

The Romanian code for the seismic assessment of existing buildings, P100-3/2008, includes several notions and concepts from its European homologue, EN 1998-3:2005 (Eurocode 8, part 3). However, Code P100-3 preserves a quantitative approach, based on seismic risk indices, as in code, P100-92 (chapters 11 and 12), and is based on a three-tier approach, similar to that of the ASCE standards [23-24]. The relevant chapters of this code [26] are:

- Generalities; Performance requirements and qualifying criteria;
- Seismic assessment of structures and non-structural components (NSC);
- Collecting the information for structural assessment; Levels of knowledge (KL1, KL 2, KL3);
- Qualitative assessment; Assessment by calculation (Level 1, 2, 3); Assessment of foundations;
- Final assessment and conclusions;
- Annex A – Performance based seismic assessment of existing buildings;
- Annex B – Reinforced concrete structures; Annex C – Steel structures; Annex D – Masonry structures; Annex E – non-structural components (NSC);
- Annex F (informative) – Guide for seismic rehabilitation of existing buildings (for different materials, energy dissipation systems and base isolation).

2.4. Overview of technical regulations in Romania in relationship with energy performance requirements

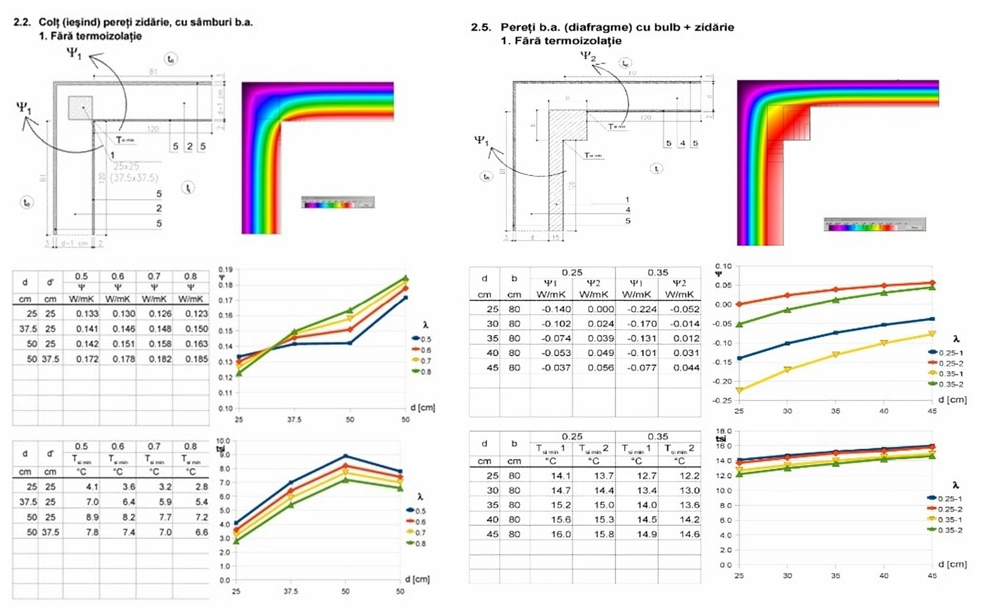
Technical regulations for the calculation of the thermal protection of the building envelope have been developed since 1961, with standard STAS 6472-61, revised in 1968, 1973, 1975, 1984 (when there is a major change in the insulation requirements of envelope elements – by normative NP-84), 1989.

In 1997, the technical regulation C107-1997 was developed, based on the European and International CEN ISO standards, revised afterwards [27-29]. It introduced the calculation of the thermal resistance values of the envelope elements taking into account the correction due to the effect of thermal bridges, evaluated by the linear thermal transmittance ψ and point thermal transmittance χ (Figure 4).

$$R' = \frac{1}{U'} = \frac{1}{\frac{1}{R} + \frac{\sum \psi . \ell}{A} + \frac{\sum \chi}{A}}$$

The calculation of a global heat loss coefficient G of buildings has been introduced, whereby the thermal performance of a building envelope can be assessed by imposing a GN norm (G ≤ GN). The heating energy requirement for buildings in Romania can be judged by the global thermal insulation coefficient G and the average G, as follows:

- 1950 - 1985 - 1.00 W/m^{3}K
- 1986 - 1997 - 0.80 W/m^{3}K
- 1998 - 2010 - 0.55 W/m^{3}K



2.2. Colț (ieșind) pereți zidărie, cu sâmburi b.a.
1. Fără termoizolație

d	d'	0.5	0.6	0.7	0.8
		Ψ	Ψ	Ψ	Ψ
cm	cm	W/mK	W/mK	W/mK	W/mK
25	25	0.133	0.130	0.126	0.123
37.5	25	0.141	0.146	0.148	0.150
50	25	0.142	0.151	0.158	0.163
50	37.5	0.172	0.178	0.182	0.185

d	d'	0.5	0.6	0.7	0.8
		$T_{si\ min}$	$T_{si\ min}$	$T_{si\ min}$	$T_{si\ min}$
cm	cm	°C	°C	°C	°C
25	25	4.1	3.6	3.2	2.8
37.5	25	7.0	6.4	5.9	5.4
50	25	8.9	8.2	7.7	7.2
50	37.5	7.8	7.4	7.0	6.6

2.5. Pereți b.a. (diafragme) cu bulb + zidărie
1. Fără termoizolație

d	b	0.25		0.35	
		Ψ1	Ψ2	Ψ1	Ψ2
cm	cm	W/mK	W/mK	W/mK	W/mK
25	80	-0.140	0.000	-0.224	-0.052
30	80	-0.102	0.024	-0.170	-0.014
35	80	-0.074	0.039	-0.131	0.012
40	80	-0.053	0.049	-0.101	0.031
45	80	-0.037	0.056	-0.077	0.044

d	b	0.25		0.35	
		$T_{si\ min}$ 1	$T_{si\ min}$ 2	$T_{si\ min}$ 1	$T_{si\ min}$ 2
cm	cm	°C	°C	°C	°C
25	80	14.1	13.7	12.7	12.2
30	80	14.7	14.4	13.4	13.0
35	80	15.2	15.0	14.0	13.6
40	80	15.6	15.3	14.5	14.2
45	80	16.0	15.8	14.9	14.6

Figure 4. Extract of a thermal bridges catalogue, showing the linear thermal transmittances ψ of a corner with an embedded, uninsulated RC member (column or shear wall) [30].

The climate zonation map in force has 5 zones with design temperatures for Winter (from -12 °C to -24 °C) (Figure 5 [31]).

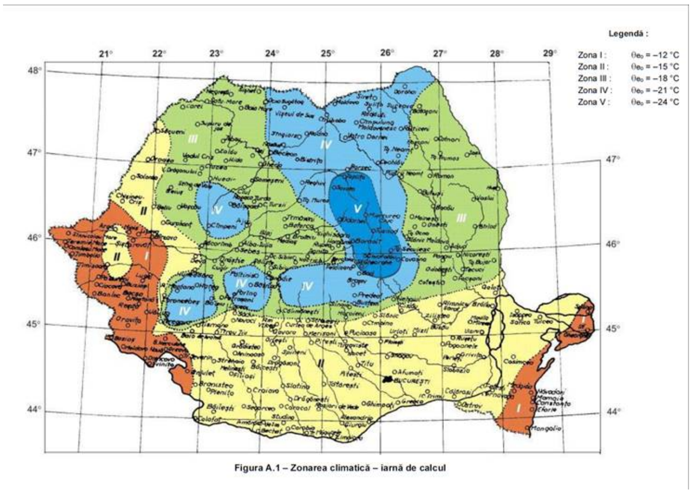


Figura A.1 – Zonarea climatică – iarnă de calcul

Figure 5. Climatic zonation map of Romania – Winter design temperatures [31].

According to 2011 Census, the existing buildings stock of Romania has some 5.3 million buildings, including 8.7 million conventional dwellings. Standardized apartment blocks have a share of up to 70% of the existing housing stock in some urban areas.

Existing apartment blocks with large panel structure (over 35 % of the total number of blocks until the 1990s) that according to the level of the achieved thermal protection are divided into two categories:

- apartment blocks erected according to standard projects up to 1985 (approx. 30% of the total built stock) having a height regime predominantly 5 stories and 9 stories, having an average global thermal insulation coefficient G of about 1 W/(m^{3}K) - corresponding to the average thermal resistances of only 0.6-0.5 m^{2}K/W, that must be prioritized from the point of view of thermal insulating level of the envelope in the framework of a general modernization action;

- apartment blocks with 5 stories and 9 stories erected after 1985 according to standard projects (about 7% of the total built stock) based on the provisions of Decree 256 and NP 15 Normative with a medium thermal resistance increased to about 0.9 m^{2}K/W, characterized by an average global thermal insulation coefficient G of about 0.8 W/m^{3}K.

Structures made of masonry predominate numerically in the dwelling buildings; even in Bucharest. Meanwhile, their number has increased throughout the country.

The level of thermal protection of buildings from the existing building stock corresponds, independently of the structural system used, to the specifications and exigencies imposed during each period, by the technical regulations for the calculation of the thermal performance of the envelope elements. According to each generation of the technical regulations, as well as to the technological level specific to the period, there are groups of buildings with the same level of thermal protection, regardless of the materials used to build the building envelope.

The share of energy consumption in the annual energy balance of an average apartment built between 1970 and 1985 is: heating energy 55.5%; DHW 9.5%; drinking water 1.4%; consumption of natural gas for the preparation of food 9,7%; electricity consumption for lighting 13.9%. Out of the annual energy consumption of a building irrespective of its destination, the heating energy and DHW production represents the main annual energy consumption of about 75%.

The implementation of the European Parliament's Energy Performance of Buildings Directive (EPBD 2002/29/EC, EPBD 2010/31/EC) is also being carried out in Romania in compliance with the provisions of Law no. 372/2005 modified and completed later. A methodology for calculating specific parameters of energy performance of buildings was based on several norms, (NP047/2001, NP048/2001, NP049/2001, later on incorporated in a comprehensive one, updated in 2006 [32], currently under review, while a model certificate energy performance of buildings, as well as an updated referential and a methodology for regular inspection of boilers and ventilation systems and air conditioning were established. Some other technical guidelines for buildings thermal rehabilitation have been developed, as well as a Catalogue of thermal bridges [30].

For all new buildings it is already mandatory, since 2007, to present the energy performance certificate at the reception of the executed work. And for existing buildings that are being rehabilitated, expanded or upgraded, such a certificate must be drawn up. For apartments in residential buildings, the energy performance certificate of the building is mandatory for sale-purchase or lease, from 2010. For public buildings, the energy performance certificate must be exposed at the entrance.

The minimum thermal resistance - R'_{min} and thermal transmissions - U'_{max} of the building envelope elements (taking into account the effect of thermal bridges), on the whole of the dwelling buildings, designed on the basis of the design contracts concluded after 1 January 2011 [33] is presented in Table 1.

Table 1. The minimum thermal resistance - R'_{min} and thermal transmissions - U'_{max} of the building elements, on the whole of the dwelling buildings, designed on the basis of the design contracts concluded after 1 January 2011 [33].

Nr. crt.	BUILDING COMPONENTS	Residential buildings	
		R'_{min} [m^{2}K/W]	U'_{max} [W/m^{2}K]
1	Exterior walls (excluding glazed surfaces, including adjoining walls of open joints)	1,80	0,56
2	Exterior windows	0,77	1,30
3	Top slabs above the last level, under terraces or attics	5,00	0,20
4	Bottom slab over unheated basements and cellars	2,90	0,35
5	Walls adjacent to closed joints	1,10	0,90

Peer-reviewed version available at Sustainability 2018, 10, 1561; doi:10.3390/su10051561

6	Slabs that delimit the building at the bottom, from the outside (in the bow-windows, passage gangs, etc.)	4,50	0,22
7	Slabs on the ground (over ground level)	4,50	0,22
8	Slabs at the bottom of heated semi-basement or basements (under ground level)	4,80	0,21
9	External walls, under ground level, of heated semi-basement or basements (under ground level)	2,90	0,35

The Energy Performance of Buildings Directive, issued in 2002 and revised in 2010 (EPBD 2010/31/EC), and the European Directive on the use of RES (RESD 2009/28/EC), were the basis for the drafting of country strategies and government policies, transposed into national laws. The National Plan [34], includes the long-term energy efficiency strategy at national level, based on a series of laws and regulations, which establishes the contribution of the state, the local administration and the owners and specifies the content of the projects and the eligible intervention works.

The definition of nZEB in Romania was detailed by the MDRAP Order 386/2016 by officially specifying the performance levels in terms of the maximum admissible level of primary energy from fossil sources and of CO_2 emissions resulting from the operation of buildings – by building types and winter climate zones in Romania (Figure 5). The levels will be applied mandatory for all new buildings starting from 2021. The maximum allowed value of the primary energy use (thermal and electric energy supply processes), determined by cost optimal calculations based on reference buildings vary according to the winter climate zoning of Romania (values between brackets correspond to the average climate zone for Romania): 98 to 217 (111) kWh/m^{2}yr for single-family residential buildings, 93 to 135 (100) kWh/m^{2}yr for multi-family apartment buildings, 45 to 89 (57) kWh/m^{2}yr for office buildings. In order to ensure the total energy use of a nZEB, energy from RES shall account for at least 10% of the total calculated primary energy of the building.

As intermediary performance values until the enforcement of nZEB obligations for new buildings, the MDRAPFE Order No. 2641/2017 recently established (for the first time in Romania) minimum requirements in terms of maximum primary energy consumption for heating (only). The limits (max primary energy for heating in kWh/m^{2}yr) vary from 60 for office buildings to 117 (large residential), 149 (hospital) and 153 (small residential). This time, the requirements are applied both for newly built and existing buildings undergoing major renovation.

3. Seismic resistance assessment and structural strengthening

3.1. Italian relevant seismic codes and expertise on seismic strengthening of the existing building stock

The identification of the structural system is of paramount importance for a proper assessment of the structure and for the design of retrofit interventions. In fact, usually designers do not know the mechanical features of the materials, size and arrangement of the structural members, and quality of structural detailing. Hence, information on these aspects have to be collected from the available documentation, analysis of the codes in force at the time of construction, field investigations and in-situ and/or laboratory measurements. Based on the completeness and reliability of the collected information, the structure is assigned to one of three “knowledge levels”: limited knowledge (KL1), normal knowledge (KL2), and full knowledge (KL3). The knowledge level of the structure determines the method of analysis that can be used for the evaluation of the structural response and the values to be adopted for the confidence factors [35] in the safety verifications.

Linear or nonlinear methods of analysis can be used for the evaluation of the seismic response of the structure. The choice depends on the achieved knowledge level of the structure. Linear methods of analysis (Lateral Force Analysis and Multi-modal Response Spectrum Analysis) must be used for knowledge level KL1, while nonlinear methods (Nonlinear Static Analysis [36-37] and Nonlinear Time-History Analysis [38-40]) may be used if the knowledge level achieved by means of the preliminarily inspection of the structure is KL2 or KL3. Since the collapse mechanism of an existing structure is not known *a priori*, any member may yield and there is no distinction between dissipative and non-dissipative members. Hence, nonlinear methods of analysis, which are able to detect the collapse mechanism and predict the inelastic demand of the members explicitly, should be preferred to the linear ones when applicable.

Criteria for safety verification are given separately for RC, steel, composite, and masonry structures. Furthermore, for each type of structure, the Italian code provides two sets of criteria: the first set applies if the seismic response to be assessed has been determined by linear methods of analysis, whereas the second one is used in combination with nonlinear methods of analysis. Criteria for linear methods of analysis are rather conservative to compensate for the low level of accuracy of these methods. Furthermore, the conservativism of the criteria for safety verification is also controlled by the values of the confidence factors, which modify the strength of the members to be considered in the verification. A lower knowledge level means a higher degree of uncertainty of the features of the structure, which is compensated by the use of larger values of confidence factors.

If the seismic response of the structure does not fulfil the standard required by the code, the gap should be filled by seismic upgrading [41]. Many strategies may be embraced to pursue this objective. The most classical way is to increase the strength and/or ductility capacity of the structure at global or local level. For instance, the (global) lateral strength of the structure can be increased by adding new seismic-resistant elements, e.g. RC shear walls or steel braced frames. The new resisting elements should be properly connected to the existing structure and stiff enough to draw part of the seismic force. Alternatively, the strength can be increased locally by interventions on individual structural elements; e.g. concrete or steel jacketing [42] as well as FRP plating and wrapping [43] can be used to improve the flexural and/or shear strength of RC members. Furthermore, these interventions also allow the enhancement of the ductility capacity of RC members through the confinement of concrete. An alternative retrofitting solution is to reduce the seismic demand of the structure by base isolation [44-47]. First, columns are cut off from foundation; then isolators are installed between column bases and foundation. These measures elongate the fundamental period of the structure and thus drastically reduce the seismic force on the structure. This strategy is very effective, but cannot be used when the building to be upgraded is contiguous with other buildings. Furthermore, its effectiveness decreases with the aspect ratio. Seismic demand can also be reduced by using dampers [48]. Many kinds of dampers (hysteretic, viscous, viscoelastic, etc.) [49-53] are available on the market and can be embedded in the structure [54-56] or inserted between the structure to be retrofitted and an external reaction structure [57]. Dampers dissipate part of the input energy provided by the earthquake, thereby reducing the displacement demand of the structure. As an example, Figures 6 and 7 show two retrofit interventions on schools in Italy. In particular, Figure 6 shows the retrofit intervention carried out at the school Cappuccini located in Ramacca at about 50 kilometres from Catania by means of buckling restrained braces (BRBs). The school was condemned owing to a severe crack pattern present in the non-structural elements after the earthquake that stroke the eastern part of Sicily in 2002. The building was built in the 1970s and endowed with RC moment resisting frames designed for gravity loads only. The BRBs were inserted in the early 2000s to reduce the seismic action effects on the existing structure and dissipate part of the input seismic energy. The BRBs were inserted within some frames located in the central part of the building. Figure 7 instead shows the retrofit intervention carried out at the school Gentile-Fermi located in Fabriano at about 70 kilometres from Ancona by means of viscoelastic dampers [58]. The building was built in the 1950s and endowed with RC moment resisting frames designed for gravity loads only. The school was condemned after an earthquake occurred in 1997. Like the previous structure, that of the school Gentile-Fermi had insufficient resistance to seismic actions and insufficient local and global ductility. Viscoelastic dampers were chosen to dissipate part of the seismic input energy and limit the increase of the lateral stiffness consequent to the introduction of braces. To reduce the interruption of the functionality of the construction, the viscoelastic dampers were inserted within some frames located on the perimeter of the building.

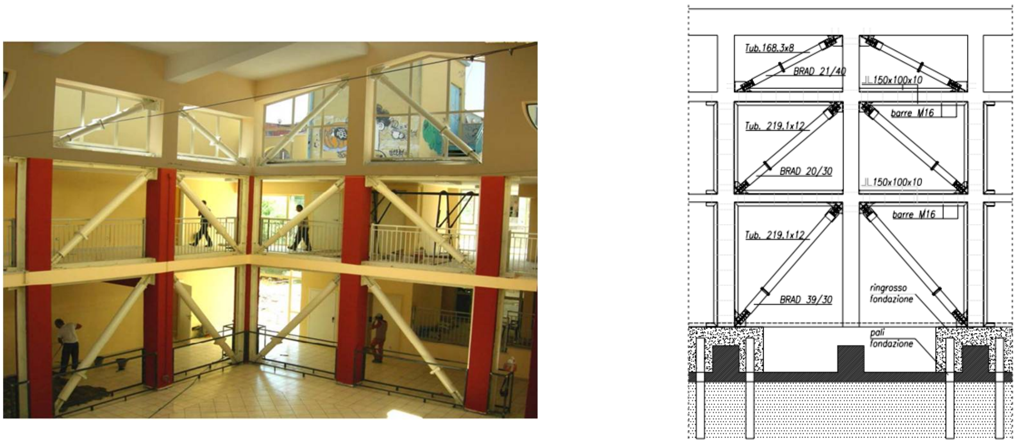


Figure 6. Retrofit intervention by means of BRBs in the school Cappuccini in Ramacca (Catania).

Figure 7. Retrofit intervention by means of viscoelastic dampers in the school Gentile-Fermi in Fabriano (Ancona) [58].

The retrofit intervention is selected based on the analysis of the structural deficiencies. Often, two or more techniques are combined together to achieve the seismic upgrading of the building [59-66]. The great variety of techniques and the need to combine them together represent a further source of difficulty with respect to the case of new structures, for which the designer needs to select just one structural type among a limited number. As an example of a retrofit intervention in which more techniques are combined, Figure 8 shows the retrofit intervention carried out at the school Varano located in Camerino at about 30 kilometers from Macerata by means of rigid rocking towers and viscous dampers [67]. The school was built in the 1960s and consists of two separate constructions. Both are endowed of reinforced concrete framed structures. The retrofit intervention was completed in 2012 (in about 7 months) without interruption of the school activities. The intervention aimed at dissipating a large amount of energy by means of the viscous dampers at the base of the towers and leave the RC structural elements to be elastic under moderate intensity earthquakes. The two steel braced towers were connected to the decks by means of steel trusses.

Peer-reviewed version available at Sustainability 2018, 10, 1561; doi:10.3390/su10051561

Figure 8. Retrofit intervention by means of dissipative towers and viscous dampers in Camerino (Macerata) [67].

The regulations given in the code are mostly for traditional retrofit interventions, while innovative techniques are not covered by code provisions. This is a gap in the code that will be hopefully filled in the future. Researches devoted to standardize the way of application of these techniques for seismic upgrading of structures and to formulate design methods of retrofit intervention able to achieve the performance objectives stipulated in the Italian code are of paramount importance. This research activity can create the background for the new generation of building codes and make innovative technique immediately available. In fact, the Italian building code has been developed in a performance-based framework. This allows the use of techniques and design methods that ensure the minimum level of structural safety required by the code, even if these techniques are not explicitly considered in the code.

3.2. Romanian relevant seismic codes and expertise on seismic strengthening of the existing building stock

The experience of 1977 Vrancea earthquake is relevant for the situation of existing built stock in terms of features, vulnerability and risk. The behavior of some of the old tall buildings in 1977, which was the most heavily affected category, may be understood in connection with some features of their urban and architectural planning, of their quality of construction works, of their history after 1940, overloading, maintenance and intervention of man until 1977. The old, relatively low and stiff, bearing masonry buildings (Figure 9) have shown, as a rule, a better performance, especially in Bucharest and collapses were noticed in isolated cases. The spectral specific of strong motion was an important factor of overloading or reduced loading [18-19].

Figure 9. Low-rise and mid-rise masonry buildings, after some 80-100 years.

The new apartment buildings, built after 1950 (Figure 10), present a wide diversity of architectural planning and of structural solutions, with many solutions used in standardized design for low-rise buildings (up to 5 stories) and high-rise buildings (8 to 18 stories, the most frequent being that of 10-11 stories).

Before 1990, various construction technologies and structural systems, included prefabrication and industrialized forms for cast-in-place concrete. The large panel standardized apartment blocks represented an increasingly important share of the new construction. The performance of these buildings was good or fair in almost all zones for five-story as well as for eight-or nine-story buildings. It is important to say that most of IPCT solutions were tested in INCERC.

The cast-in-place, reinforced concrete, shear wall buildings that present the greatest share among the structural solutions in seismic zones, especially for high-rise buildings, have shown various behavior patterns, depending on their overall number of stories, on the quality of workmanship and

Peer-reviewed version available at Sustainability 2018, 10, 1561; doi:10.3390/su10051561

structural solution, as well as on the intensity of shaking. Under such circumstances, five-story buildings have shown a good or fair behavior, independent of the structural solution adopted (smaller or large intervals between shear walls).

The new reinforced concrete framed structures, with five or eleven to twelve stories, for which a regular pattern of columns and beams has been provided, have shown generally a much better performance than old buildings (pre-1940) with reinforced concrete framed structures, for which the place of columns has been an irregular one.

After March 4, 1977, the specialists of INCERC, as well as the great number of civil engineers existing in 1977 in numerous design institutes provided immediate technical guidelines for repair and strengthening. But on March 30, 1977 the Government of that time ordered that the existing structures be maintained or rehabilitated, nominally, at the initial strength level. On July 4, 1977 it was ordered to make only local repairs. Thus, political orders left Bucharest with a large stock of high-occupancy, high-rise residential buildings that have been damaged by the 1977 (and possibly the 1940) Vrancea earthquake. Most of these buildings, still in use, represent at significant risk from future Vrancea earthquakes [21].

The new seismic design codes P100 - 1991, revised 1992 and 1997, introduced in chapters 11 and 12 the obligation to evaluate buildings and indicate classes of risk, as it is also in Code P100-3/2008, in force, and, if required, to rehabilitate the existing buildings, with some public financing. Buildings of first class of risk are labeled with a red dot.

By Law, i.e. Government Ordinance on Existing Buildings Risk Reduction [68], evaluation of residential buildings resistance (in terms of Code P100-92, later on in Code P100-3/2008) was provided for free, while for design and strengthening works the owner may receive a bank credit at 5% interest up to 20 years, paid by Government; the apartment owners in buildings of first class of risk, with an income under the country average, may receive full subsidies.

Figure 10. High-rise apartment building, with RC columns and beams, infilled with masonry, erected before 1940. Left side – a building without visible strengthening or renovation. Right side: with local repair, i.e. limited and inadequate jacketing of columns, after March 4, 1977 earthquake

For pre-1940 high-rise buildings (Figure 11), conceived without seismic design, the strengthening means a rather general jacketing of existing frames, from foundations to the top, to become moment-resisting ones, ductile and able to withstand lateral forces. This implies local or general evacuation and relocation of occupants for 1 to 2 years. For other 1950-1977 structural types, designed for lower seismic loads, interventions may be on some specific members or zones, or on several stories. In such cases, some advanced techniques, as frame bracing can be applied, with less need of evacuation.

Peer-reviewed version available at *Sustainability* **2018**, *10*, 1561; doi:10.3390/su10051561

Figure 11. High-rise apartment building erected in the 1970s, having commercial spaces at ground-floor, with visible damages from March 4, 1977 earthquake, before renovation

4. Current technologies for energy efficiency

4.1. Current technologies for energy efficiency

The current retrofit technologies used in Italy for enhancing the energy efficiency of buildings can be categorized into three main categories:

(i) heating and cooling demand reduction;
(ii) upgrade of the Heating, Ventilating and Air Conditioning (HVAC) equipment;
(iii) installation of RES technologies.

To category (i) belong all the interventions that involve the building fabric: envelope insulation (roof, wall, ground floor) [69], windows retrofits (thermal-break frames, multiple glazing, inert gas filling, low-emission coatings, external sun-shading systems, etc.), cool roofs and coating, and increased air tightness. To this group one may also add bioclimatic technologies for exploiting natural resources: solar radiation, natural ventilation, evaporative cooling, etc.

Category (ii) includes mostly the improvement of the heating and cooling systems, e.g. by installing high efficiency heat pumps, biomass boilers, geothermal power systems, etc.

Finally, category (iii) embraces the integration of different RES systems, such as solar thermal (ST) collectors, photovoltaic (PV) or PV/T panels, wind power micro-turbines, etc. [70-73].

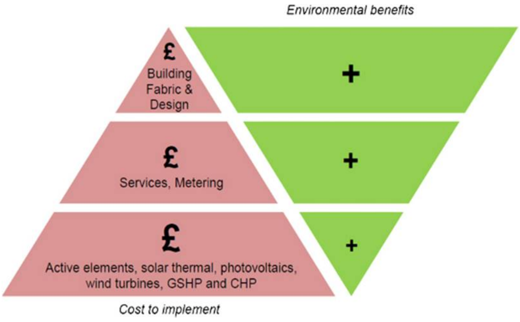


Figure 12. Intervention cost versus environmental benefits [74].

In case of relevant renovations of first level (see Section 2.2.), from 2019 or 2021 in Italy it will be necessary to reach the nZEB standard. In this case further strategies should be necessary in some cases, such as the integration into the building envelope of Phase Change Materials (PCM), the use of low conductivity insulation materials (e.g. aerogel, vacuum insulated panels), as well as the use of Building Energy Management Systems (BEMS) [75-78], i.e. computer-based control devices that su-

Peer-reviewed version available at Sustainability 2018, 10, 1561; doi:10.3390/su10051561

pervise and monitor the mechanical and electrical equipment (e.g. HVAC, RES, household appliances, lighting and power systems) [79-80], according to comfort requirements, occupancy regimes, energy demand and current electricity price.

For each renovation intervention, the implementation cost and the potential benefits are different. Figure 12 shows the intervention costs versus environmental benefits (reduction of CO_2 emission). It can be observed, that the installation of RES systems may require high investment costs and low environmental benefits. This is mostly due to the high environmental impact of the disposal of some RES systems (e.g. PV, PV/T).

In Romania, the lack of insufficiency of the thermal insulation of the existing buildings compared to the requirements stipulated in the current thermal regulations is added to the limited seismic resistance of some structural types, as well as a state of degradation of the built part or an advanced wear of the installations. Therefore, many of the buildings requiring energy rehabilitation also need the assessment of the structural resistance and of strengthening scenarios.

The implementation of the Energy Performance Building Directive (2002/91/CE followed by the recast version 2010/31/UE) in Romania, has determined an upgrading of the minimum standards of energy performance of the buildings. It was introduced a methodology for energy balance calculation and an energy performance certificate, both for new and for existing buildings at their rehabilitation moment (Figure 13). Special norms for the inspection of the heating, cooling and ventilation devices were elaborated. Several successive National Programs for the rehabilitation/modernization of the multi-story residential buildings were applied in the last decades. Currently, the attention is directed to public buildings rehabilitation and certification.

As for the building envelope (opaque components and fenestration), till now, it was applied additional thermal insulation layers using polystyrene or mineral wool plates with thermal conductivity (λ) between 0.030 and 0.045 W/mK (on external walls, roofs, ground slab), in many apartment blocks built during 1950-1990. Maximal values of the thermal transmittance U, for external walls, were $U' = 0.70$ W/m^{2}K till 2010 and then $U' = 0.55$ W/m^{2}K, taking into account the effect of thermal bridges for each envelope element.

The old types of windows (with wood frames and double glass without any coating) were replaced, in retrofitting programs, with high efficiency double glazing windows with low emissivity coatings, tinted and/or gas filled, having especially PVC frames ($U = 2$ W/m^{2}K till 2010 and since 2011 $U = 1.3$ W/m^{2}K). In the last 2-3 years there are provided windows with triple glazing and low emissivity coatings having $U = 1.1$ W/m^{2}K.

With the implementation of the first projects under the National Rehabilitation Program of the Housing Blocks - Condominiums, coordinated and funded by MDRAPFE and the Local Councils of City Halls, a number of new issues emerged.

The choice of technical and architectural solutions to improve the thermal performance of vertical envelopes must be done, in the future, using the optimal cost method and taking into account and controlling all important aspects.

The new approaches, which can be effectively adopted both in Italy and in Romania, are as follows:

- Ventilated facades (opaque ventilated façades, double skin glass façades, hybrid façades - wall/glass) were provided only for special buildings (offices, hospitals, public buildings, etc.) due to their initial high cost. The curtain walls using special glass were used for office buildings.
- Green walls and green roofs were used sometimes. Solar shading devices – external or internal, were provided without a detailed analysis. Passive solar energy systems like solar greenhouse were studied and provided in some cases.
- Active solar energy systems as PV panels, ST collectors and mixed systems were provided on some demonstration buildings, but Building Integrated Photovoltaics (BIPV) in building envelopes are not usual, although used in pilot buildings. Acoustic performance for the external thermal insulating systems is under study.

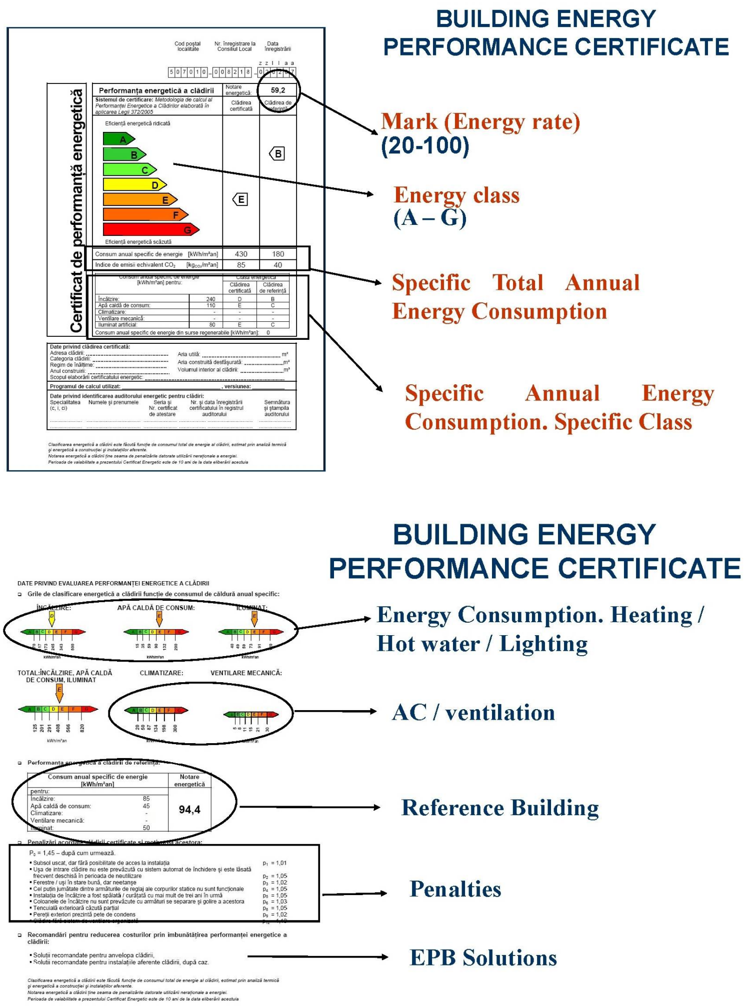


Figure 13. Content of the Romanian Building Energy Performance Certificate [32].

For roofs (flat or sloped), technologies to improve ventilation (single or double ventilation layers for sloped roofs), passive cooling (cool roofs), thermal inertia and waterproof (green roofs or cool roofs), RES use, etc., must be provided

In Figures 14-15 some of the main solutions for thermal energy renovation are presented. The legend is common for the 3 figures and the relative numbers indicate: 1 - external wall, possibly plastered; 2 - efficient thermal insulation layer (EPS, mineral wool, etc.); 3 - insulation protection layer (mineral additives mortar, with fiber glass reinforcement); 4 - thin external finishing; 5 - protective layer against wind; 6 - ventilated layer; 7 – external cladding with closed joints; 8 – damp-proof course; 9 - interior gypsum boards / dry plastering.

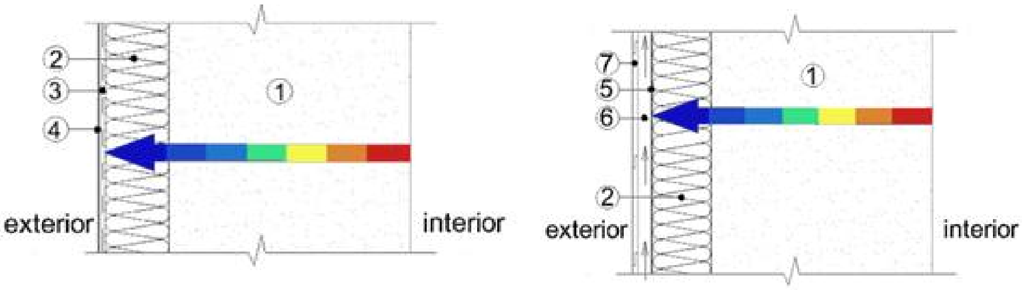


Figure 14. Main solutions for thermal energy renovation of external walls in current field, with external insulation. Left: "ETICS" composite compact structure with protection layer of thin rendering with fiberglass reinforcement. Right: ventilated layer structure with protection layer and external cladding fixed trough a metallic frame [30].

Peer-reviewed version available at *Sustainability* **2018**, *10*, 1561; doi:10.3390/su10051561

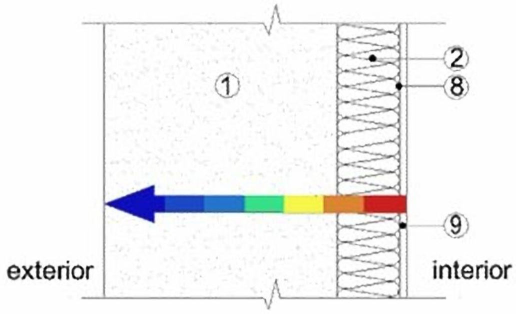


Figure 15. Main solutions for thermal energy renovation of external walls in current field, with internal insulation and finishing of gypsum boards [30].

For the future buildings (nZEB), the most promising and interesting insulating materials are: Aerogel, PCM, TIM (Transparent Insulation Materials), VIP (Vacuum Insulating Panels), organic materials (cork, sheep-wool, etc.), high efficiency windows.

In Romania, the nZEB concept does not seem to be easily applicable yet, in particular in the case of the renovation of existing buildings [82]. Besides the required investments and optimal integration of the technologies suitable for the construction and/or renovation of buildings at nZEB level, one of the main barriers for this consists in the skills gaps experienced by the building sector.

Some projects [81, 83-85] approach this barrier by developing a roadmap for construction workforce qualification to achieve the sustainable energy policy objectives set for Romania for 2020. Thanks to them, mechanisms to supporting the national implementation of large-scale and long-term qualification schemes for thermal insulation systems and high thermal performances windows installers are defined (Figure 16).

Figure 16. Practical training facility for nZEB in the Building Knowledge Hub (Bucharest).

Aspects such as the arrangement of the ventilation of the spaces in order to obtain adequate indoor air quality, the repair of the sidewalks, the removal of moisture and mold, the rehabilitation of the waterproofing, the modernization of the balconies and loggias were subsequently explicitly included in the current legislation. The arrangement of extensions and mansard spaces is of interest to a number of investors. The approach aims to provide RES, in order to achieve the cost-optimal energy performance of a building or, rather, of a district of buildings and also the highest indoor comfort by a good thermal insulation, restricting the heating load, the use of air conditioning units and artificial lights.

4.3 Common practice and current projects of energy renovation in Romania

The compound Prietenia of Sfantu Gheorghe City, consisting of 18 apartment buildings of five stories made of large panels, with 410 apartments, was under energy renovation from 2008 to 2009 (Figure 17-20). The project was done with the consultancy of UAUIM and IPCT Instalatii, in an integrated approach, to address also the architectural and landscape image as local urban issues.

The Prietenia Project allowed an energy reduction of ca. 60%, and for this goal the following solutions and technologies have been applied:

- for terrace - EPS 120 of 16 cm thickness;
- for external walls – EPS 80 of 10 cm thickness (XPS 8 cm at socle);
- for slab over basement – EPS 70 of 8 cm thickness;
- for internal walls and slabs of entrance hall EPS 80 of 10 cm thickness;
- thermostatic valves and mixing water faucets, with reduced consumption.

Figure 17. The apartment buildings before renovation, Prietenia compound, Sfantu Gheorghe.

Figure 18. The apartment buildings under renovation, Prietenia compound, Sfantu Gheorghe.

Peer-reviewed version available at Sustainability 2018, 10, 1561; doi:10.3390/su10051561

Figure 19. The apartment buildings under renovation, Prietenia compound, Sfantu Gheorghe. Community members were able to choose the colors of renovated facades.

Figure 20. The apartment buildings and adjacent spaces, including playing grounds for children, at the end of renovation, Prietenia compound, Sfantu Gheorghe.

The mass renovation programs in Bucharest (Figure 21-25) and other large cities were quite successful and popular in the view of communities, especially because and when the cost was fully supported by local authorities or from European funds. However, from the point of view of architectural and technical quality the high speed of works and the lack of workers training caused some critics.

Figure 21. Large high-rise apartment buildings in Bucharest, erected in the 1970s, before and after energy renovation.

It is worth to mention that the shear wall structural types of 1970s, although designed to forces lower than current code, behaved satisfactorily in 1977 earthquake, and thus they were included in energy renovation projects without other structural upgrading.

Figure 22. Large high-rise apartment building in Bucharest, erected in the 1970s, during energy renovation.

Figure 23. Large high-rise apartment building in Bucharest, erected in the 1970s, after energy renovation.

Figure 24. The UTCB Lacul Tei Students Dormitory building after energy renovation (2007). The first public building with displayed Energy Performance Certificate.

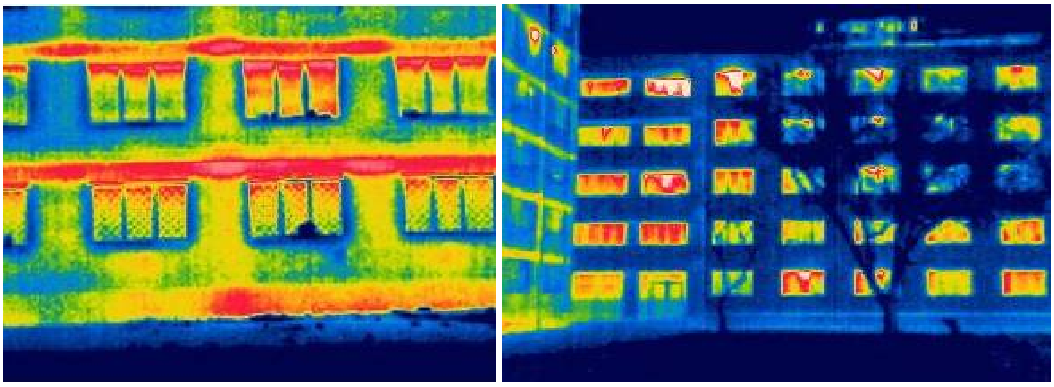


Figure 25. The UTCB Lacul Tei Students Dormitory building. IR thermography images before and after energy renovation (2007).

Based on the JRC study, Romania has one of the 10 exemplary Renovation Strategies (as required art. 4 of the Directive 2012/27/EU), ranked the 3rd at EU level, mainly for having detailed estimations, 4 scenarios, multiple benefits assessed, cost benefit analysis. The biggest source of funding for energy efficiency comes from EU Cohesion Policy Funds, while between 2014 and 2020, Romania intends to allocate more than €1.25 billion to building renovation of residential and public building. The majority of the funds will be used as grants for the building owner/association, covering (some of) the cost of the thermal renovations. However, deep renovations rate remains among the lowest in Europe, while the energy renovation of individual houses is not effectively supported by public funding nor stimulated by actual incentives. Moreover, the energy performance level of current deep renovation is far from the nZEB levels both in terms of design specifications and performance of works (limited insulation, attention to thermal bridges, no mandatory airtightness levels or mechanical ventilation with heat recovery, etc.). Nevertheless, minimum requirements in terms of maximum primary energy use for space heating are in force for major renovation of existing buildings since 2017. One could envisage that this is a first step towards building renovation at nZEB levels in Romania, still regulation has to be improved, nZEB technology market growth has to be stimulated and private investments have to be attracted by innovative and sustained communication campaign along the public funding energy renovation programs applied for demonstration buildings.

4.4 Common practice and current projects of energy renovation in Italy

The requalification of the multistory reinforced concrete buildings is one of the harvest achievement, according with their peculiarity [86]. Recently, has been realized a simulation to verify the possibilities to transform this kind of buildings in nZEB, with especial attention to the Southern part of the country. The target of this simulation is to contain the Pay Back Time into the limit suggested by UE, i.e. 7 years [87]. To get this aim has been defined the best economic way for the insulation of the envelope (both opaque and transparent) and for the integration of PV panels in the building façade (Figure 26). This approach solve a relevant problem related to the energy requalification of the apartment blocks, i.e. the limited horizontal surfaces available to locate the RES devices.

Cost evaluation	
Intervention costs	150 €/m²
Energy saving	18,11 €/m²y
Pay Back Time	12 years (without fiscal incentives) 7 years (with fiscal incentives)

Figure 26. Transformation plan in N-zeb of a high-rise building in Librino - Catania [87].

5. Seismic vs energy renovation: technical solutions, between opportunities and constraints

Peer-reviewed version available at *Sustainability* **2018**, *10*, 1561; doi:10.3390/su10051561

In Italy and Romania, a large number of RC structures need seismic strengthening. While for some recent generations the base isolation and bracing is possible and feasible, for most of cases a considerable amount of new members and concrete is required. Many traditional techniques are available and provisions that regulate their use are given in the relevant parts of the Italian [6-8], Rumanian [26] and European [9] codes. Some examples of possible solutions are presented below, along with comments on their implications on the energy renovation solutions.

Figure 27 shows the strengthening of columns by concrete jackets. The concrete cover added to most of columns involves also the cutting and/or removal of some envelope material. The final design must take into account the adequate detailing and calculation in order to ensure a continuous thermal insulation for control of thermal bridges impact on performances.

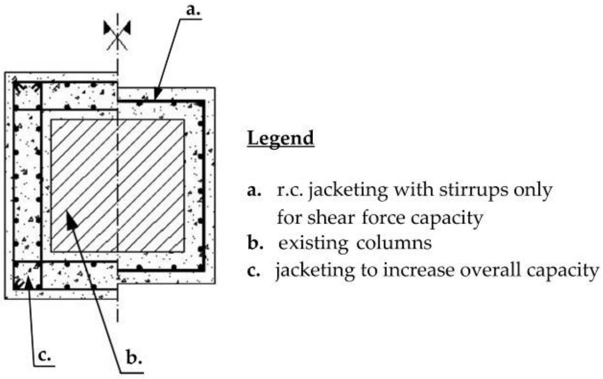


Figure 27. Strengthening solution for existing columns, using concrete jacketing (adapted after [25]).

In Figure 28 the new shear wall, when and if it is added at exterior, will change completely the envelope thermal parameters therefore the energy renovation design shall take into account the new details and thermal transmittance values. In Figures 29-30 the jacketing of shear walls is necessary on the edges. In case of external walls, the need of special care for energy renovation detailing may be limited to those areas.

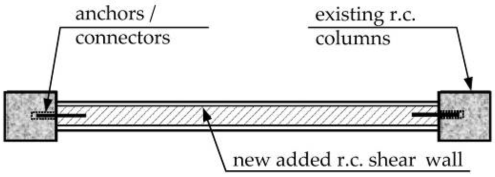


Figure 28. Strengthening solution using new structural walls, as shear walls (adapted after [25]).

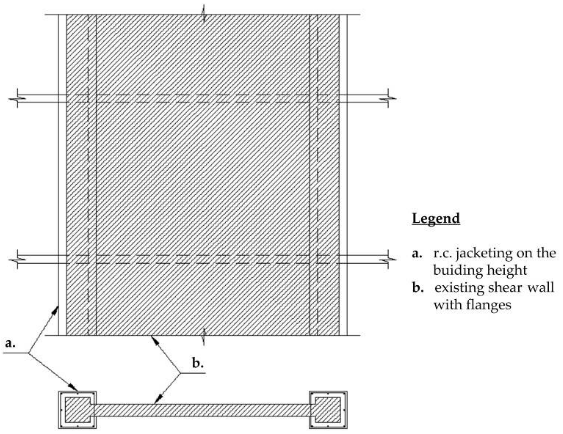


Figure 29. Strengthening solution for structural walls, with RC jacketing interventions on the edges (adapted after [25]).

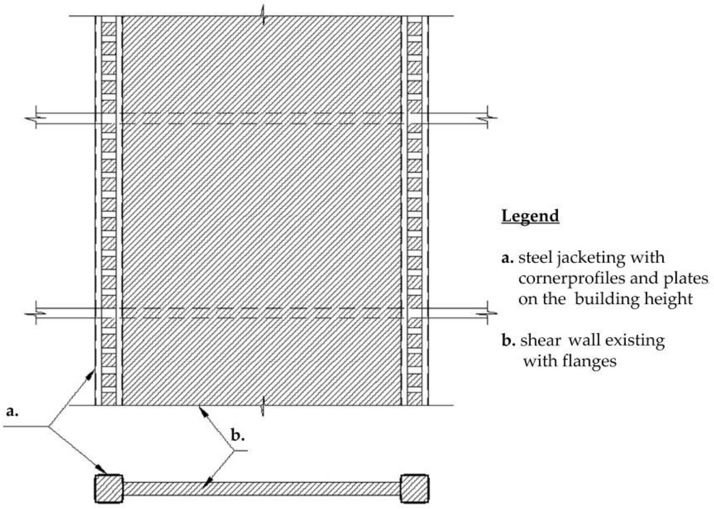


Figure 30. Strengthening solution for structural walls, with steel jacketing interventions on the edges (adapted after [25]).

However, when looking in details of such solutions, as in Figure 31, the building of a new and greater flange-column of a shear wall also changes the envelope situation, with the need of careful thermal bridges analysis. In Figure 32, the renovation with steel elements is much easier to apply, but steel has a greater heat transfer capacity and also changes the envelope situation, with the need of careful thermal bridges analysis.

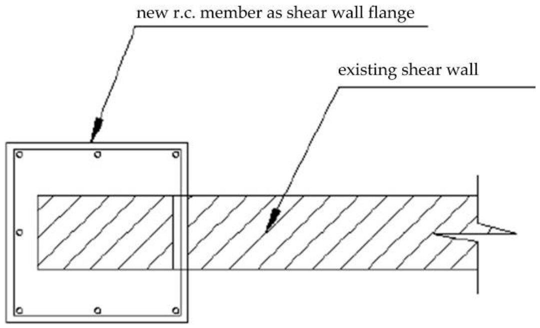
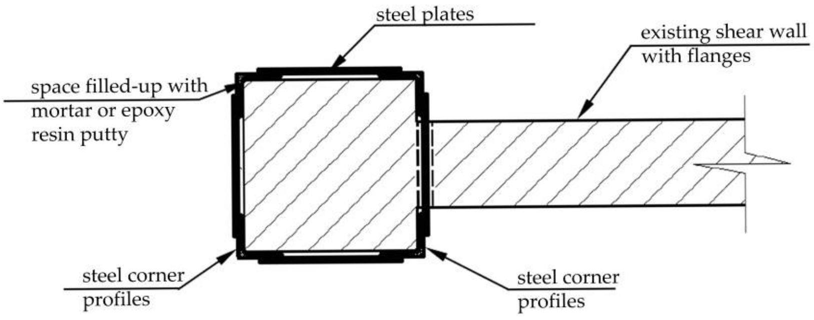


Figure 31. Detail of strengthening solution for structural walls, with RC jacketing interventions on the edges (adapted after [25]).



Peer-reviewed version available at *Sustainability* **2018**, *10*, 1561; doi:10.3390/su10051561

Figure 32. Detail of strengthening solution for structural walls, with steel jacketing interventions on the edges (adapted after [25]).

The examples herein presented point out that many solutions are available in literature to upgrade existing structures by enhancing its stiffness, strength and ductility capacity. However, these interventions may have a negative impact on the thermal performance of the building, thus requiring additional measures. On the other hand, any intervention devoted only to the energy requalification of RC buildings could be nullified by the effect of the earthquake if the building is not seismic-resistant. Based on this consideration, existing buildings should always be assessed in terms of both seismic and energy deficiencies and the new challenge will be to ideate, design and realize interventions that integrate seismic upgrading and energy renovation. An example that fits well this philosophy is the intervention by Takeuchi et al. [88-89] on the Midorigaoka-1st building of Tokyo Institute of Technology, a 6-story RC building designed in 1966 before the revision of Building Code of Japan in 1971. The main deficiency of the structure was the low ductility capacity of the columns. Furthermore, the thermal performance of the building envelope did not satisfy the current standard in Japan. The solution proposed by Takeuchi et al. is an integrated facade that includes glasses, louvers and a steel BRB frame (Figure 33). This multi-skin exoskeleton improves both the seismic and the thermal performance of the building. In particular, the steel frame equipped with BRBs is firmly attached to the ground and to the building façade. In occurrence of ground motions, the BRBs act as hysteretic dampers, yield and absorb input seismic energy before that the RC structure is damaged, thus reducing the drifts and protecting the structure. The system of glasses and louvers properly oriented can mitigate the inner temperature both in summer and winter and reduce the consumption of energy needed for heating and refreshing, respectively.

Figure 33. Midorigaoka-1st building after retrofit [89].

There are also some recent and interesting research works that propose and/or assess combined seismic ad energy renovation scenarios for recent buildings. For instance, Leone and Zuccaro [90] have developed, within the EU-FP7 CRISMA project, a multi-criteria decision support system to select the optimal integrated retrofitting scenario, taking into account technical, financial and economic aspects. The proposed tool aims at enabling decision makers and local authorities to implement policies and large-scale programs devoted to the sustainable improvement of the existing residential stock. Calvi et al. [91] have proposed a “green and resilient indicator” to evaluate the earthquake resilience and energy efficiency of the exiting building stock. Manfredi and Masi [92] have proposed an integrated retrofitting intervention that consists in replacing the existing masonry infill walls with hollow clay blocks that are able to increase both seismic and thermal performance. For mid-low hazard areas, this technique could determine a full rehabilitation with regards to both seismic and thermal requirements, in compliance with the corresponding codes. La Greca and Margani [13] have highlighted the advantages of combined renovation actions, indicating the barriers that currently limit such actions and suggesting possible countermeasures. Moreover, the H2020 ProGETone project [93] is currently developing retrofitting solutions based on the implementation of multi-skin exoskeletons to enhance the seismic resilience and the energy performance.

6. Discussion

The seismic and energy renovation combined approach has strong and weak points, both in Italy and in Romania.

The recent Italian legislative has introduced different incentives, in form of tax credit (so-called 'SismaBonus'), which, especially from 2017, considerably reduce the economic investment for the renovation of earthquake-prone buildings. In particular, the building owners in seismic areas may receive a tax credit distributed over 5 years that covers up to 85% of the cost of the retrofit intervention, with a cost limit of € 96.000 per apartment. Simple guidelines are provided to assess the seismic risk class of buildings in compliance with the current seismic technical code for constructions. Hence, the amount of the tax deduction is related to the class increase due to the strengthening intervention.

In addition, in Italy also the energy efficient renovation benefits from different fiscal incentives, which since 1998 have considerably encouraged this kind of intervention. Nowadays, energy retrofitting investments take advantage of VAT reductions (10% instead of 22%) and tax credits that range from 36% to 75% of the renovation cost, with a limit of € 40.000 per apartment (so-called 'EcoBonus'). In particular, interventions on single family houses benefit from fiscal incentives that allow to write off 36% of costs on taxes, with deductions equally distributed over 10 years. This share increases from 70% up to 75% for apartments buildings, according to the reached energy performance. If required, the tax credit can be assigned to third parties, such as construction companies. Alternatively, it is possible to benefit from incentives governed by the Ministerial Decree of 16 February 2016 (also known as 'Conto Termico 2.0') that provides subsidies for the production of thermal energy from RES and the increase in energy efficiency. These subsidies cover 40% of the eligible expenditure, with specific limits for the unit and total costs of each type of interventions. They will be refunded either in five annual rates or in a single solution in the case of public administrations or Energy Service Companies (ESCOs).

From January 2018 [94], it is also possible to benefit from tax credits that cover up to 85% of the cost for combined seismic and energy renovation actions of apartment blocks, with a limit of € 136.000 per apartment and deductions distributed over 10 years (so-called 'SuperBonus').

The Italian residential real estate has a very high level of fragmentation. It is usually quite difficult to reach a consensus among the building owners for the implementation of renovation works.

In Romania, since 69% of residential buildings existing in 2011 have been erected before 1977, many dwellings may have insufficient earthquake protection. The technical aspects of assessment, design and solutions for seismic strengthening are solved in relevant codes and laws starting during the1990s, while the energy rehabilitation has also a pertinent evolution, fully correlated with the EU Directives.

The problem of funding seismic strengthening is legally and financially solved since 1994, but the key issue is that of relationship between the funding provided by MDRAPFE and actual management of seismic strengthening projects which is done by local authorities. In Bucharest, there is a large list of pre-1940 buildings ranked at seismic risk but the number of buildings that were strengthened is relatively low.

Presently in Romania, is in force a yearly National Program for seismic risk reduction (based on Ordinance n. 20/1994) [68] correlated with Code P100-3/2008 [26] and Eurocode 8 provisions. For the time being, the National Program for thermal and energy rehabilitation [67] is a more successful social project, because it was applied on buildings with low or any seismic risk. The cost of energy rehabilitation was born in most cases by local authorities, from own budgets or European Programs.

Peer-reviewed version available at Sustainability 2018, 10, 1561; doi:10.3390/su10051561

In both country, the main reason that makes the energy rehabilitation to be one step in front of structural interventions is that seismic strengthening involves the structure and is operated mainly from the inside of the building, while the energy renovation involves, above all, the envelope and is operated mostly from the outside. The energy renovation works are speedy, while for seismic strengthening owners are often afraid of high costs and related mortgaging; many of them are rather old and low-income, absentees or just do not want to de disturbed by evacuation and long-term noisy works. On the other hand, the funding is from separate sources and under separate legal framework, thus the full renovation approach is difficult.

From the energy renovation perspective, the level of ambition in terms of performance follows the nZEB target. Even if these performances are made mandatory only for new buildings authorized in very short time from now, the EU policies are rapidly advancing towards the renovation of existing building stock at nearly zero energy levels. This implicates a very high insulation level, high performance (and usually heavy) windows (installed in line with the applied insulation, i.e. outside the mechanical resistance layer) and with minimized thermal bridges. This could be a very difficult task for the design of energy renovation technical solutions, especially in respect to the highly enforced design provisions due to the high seismic risk. In current practice most of the building envelope renovation details (e.g. joining different building components) are designed with greater focus on mechanical resistance issues than heat transfer concept (e.g. avoiding thermal bridges), the result being usually an interrupted insulating envelope. In all cases, mechanical resistance has to be ensured, but if penetration of the insulating layer is unavoidable, then the thermal conductivity of the penetrating material should be as low as possible and insulation layers at building component connections should merge into each other over the entire surface without interruption.

In this respect, best-practice guidelines and detailed specification for the building envelope have to be developed in order to support suitable solutions for nZEBs, tested in order to comply with the rigorous seismic design provisions. The aim is to inform and to shape the internal market in order to increase the current level of technical knowledge and technologies before the legal requirements under Directive 2010/31/EU cause a blockage of the local construction industry due to the inability to fulfill the Directive.

7. Conclusion

The European and National Standards and Directives have been promoting, from different sustainability reasons, seismic and energy renovation actions to mitigate disasters and climate changes impact. In Italy, over 60% of the current building stock was built between the 1950s and the 1980s, when seismic safety and energy efficiency regulations were absent or mandatory only in few regions. As a consequence, most of the real estate is earthquake-prone and highly energy-consuming [13]. The combined seismic and energy renovation of Italian buildings is of paramount importance for the safety of the population against earthquakes and other natural hazards related to climate change.

In Romania, there is a comprehensive framework of laws and technical regulations, both for earthquakes and energy, implemented over the last five decades for new and existing buildings. In this country, the wide impact of the 1940 and 1977 earthquake is a landmark, while the probability of a large earthquake in the near future is increasing, thus the seismic risk reduction is a national priority. The National Program for thermal and energy rehabilitation of buildings is a separate endeavor, also a priority, pushed by the impact of climate changes and the related European Union Directives. In order to achieve the ambitious and very demanding objectives of Eurocodes and European Energy Performance Directives, under Romanian laws, it is necessary to mobilize all the involved stakeholders, to identify and face the positive and negative aspects and barriers, as well as the deficiencies that exist or may occur in the future.

In both countries, the policy of renovation of the real estate is hindered especially by high costs and disruptions for users. The integration of structural, architectural and urban planning approaches may improve the effectiveness and diffusion of these actions. However, steps like structural analysis, energy audits, public tender procedures, quality of projects and execution, regulatory framework,

Peer-reviewed version available at *Sustainability* **2018**, *10*, 1561; doi:10.3390/su10051561

financial and fiscal incentives, quality control, training of designers and builders, and workers' qualification still represent critical issues.

A variety of techniques for seismic upgrading and energy renovation of buildings are already available. Some of these techniques are known to structural designers and construction companies for a long time now and provisions for their application are provided in the current technical regulations. Other techniques, which are classified as innovative, are also applicable because studies that demonstrate their effectiveness and the relevant design guidelines are available in the technical literature. However, each of these techniques aims at improving only one aspect of the building performance: reduction of the risk of damage/failure caused by earthquakes or reduction of the energy consumption during the building operation. Based on the framework depicted above, it emerges that often seismic upgrading interventions can have no effect or may be even detrimental on the energy performance of the building and *viceversa*. Hence, the main challenge of the next years is to develop approaches that integrate together techniques for energy and seismic renovation. Important aspect to be deepened are the study of the compatibility of the integrated techniques and the definition of interventions that improve both seismic energy performance. The target of these approach should be the transformation of the existing energy-consuming and seismic-prone buildings in nZEB seismic-resistant ones. The availability of such integrated approaches for seismic-energy upgrading can promote the renovation of existing buildings by pursuing multiple targets: (i) to benefit from fiscal and financial incentives for both seismic and energy renovation, (ii) to maximize the positive effect gained by the intervention on the building (two performance objectives are reached with a single intervention), and (iii) to preserve in time the value of the investment (the investment for energy renovation could be nullified by earthquakes if seismic upgrading has not been pursued too). On this purpose, the exchange of experience among countries with similar issues, such as Italy and Romania, plays a crucial role to share best practices and to define correct skill and adequate competences.

Acknowledgments: This article consists in the first step of the activity of a transnational research group, which has been recently formed by Catania University, Ion Mincu University and NIRD URBAN-INCERC of Bucharest.

The authors of NIRD URBAN-INCERC acknowledge the research framework and financial support provided by the Ministry of Research and Innovation under the Nucleu Program CRESC.

The authors of University of Architecture and Urbanism "Ion Mincu" acknowledge the results based on the financing provided by Romanian Ministry of Research and innovation in the following contracts:

- UAUIM Contract no. 23/2008, 2008-2010, PNCDI 2, n. 1511, Program - INNOVATION, module I: Product-system development, Project category: PDP, project type: CDI Oriented: "Passive houses suitable for climatic conditions in Romania - acronym Passive House";
- UAUIM Contract no. 21/2008-2011, contract PNCDI 2, no. 22120, 2008-2011, Program 4 - partnerships in the priority areas, research direction: D3, domain 2: "Integrated solutions systems for the rehabilitation of buildings / residential neighborhoods – Acronym SIR".
- The project "Train-to-nZEB: The Building Knowledge Hubs" is funded by the European Union's Horizon 2020 research and innovation programme under grant agreement n. 649810.
- The project "Fit-to-nZEB: The Building Knowledge Hubs" is funded by the European Union's Horizon 2020 research and innovation programme under grant agreement n. 754059.

References

[1] Salemi, A.; Patania, F.; Cascone, S.; Gagliano, G.; Lo Faro, A.; Lombardo, G.; Moschella, A.; Sapienza, V. Thermal performance of existing buildings in Mediterranean climate area. In *Changing needs, adaptive buildings, smart cities*, POLIScript: Milan, Italy, 2013, 1017-1024.

[2] Detommaso, M.; Gagliano, A.; Nocera, F.; Patania, F.; Sapienza, V. Deploy Energy-efficient Technologies in the Restoration of a Traditional Building in the Historical Center of Catania (Italy). *Energy Procedia*. **2014**, 62, 62-71, DOI: 10.1016/j.egypro.2014.12.367.

[3] Sapienza, V. Spontaneous architecture and energetic sustainability: the Aeolian homes of Filicudi Isle. In Proocedings of ZEMCH-12, Glasgow, UK, August 2012, 340-350.

[4] Royal Decree n.193, 18/04/1909, *Mandatory technical and hygienical rules for repair of existing and new buildings in the areas struck by the earthquake of 28 December 1908 and others listed in the Royal Decree of 15/04/1909*. Gazzetta ufficiale n. 95, 22/04/1909, Rome, Italy, 1909. (In Italian)

[5] Ricci P.; De Luca F.; Verderame G.M. 6th April 2009 L'Aquila earthquake, Italy: reinforced concrete building performance. *Bulletin of Earthquake Engineering* **2011**, 9, 285–305, DOI 10.1007/s10518-010-9204-8.

[6] Italian Ministry of Public Works, Ministry Decree, 14/01/2008, *Technical regulations for constructions*; Suppl. Ord. Gazzetta Ufficiale n. 29, 4/02/2008, Rome, Italy, 2008. (In Italian)

[7] Italian Ministry of Public Works: Circolare n. 617, 2/02/2009, *Commentary on Technical regulations for constructions*, Rome; 2009. (In Italian)

[8] Presidence of the Council of Ministers of the Italian Republic: Ordinance n. 3431, 3/05/2005, *Technical regulations for design, assessment and seismic upgrade of buildings*, Suppl. Ord. Gazzetta Ufficiale n. 85, 10/05/2005, Rome, Italy, 2005. (In Italian)

[9] CEN EN 1998-3, EuroCode 8, *Design of structures for earthquake resistance – Part 3: Assessment and retrofitting of buildings*. European Committee for Standardization, Bruxelles, June 2005.

[10] Italian Ministry of Infrastructure and Transport, Ministry Decree, 21/07/2012, *Ratification of National Annexes with parameters ascribed for application of Eurocodes*), Suppl. Ord. Gazzetta Ufficiale n. 73, 27/03/2013, Rome; 2013. (In Italian)

[11] Law 373/1976. In *Norme per il Contenimento del Consumo Energetico per usi Termici Negli Edifici*; Gazzetta Ufficiale della Repubblica Italiana n. 148 del 7.6.1976: Rome, Italy, 2015. (In Italian)

[12] Law 10/1991. In *Norme per L'attuazione del Piano Energetico Nazionale in Materia di Uso Razionale Dell'energia, di Risparmio Energetico e di Sviluppo Delle Fonti Rinnovabili di Energia*; Gazzetta Ufficiale della Repubblica Italiana s.o. n. 13 del 16.1.1991: Rome, Italy, 1991. (In Italian)

[13] La Greca, P.; Margani, G. Seismic and energy renovation measures for sustainable cities: A critical analysis of the Italian scenario. *Sustain.* **2018**, *10* (1) DOI: 10.3390/su10010254.

[14] Inter-ministerial Decree, 26/6/2015, *Application of the calculation methodology of the energy performances and definition of the prescription and of the minimum required for buildings*, 2015.

[15] Legislative Decree n. 28, 3/3/2011, *Attuazione della direttiva 2009/28/CE sulla promozione dell'uso dell'energia da fonti rinnovabili, recante modifica e successiva abrogazione delle direttive 2001/77/CE e 2003/30/CE*; 2011. (In Italian)

[16] Law 90, 3/8/2013, *Conversione in legge, con modificazioni, del decreto-legge 4 giugno 2013, n. 63, recante disposizioni urgenti per il recepimento della Direttiva 2010/31/UE del Parlamento europeo e del Consiglio del 19 maggio 2010*; 2013. (In Italian)

[17] Cicero, C.; Lombardo, G. Building envelope and energy, *Journal of Civil Engineering and Architecture*, **2011**, 8.

[18] Balan, St.; Cristescu, V.; Cornea, I. *The Romania Earthquake of March 4, 1977*. Editura Academiei: Bucharest, Romania, 1982. (In Romanian)

[19] Georgescu E S. Earthquake Engineering Development before and after the March 4, 1977, Vrancea, Romania Earthquake, In Proceedings of the 25 years of Research in Earth Physics, Bucharest, Romania, September 2002, pp. 93-107.

[20] Berg, G.V.; Bolt, B.A.; Sozen, M.A.; Rojahn, C. *Earthquake in Romania March 4, 1977. An Engineering Report*. National Academy Press: Washington D.C., USA, 1980.

[21] Georgescu E. S.; Pomonis A. The Romanian Earthquake of March 4, 1977; Revisited: New Insights into its Territorial, Economic and Social Impacts and their Bearing on the Preparedness for the Future, Proceedings of the 14th World Conference on Earthquake Engineering, Beijing, China, 2008, October, 2008.

[22] Code P100-1/2006. Seismic Design Code, Part I - Provisions for the design of buildings. Indicative P100-1; elaborated by UTCB, endorsed by MDRL. Official Journal of Romania, part I, n. 803 and 803 bis, 25.09. 2006. (In Romanian)

[23] Craifaleanu, I. Romanian Seismic Design Code: Benchmarking Analyses with Reference to International Codes and Research Needs for Future Development. *Constructii*, **2011**, p. 55-64, ISSN 1221-2709, eISSN 2247-0328.

[24] Craifaleanu, I. Eurocode 8, Part 3 and the Romanian Seismic Code for the Assessment of Existing Buildings, P100-3: Similarities and Differences. Presented at the Workshop Implementation of the EC 8-Part 3: 2005: Assessment and interventions, on buildings in earthquake prone areas, Athens, Greece, April 2013.

[25] Code P100-1/2013. Seismic Design Code - Part I- Provisions for the design of buildings. Indicative P100-1 (in Romanian) Elaborated by UTCB, endorsed by MDRAP; Official Journal of Romania, part I, n. 558 of 03. 09. 2013; 2013. (In Romanian)

[26] Code P100-3/2008. *Seismic Design Code – Part III – Provisions for Seismic Assessment of Existing Buildings, Indicative P 100-3/2008*. Elaborated by UTCB, endorsed by MDRL, Official Journal of Romania n. 704, September 9, 2009, in force from January 1, 2010. (In Romanian)

[27] C107/2016. "Normative regarding the thermal calculation of building elements of buildings", indicative C 107-2005, approved by Order of the Minister of Transports, Constructions and Tourism no. 2055/2005 Annex A: Climate Zoning of Romania, Annex B: Energy requirement for buildings whose energy consumption is almost equal to zero, modified and completed by Government Ordinance no.386 / 28.03.2016. Official Journal of Romania Part I, no. 306 bis / 21.IV.2016.

[28] C107/6-2002 General norm for calculating the mass transfer (humidity) through the building elements (Bulletin of Constructions no. 14/2002, INCERC), 2002

[29] C107/7-02 Norm for thermal stability design of building closures - (Bulletin of Constructions no. 8/2003). 2003

[30] Catalogue of thermal bridges specific to buildings, Annex K (informative) to Order n. 1590/24.08.2012 for the modification and completion of Part 3 - Normative regarding the calculation of thermal energy performance of building elements of buildings, Indicative C107/3 of the Technical Regulation "Normative regarding the thermo-technical calculation of building elements of buildings" 2005, approved by the Order of the Minister of Transports, Constructions and Tourism no. 2055/2005. Official Journal of Romania, Part I, no. 650 bis /12.IX.2012.

[31] SR 1907-1:2014, Heating plants. Design heat requirements computation for buildings. Computation method, Annex A (In Romanian)

[32] Mc 001/2006 *Methodology of buildings energy performance calculation*. MTCT Order No. 157, with Annexes 1, 2 and 3, Official Journal of Romania part I, no. 126 bis, 21.02.2007.

[33] C107/2010. Normative regarding the thermo-technical calculation of building elements of buildings, indicative C107-2005 modified by Order n. 2513 of November 22, 2010 for the amendment of Official Journal of Romania, Part I, n. 820 of December 18, 2010.

[34] Decision No. 122/25.02.2016 for approval of "National Plan of action in the field of energy efficiency. Monitorul Oficial / Official Journal of Romania, Part I, nr. 169 bis of 11.03.2015 (in Romanian).

[35] Franchin P.; Pinto P.E.; Rajeev P. Confidence factors? *Journal of Earthquake Engineering* **2010**, 14, 989–1007, DOI: 10.1080/13632460903527948.

[36] Bosco M.; Ghersi A.; Marino E.M. On the evaluation of seismic response of structures by nonlinear static methods. *Earthquake Engineering and Structural Dynamics* **2009**, 38, 1465–1482, DOI: 10.1002/eqe.911.

[37] Fajfar P. Capacity spectrum method based on inelastic demand spectra. *Earthquake engineering and Structural Dynamics* **1999**, 28, 979-993, DOI: 10.1002/(SICI)1096-9845(199909)28:9<979::AID-EQE850>3.0.CO;2-1.

[38] Iervolino I.; Galasso C.; Cosenza E. REXEL: computer aided record selection for code-based seismic structural analysis. *Bulletin of Earthquake Engineering* **2010**, 8, 339–362, DOI 10.1007/s10518-009-9146-1.

[39] Tanganelli M.; Viti S.; Mariani V.; Pianigiani M. Seismic assessment of existing RC buildings under alternative ground motion ensembles compatible to EC8 and NTC 2008. *Bulletin of Earthquake Engineering* **2017**, 15, 1375–1396, DOI10.1007/s10518-016-0028-z.

[40] Vamvatsikos D.; Cornell C.A. Incremental dynamic analysis. *Earthquake Engineering and Structural Dynamics* **2002**, 31, 491–514, DOI: 10.1002/eqe.141.

[41] Garevski M.; Ansal A. *Earthquake engineering in Europe. Geotechnical, Geological and Earthquake Enigneering*, Springer: Berlin, Germany, 2010; ISBN 978-90-481-9543-5.

[42] Regione dell'Umbria. *Guidelines for post-seismic rehabilitation and reconstruction of buildings*, Tipografia del genio civile, Italy, 1999; ISBN: 88-7722-460-6. (In Italian)

[43] Bakis C.E.; Bank L.C.; Brown V.L.; Cosenza E.; Rizkalla S.H.; Triantafillou T.C. Fiber-reinforced polymer composites for construction - State-of-the-art review. *Journal of Composites for Construction* **2002**, 6, 73–87, DOI: 10.1061/~ASCE!1090-0268~2002!6:2~73.

[44] Barbagallo F.; Hamashima I.; Hu H.; Kurata M.; Nakashima M. Base shear capping buildings with graphite-lubricated bases for collapse prevention in extreme earthquakes. *Earthquake Engineering and Structural Dynamics* **2017**, 46, 1003–1021, DOI: 10.1002/eqe.2842.

[45] Fenz, D. M.; Constantinou M. C. Behaviour of the double concave Friction Pendulum bearing. *Earthquake Engineering & Structural Dynamics* **2006**; 35(11), 1403–1424, DOI: 10.1002/eqe.589

[46] Naeim F.; Kelly J. M. *Design of Seismic Isolated Structures: From Theory to Practice*, Wiley & Sons: New York, USA, 1999; ISBN: 978-0-471-14921-7.

[47] Kumar M.; Whittaker A.S.; Constantinou M.C. Characterizing friction in sliding isolation bearings. *Earthquake Engineering & Structural Dynamics* **2015**, 44(9), 1409–1425, DOI: 10.1002/eqe.2524

[48] Christopoulos C.; Filiatrault A. *Principles of passive supplemental damping and seismic isolation,* IUSS Press: Pavia, 2006; ISBN: 8873580378.

[49] Deng K.; Pan P.; Nie X.; Xu X.; Feng P.; Ye L. Study of GFRP Steel Buckling Restraint Braces. *Journal of Composites for Construction* **2015**, 19, 04015009, DOI: 10.1061/(ASCE)CC.1943-5614.0000567.

[50] Lavan O. Optimal Design of Viscous Dampers and Their Supporting Members for the Seismic Retrofitting of 3D Irregular Frame Structures. *Journal of Structural Engineering* **2015**, 141, DOI10.1061/(ASCE)ST.1943-541X.0001261.

[51] Lee K.S.; Fan C.P.; Sause R., Ricles J. Simplified design procedure for frame buildings with viscoelastic or elastomeric structural dampers. *Earthquake Engineering and Structural Dynamics* **2005**, 34, 1271–1284, DOI: 10.1002/eqe.479.

[52] Rossi P.P. Importance of isotropic hardening in the modeling of buckling restrained braces. *Journal of Structural Engineering* **2015**, 141, DOI: 10.1061/(ASCE)ST.1943-541X.0001031.

[53] Xie Q. State of the Art of Buckling-Restrained Braces in Asia. *Journal of Constructional Steel Research* **2005**, 61, 727–748, DOI: 10.1016/j.jcsr.2004.11.005.

[54] Barbagallo F.; Bosco M.; Marino E.M.; Rossi P.P.; Stramondo P.R. A multi-performance design method for seismic upgrading of existing RC frames by BRBs. *Earthquake Engineering and Structural Dynamics* **2017**, 46, 1099–1119, DOI: 10.1002/eqe.2846.

[55] Formisano A.; Castaldo C.; Chiumiento G. Optimal seismic upgrading of a reinforced concrete school building with metal-based devices using an efficient multi-criteria decision-making method. *Structure and Infrastructure Engineering* **2017**, 13, 1373–1389, DOI 10.1080/15732479.2016.1268174.

[56] Pan P.; Li W.; Nie X.; Deng K.; Sun J. Seismic performance of a reinforced concrete frame equipped with a double-stage yield buckling restrained brace. *The Structural Design of Tall and Special Buildings* **2017**, 26, e1335, DOI: 10.1002/tal.1335.

[57] Impollonia N.; Palmeri A. Seismic performance of buildings retrofitted with nonlinear viscous dampers and adjacent reaction towers. *Earthquake Engineering and Structural Dynamics* **2018**, DOI: 10.1002/eqe.3020.

[58] Antonucci R.; Balducci F.; Castellano M. G.; Ahmadi H.; Goodchild I.; Fuller K. Viscoelastic dampers for seismic protection of buildings: an application to an existing building. In Proceedings of the 5th World Congress on Joints, Bearings and Seismic Systems for Concrete Structures, Rome, Italy, October 2001.

[59] Sorace S.; Terenzi G.; Magonette G.; Molina F.J. Experimental investigation on a base isolation system incorporating steel–Teflon sliders and pressurized fluid viscous spring dampers *Earthquake Engineering and Structural Dynamics* **2008**, 37, 225–242 DOI: 10.1002/eqe.753

[60] Marshall J.D.; Charney F.A. Seismic response of steel frame structures with hybrid passive control systems *Earthquake Engineering and Structural Dynamics* **2012**, 41, 715–733 DOI: 10.1002/eqe.1153

[61] Wolff E.D.; Ipek C.; Constantinou M.C.; Tapan M. Effect of viscous damping devices on the response of seismically isolated structures *Earthquake Engineering and Structural Dynamics* **2015**, 44, 185–198 DOI: 10.1002/eqe.2464

[62] De Domenico D.; Ricciardi G. An enhanced base isolation system equipped with optimal tuned mass damper inerter (TMDI) *Earthquake Engineering and Structural Dynamics* **2017**, 1-24 DOI: 10.1002/eqe.3011

[63] Qu Z.; Wada A.; Motoyui S.; Sakata H.; Kishiki S. Pin-supported walls for enhancing the seismic performance of building structures. *Earthquake Engineering and Structural Dynamics* **2012,** 41, 2075-2091 DOI: 10.1002/eqe.2175

[64] Toranzo-Dianderas L.A.; Restrepo J.I.; Carr A.J.; Mander J.B. Rocking confined masonry walls with hysteretic energy dissipators and shake-table validation. In Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, B.C. (Canada), 2004.

[65] Panian L.; Steyer M.; Tipping S. An innovative approach to earthquake safety and concrete construction in buildings. *Journal of the Post-Tensioning Institute* **2007**, 5(1), 7-16.

[66] Stevenson M.; Panian L.; Korolyk M. Post-tensioned concrete walls and frames for seismic-resistance - a case study of the David Brower Center, In Proceedings of the SEAOC Annual Convention, Hawaii (USA), 2008.

[67] Balducci A.; Castellano M.G. Seismic retrofitting of a RC school building through the "Damping Towers" system. *Progettazione Sismica* **2015**, 6(1), DOI 10.7414/PS.6.1.69-91. (In Italian)

[68] Ordinance n. 20/1994. *Government Ordinance on Existing Buildings Risk Reduction, revised, republished, Official Journal of Romania*, Part I, n. 863 of 19.11. 2015; 1994; 2015. (In Romanian)

[69] Stazi F., Vegliò A., Di Perna C., Munafò P., Experimental comparison between 3 different traditional wall constructions and dynamic simulations to identify optimal thermal insulation strategies, *Energy and Buildings*, **2013**; 60, 429–441.

[70] Baljit, S.S.S.; Chan, H.-Y.; Sopian, K. Review of building integrated applications of photovoltaic and solar thermal systems. *J. Clean. Prod.* **2016**, 137, 677–689.

[71] Tripathy, M.; Sadhu, P.K.; Panda, S.K. A critical review on building integrated photovoltaic products and their applications. *Renew. Sustain. Energy Rev.* **2016**, 61, 451–465.

[72] Maurer, C.; Cappel, C.; Kuhn, T.E. Progress in building-integrated solar thermal systems. Sol. Energy **2017**, 154, 158–186.

[73] Gagliano, A.; Nocera, F.; Patania, F.; Capizzi, A. Assessment of micro-wind turbines performance in the urban environments: An aided methodology through geographical information systems. *Int. Journal of Energy and Environm. Engin.*, **2013**; 4 : 1 -14.

[74] Ma, Z.; Cooper, P.; Daly, D.; Ledo L. Existing building retrofits: Methodology and state-of-the-art. *Energy and Building* **2012**, 55, 889–902, DOI: 10.1016/j.enbuild.2012.08.018.

[75] Özkan, H. A. A new real time home power management system. *Energy Build.* **2015**, *97*, 56–64 DOI: 10.1016/j.enbuild.2015.03.038.

[76] Sapienza, V.; Rodonò, G. Intesa Sanpaolo Tower, *Arketipo*, **2016**, 100, 104-115, ISSN: 1828-4450.

[77] Sapienza, V. The new chamber building of Malta: architectural image and building technology, Techne, **2014**, 8, 219-227, ISSN: 2239-0243; DOI: http://dx.doi.org/10.13128/Techne-15077.

[78] Lu, Y.; Wang, S.; Shan, K. Design optimization and optimal control of grid-connected and standalone nearly/net zero energy buildings. *Appl. Energy* **2015**, *155*, 463–477 DOI: 10.1016/j.apenergy.2015.06.007.

[79] Gagliano, A.; Patania, F.; Nocera, F.; Capizzi, A.; Galesi A. GIS-based decision support for solar photovoltaic planning in urban environment Smart Innovation, *Systems and Technologies*, **2013**; 22, 865-874, DOI: 10.1007/978-3-642-36645-1_77.

[80] Caponetto, R.; Caponetto, R.; Cecere, C.; D'Urso, S.; Habib, E.; Margani, G.; Sapienza, V. Automated collecting building envelopes. In: *ICT, Automation and Industry of the Built Environment: from the Information Exchange to the Field Management*; Maggioli Editore: Rimini, 2013; pp. p. 340-357, ISBN: 88-387-6258-1.

[81] Building Knowledge Hubs http://www.train-to-nzeb.com. Accessed 2017.

[82] Complex, multicriterial, integrated rehabilitation of urban and housing complexes. Certification of Sustainable Buildings. "Ion Mincu" University Publishing House, Bucharest, 2011, ISBN 978-606-638-002-7

[83] SC 007-2013 *Framework solutions for the thermo-hygro-energetic rehabilitation of existing building envelope*. Monitorul Oficial / Official Journal of Romania, Part I, no. 540 bis / 27.08.2013.

[84] BUILD UP Skills Project Romania (ROBUST). http://www.iee-robust.ro. Accessed 2017.

[85] BUILD UP Skills QualiShell project. http://www.iee-robust.ro/qualishell. Accessed 2017.

[86] Castellazzi L.; Zangheri P.; Paci D. Synthesis Report on the assessment of Member States' building renovation strategies, *Publications Office of the European Union* **2016**, ISBN 978-92-79-54703-4 (print), 978-92-79-54704-1 (PDF), 978-92-79-63914-2 (ePub), ISSN: 1018-5593 (print),1831-9424 (online).

[87] Caponetto, R.; Margani, G.; Sapienza, V. La riqualificazione energetica dell'edilizia residenziale. *Il Progetto Sostenibile* **2016**, 38, 58–73. (In Italian)

[88] Takeuchi, T.; Yasuda, K.; Iwata, M. Studies on Integrated Building Facade Engineering with High-Performance Structural Elements. *IABSE Symp. Rep.* **2006**, *92* (4), 33–40, DOI: 10.2749/222137806796185526.

[89] Takeuchi T.; Yasuda K.; Iwata M. Seismic retrofitting using energy dissipation façades. In Proceedings of ATC-SEI09, San Francisco, USA, 2009.

[90] Leone, M. F.; Zuccaro, G. Seismic and energy retrofitting of residential buildings: a simulation - based approach. *UPLanD* **2016**, 1 (1), 11–25.

[91] Calvi, G. M.; Sousa, L.; Ruggeri, C. Energy Efficiency and Seismic Resilience: A Common Approach. In: *Multi-hazard Approaches to Civil Infrastructure Engineering*; Springer International Publishing: Cham, **2016**; pp 165–208.

[92] Manfredi, V.; Masi, A. Seismic Strengthening and Energy Efficiency: Towards an Integrated Approach for the Rehabilitation of Existing RC Buildings. *Buildings* **2018**, 8 (3), 36 DOI: 10.3390/buildings8030036.

[93] ProGETone. https://www.progetone.eu/. Accessed 2017

[94] Law 205/2017. In *Bilancio di previsione dello Stato per l'anno finanziario 2018 e bilancio pluriennale per il triennio 2018-2020*; Gazzetta Ufficiale della Repubblica Italiana s.o. n. 302 del 29.12.2017: Rome, Italy, 2017. (In Italian)