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Review paper

REVIEW OF METHODS FOR INTEGRAL SEISMIC AND ENERGY RENOVATION OF EXISTING MASONRY BUILDINGS IN SERBIA

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Abstract

The research of the methods for integral renovation of the existing architectural stock is necessitated by weak seismic resistance and poor energy performances of these buildings. Most of the existing buildings in Serbia are masonry buildings, which had been built before the first comprehensive seismic design code in the SFRY, that was issued in 1964, and also before the requirements regarding thermal protection were enacted. Today, technical regulations define the required level of load bearing capacity and safety that buildings should satisfy, as well as the appropriate level of energy efficiency, so that the quality of housing and the conditions of service of the building correspond to modern living standards. In practice, several separate techniques have been used for years for improving the thermal protection of existing buildings, and also for the rehabilitation and strengthening of structural elements in case of global and local interventions. The focus of the research is increasingly shifting towards integrated strategies that synergistically deal with the study of both aspects. The paper shows the methods of integrated renovation that are applied from the outside of the building, in order to facilitate their execution in buildings that are in use, with minimal disturbance of the building residents. The application of appropriate comprehensive and effective solutions is a process that still requires further research in order to optimize strategies.

Key words: *masonry buildings, seismic design, thermal protection, structural measures, integral improvement*

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1. INTRODUCTION

The aging of the building stock is a problem that affects many regions of the world. This means that a large proportion of existing buildings are considered energy inefficient, as they use a lot of energy for heating and cooling. In addition to this, a big problem is the weak resistance to seismic effects. Recent earthquakes have caused significant economic losses, mainly due to the vulnerability of older buildings that were not designed and built to modern standards.

Addressing seismic and energy performance with separate interventions is a common approach that is topical. However, to achieve better cost-effectiveness, safety and efficiency, a new holistic approach to building renovation is an emerging topic in the scientific literature and also in practice.

A holistic approach to building renovation could be a leading instrument for promoting renovation and ensuring the longevity of investments made to improve energy efficiency. Until recently, retrofitting and renovation efforts were mainly focused on improving the thermal protection, without taking into account the structural integrity of the building. Looking at the structure is crucial when it comes to renovation, because neglecting the structural integrity of the building can later lead to major damage and irrational ineffective finance spending.

In the scientific literature [1], [2] the topic of integrated seismic and energy retrofitting has become popular in the last five years. This topic entails the formation of an appropriate methodology for combined assessments of existing buildings, as well as for the analysis of potential benefits from integrated interventions. Observing the scope and complexity of interventions related to energy efficiency and seismic resistance, as well as their accompanying costs, and the assessment of the condition of existing buildings and their comprehensive analysis are of great importance for the formation of the process of deciding on the renovation of buildings. The feasibility of applying appropriate integrated retrofitting, available materials and production technologies is presented in the paper. The selection and implementation of the appropriate methods largely depends on the applied structural systems, the quality of the built-in materials, the condition in which the building is located and other characteristics of the buildings.

It is crucial to emphasize that the renovation of existing buildings not only extends the life of a particular building, but also significantly preserves natural resources. Improvements in energy efficiency in existing buildings lead to significant reductions in the energy required for heating and cooling, thereby reducing costs, and the economic aspect is also improved. In addition to the basic goals of such a comprehensive integrated renovation, it is important to emphasize the improvement of the comfort and quality of life of the users. It becomes evident that the benefits resulting from such a comprehensive renovation go beyond the basic goals and extend to other aspects, making this process even more complex and meaningful.

This paper shows the available methods, i.e. those that have the most common application in practice, when it comes to seismic strengthening and improvement of energy efficiency. Although not all available methods are presented here, the selected ones show the appropriate possibilities and advantages provided by the integration of structural and energy measures [2], [3].

2. MATERIALS AND METHODS

The research methodology consists of few stages. The first phase includes an analysis of the types of existing multi-family residential buildings built in the period of mass construction after World War II. Depending on the time of construction, different systems, structural assemblies and materials were applied, and very often these buildings were extended and reconstructed. A certain number of buildings, despite their solid structure, are damaged by sudden events, such as earthquakes, fires, explosions and the like. Earthquakes are external factors that cause damage to buildings, and they cannot be predicted. Depending on their severity, these damages can range from minor to devastating. The second step includes the analysis of the existing situation, primarily from the structural aspect, and then from the point of view of energy efficiency. The third step consists in the presentation of variant solutions for improving the structural elements of buildings, and then the application of appropriate systems essential for improving the thermal protection.

Structural strengthening and improvement of thermal protection of existing buildings have so far been mostly observed and carried out independently. However, we could see in numerous examples that after sudden seismic events, the investments on the buildings that were not structurally reinforced, and had interventions around the thermal envelope, is lost in this rehabilitation as well. Also, the additional costs occurring in that case, as well as the additional disruption of the normal life activities of the tenants in the building, can be mentioned as a downside of the separate execution of these interventions. On the other hand, if integrated structural and energy upgrading is applied, then the structural integrity of the building can be considered truly safe. This means that even if a certain seismic effect occurs, the building will be able to withstand the event without it affecting the energy reconstruction at all. Practically, in areas with moderate to high seismic risk, it is imperative that any energy reconstruction is carried out only after the building has been brought to a level of appropriate structural stability, in accordance with modern standards. Otherwise, the risk of losing the investment is excessively high, as shown by many examples in the practice.

3. EXISTING MASONRY BUILDINGS CONSIDERED IN THE STUDY

Residential building in the period after World War II introduces a new concept of designing and organizing housing space, breaking ties with the previous tradition and certain characteristics of cultural heritage. Apartments for social housing and newly designed workers' neighborhoods are defined by strict uniformity, a simple repeating form, small number of floors and emphasized horizontal lines of openings on the facades. The buildings are still mostly built in the system of load-bearing brick walls, with reinforced concrete ceilings and wooden roof structure.

The period from the fifties to the mid-sixties is characterized by a large number of built apartments, which, however, did not always meet the needs of the users. The reason for this situation was the lack of design standards and regulations. The first national standard related to seismic design was issued in 1964 [4], after the catastrophic earthquake in Skopje in 1963.

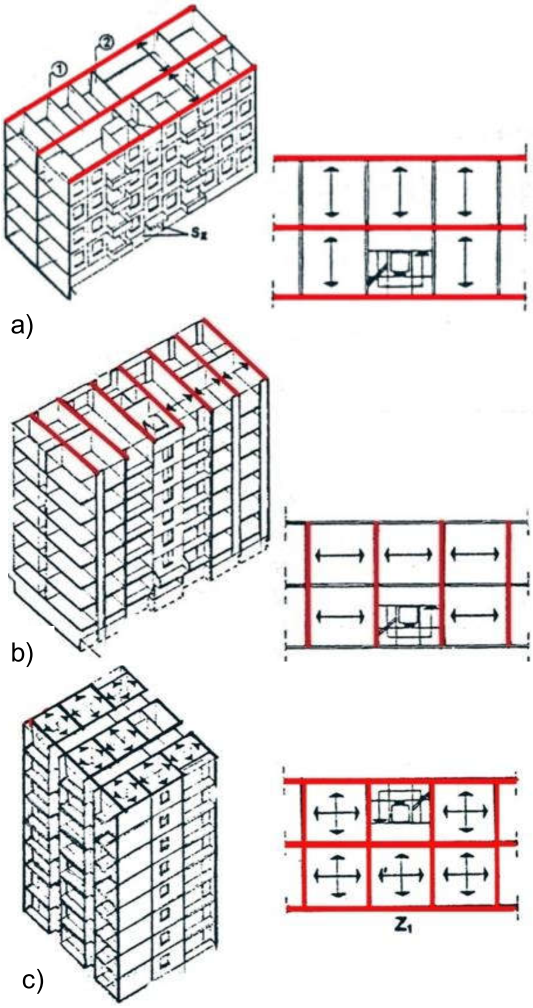


Figure 1. Massive structural system [5]
a) longitudinal, b) transverse, c) crossed

Most of the multi-family residential buildings built before 1964 are generally low, from 3 to 5 stories. Bearing walls in structural systems can be arranged as longitudinal, transverse or placed in both orthogonal directions. In this period, the walls were built as unreinforced masonry (URM), 25 to 38 cm thick. Solid bricks measuring 12x25 cm and compo were used for masonry. These buildings are heavy and massive, due to the relatively large thickness of the masonry walls. The distance between the load-bearing walls is determined by the span of the ceilings and is not greater than 5.0 meters. The seismic behavior of URM walls can be characterized as brittle, since cracks occur when tensile stresses exceed the tensile strength of the wall, as stated in [6]. Floors were in the form of semi-prefabricated composite masonry and stiffened with horizontal concrete beams.

Builders of masonry (URM) buildings often made gross structural errors by designing load-bearing walls only in one direction without adequate connections between the walls and the floor slabs, with insufficient connections with the surrounding walls, large openings, poor quality materials, and the like. The expected longer service life of these buildings and modern building design standards require a higher level of safety.

The disadvantages of existing buildings in terms of energy efficiency are mainly due to the lack of regulations at the time of their construction, as well as the deterioration of materials over time. The first application of the thermal envelope in our region occurred in the early 1970s, as a result of the oil supply crisis [2]. Nowadays, new buildings during the design process must comply with a set of regulations on energy efficiency, and also existing buildings during reconstruction must satisfy minimum energy performance requirements. Within the framework of the *National Typology of Residential Buildings in Serbia* (Table 1) [3], a specific categorization of the existing building stock and its extensive research in terms of energy characteristics have been carried out. Existing residential buildings most often have load bearing facade walls made of bricks without thermal insulation.

Table 1. National typology of residential buildings in Serbia from 1946 to 1960 [3]

	Family housing (up to 4 appartement)		Multifamily housing (more than 4 appartement per entrance)			
Type	1	2	3	4	5	6
	Freestanding	In a row	Freestanding	Lamela	In a row	High rise
1946-1960						

The thermogram shows a high intensity of heat loss through the facade walls of the heated part with prominent horizontal reinforced concrete ring beams in comparison to the unheated ground floor part of the building (Fig. 2). On the higher floors, secondary heating from solar radiation can be observed, as well as increased heat loss through the facade joinery. The original joinery is double-glazed wood and in a large number of apartments it has been replaced with new PVC or aluminum.

Figure 2. A residential building with load bearing facade brick walls without thermal insulation [3]

The lack of energy standards is also clearly visible when looking at the evolution of thermal transmittance (U-value) of different building elements (walls, windows, roofs and floors) for residential buildings. As can be seen in Table 2, older structures have significantly higher thermal transmittance values than modern ones, leading to higher energy consumption and significantly worse thermal comfort.

It is important to emphasize, an energy upgrade investment will not be effective when applied in a building of questionable structural integrity. First the building must be brought into a state of required load-bearing capacity and safety. This phase is primary and must be a guarantee for the successful implementation of other measures that should achieve the desired quality of housing and the achievement of overall goals.

Parts of buildings where increased heat transfer occurs are called thermal bridges. Their formation is most often the result of the complex structural composition of the building, or its geometric discontinuity, and therefore they can appear at the base of buildings (plinths), on ring beams, reinforced concrete columns, window lintels, or around windows if they are not installed correctly. In existing buildings, the goal is to reduce the effects of thermal bridges to a tolerable level.

Table 2. Elements of the thermal envelope-Present state [3]

Structure	Figure	Description	Thermal transmittance
External Wall 1	Inside Outside 	Plaster 2cm, brick wall 38cm, decorative plaster 3cm	1.26
External Wall 2	Inside  Outside	Plaster 2cm, brick wall 25cm, decorative plaster 3cm	1.67
Floor Construction to Unheated Area (Basement)	Inside 	Parquet 2.2cm glued, cement screed 3cm, ribbed semi prefabric. concrete slab *Avramenko* 30cm	2.05
Floor Construction to Unheated Area (Attic)	Outside  Inside	Sand 2 cm, rammed earth with chaff 5cm, ribbed semi prefabric. concrete slab *Avramenko* 30cm, straw plaster ceiling 5cm	1.06
Windows and Balcony Doors		Wooden, double frame, double sash (narrowbox) with single glazing. Internal canvas roller blind	3.50

4. INTEGRATED SEISMIC AND ENERGY RETROFITTING TECHNOLOGIES

During the process of designing and preparing the renovation work, it is important to consider compatibility already in the design phase, especially in terms of: possible spatial overlap; scope of application; level of disturbance; and the desired level of performance. Certain overlaps may hinder the application of seismic or energy techniques because of the practical limitations they impose on each other. The scope of application is related to the number of building elements on which the intervention is applied, while the level of required interventions is related to the time required for the realization of those works. So, for example, if seismic intervention is required only on a few elements of the building, while the energy intervention is intended to require work on the entire building, the two interventions can be considered less compatible in terms of scope, but probably also in terms of the disturbance level.

Technologies and methods currently topical in the scientific literature, by Gkatzogias, Pohoryles at al. [2], can be classified into four main directions: (1) integrated exoskeleton solutions; (2) integrated interventions on the existing building envelope; (3) replacement of envelope elements by higher performance elements and (4) interventions on horizontal elements, such as roof and floor slabs.

4.1. Integrated exoskeleton solutions

Integrated exoskeletons are external structures that are connected to existing buildings in order to improve their structural stability and safety and reduce energy consumption. Concrete or steel systems are most commonly used. The exoskeleton system can be superimposed on the facades by creating an independent structure on its foundations. It can accommodate new spaces and support possible elevations.

Examples of such external structures range from simple beams combined with shading elements, to diagonal steel trusses or frames that carry different types of panels, such as integrated photovoltaic systems, green facades or shading elements, as shown in Figure 3. Integrated solutions also include the use of thermal insulation integrated with auxiliary reinforced concrete frames or walls.

Figure 3. Application of a steel exoskeleton wall system for integrated seismic and energy retrofitting of buildings [7],[8]

Exoskeleton systems are not always feasible, as in the case of densely built-up urban areas, which lack the space around the exoskeleton facility, which further complicates the excavation of additional foundations [9],[10]. Since forces are usually transferred from the existing building to the exoskeleton by slab-level connections, application of the exoskeleton may not be effective when the horizontal slab is not rigid. An additional limitation for exoskeletons is a significant change in the external appearance of the structure, which may make the intervention inapplicable for certain types of buildings.

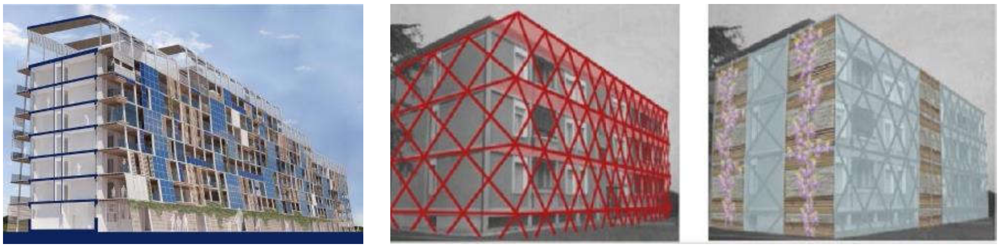


Figure 4. Application of a steel exoskeleton shall system for integrated retrofitting [8],[11]

The steel exoskeleton system which features solar green-buildings on the southern façade, along with thermal insulation using EPS, new energy-efficient windows, and adjustable louvre shading systems for controlling solar radiation can ensure a 70 % reduction in heating, as proposed by Stasi et al. This systems integrates various technologies to create thermal buffer zones, shown in Figure 4, such as balconies or additional space, which help to reduce solar radiation during the summer months, provide solar heating during the winter, and support plug-and-play installations for new HVAC systems [11].

4.2 Integrated interventions on the existing building envelope

Considering the high stiffness of the walls and the high energy transmittance of the vertical envelope of the building, special attention is paid to the development of combined renovation strategies of these elements, to satisfy both seismic and energy aspects. Different variant solutions can be found in the literature, such as: (1) application of composite materials; (2) in situ constructed panels/walls, (3) prefabricated panels (cement-based or wood-based), and (4) the local strengthening of the existing openings integrated with upgrading of the old fenestration. In the case of all envelope strengthening solutions, the increase in shear capacity in the foundation, as well as in the shear forces acting on the existing frame, means that a careful assessment of the foundation and frame elements should be carried out, as these elements may need to be further reinforced.

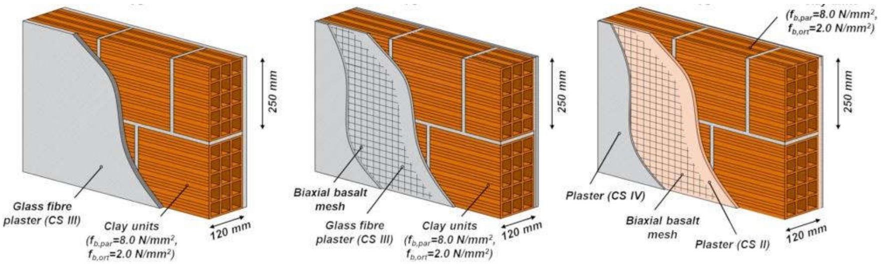
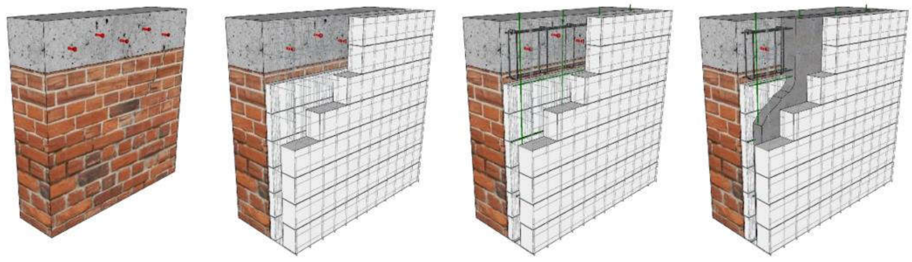


Figure 5. Composites for the combined seismic and energy retrofitting [12]

Until now, methods of strengthening masonry structures with composite materials, shown in Figure 5, have been widely used in practice. As stated in *Technologies for the combined seismic and energy upgrading of existing buildings [7]*, they range from textile-reinforced mortars (TRM), fibre-reinforced polymer sheets, which are bonded using epoxy raisins (FRP) and engineered cementitious composites (ECCs) or steel fibre reinforced mortars (SFRM), using short fibres dispersed in a mortar, to steel meshes for reinforcing thin layers of plaster. These systems can be applied in the form of two- or one-sided jacketing and with the insulating panel either on the outer face or between the TRM and the masonry. Previous research has shown that the exact positioning of the TRM and the insulation material does not play an important role in the in-plane response, as long as proper bonding between the different layers is achieved. Positioning the TRM reinforcement above the insulation layer does not seem to compromise the activation of its fibres. Compared to the symmetrically reinforced specimens, single-sided configurations resulted in only a slight reduction of their efficiency This is a key benefit in a real-world retrofitting scenario, as it allows to perform all the work from the outside of the structure, drastically reducing the cost and the disruption of building occupancy.

In situ constructed panels/walls represent the system consists of a thin RC wall cast in-situ between pre-assembled layers of insulating material, as shown in Figure 6.The reinforcement of the concrete layers consists of steel bars arranged in the longitudinal and transverse direction with defined spacing. The retrofitting system is connected to the existing structure at each floor level, using steel connectors embedded in the horizontal ribs.



a) b) c) d)

Figure 6. Installation phases of the Insulated Concrete Formwork technology: (a) installing the connectors, (b) placing the insulated formwork, (c)placing the steel reinforcement, and (d) casting the concrete.[10]

Prefabricated panels (cement-based or wood-based) have recently gained traction for their use in integrated seismic and energy strategies (Figure 7). Multiple studies have proposed the use of CLT and OSB panels as an integrated retrofitting strategy for either load-bearing masonry buildings or RC buildings. The advantage of precast panels is that they may be applied faster onsite, reducing the time and cost of the intervention.

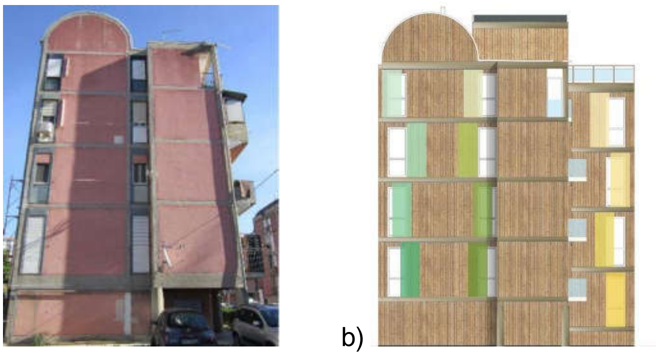
a)  b)

Figure 7. Proposed external cladding for CLT panel retrofit of case study building: (a) current state; (b) cladding with wooden boards [2]

Strengthening of openings with structural window frames integrated with fenestration replacement is particularly suitable for URM buildings. The seismic behaviour of the existing structure can be improved if the steel frame is adequately linked to the masonry and designed considering the original stiffness of the wall. The auxiliary elements work in parallel with walls and provide a beneficial confining effect to the surrounding masonry, increasing the in-plane shear strength and stiffness of the existing masonry wall [7]. The use of a structural steel window frame has been recently tested for individual masonry wall specimens.

4.3 Replacement of envelope elements with better performing materials

Retrofitting interventions on existing non-structural envelope elements, e.g. for masonry infills, may often not be feasible in practice or not economically viable. Researchers has focused on the development of elements that can provide at the same time adequate seismic resistance and improved energy performance. In terms of the seismic performance, this can mean (1) an increased stiffness and strength of the new infills, or (2) increased deformability of the frame by reducing interactions between infill and RC frame. For energy performance, approaches can include the use of new and more energy efficient materials.

4.4 Interventions on floor diaphragms and roofs

In the seismic behaviour of a structure, horizontal diaphragms have the task of transferring the horizontal actions to the resistant elements. In masonry buildings particularly, the floor and the roofs are typically made of timber joists and wooden planks or one-way steel beams with large flexural deformability and low in-plane stiffness, for this reason, stiffening interventions are often necessary [7].

For roofs, Pohoryles, Bournas, da Porto et al. [7] proposed a technique for the recovery of historic wooden roofs. The solution is based on the construction of a thin folded shell overlaying the existing roof pitch rafters and planks. Each pitch plane is transformed into a diaphragm composed of pitch joists, by perimeter chords and by web panel overlaying the existing planks.

5. CONCLUSION

The need for seismic and energy reconstruction of existing masonry buildings stems from the desire to protect and preserve the buildings, to extend their life, to improve the level of housing and to ensure safety and security. In the past, several solutions were used in practice, but the integration between these two aspects limited their application and made them more expensive. Starting from the current need for a holistic approach to renovation, this study aimed to highlight the possible advantages of an integrated solution that combines seismic and energy retrofitting in a single intervention. In addition to the possible higher performance that includes a harmonious combination of seismic and energy reconstructions, less time-consuming interventions have been improved, and therefore the costs of subsequent reconstruction have been reduced, even considering the lower investment return period. The paper provides an overview of open questions and possible promising solutions that can be further improved to overcome the shortcomings and obstacles that still prevent their widespread use in practical applications. Various proposals have attempted to fill the research gaps that still exist by adopting several techniques and materials, either more traditional or more innovative. Since this is a truly new research area, existing solutions are continuously improved, new solutions and ideas are provided, thus enriching the current overview and possible available methods.

Experimental research should enable better evaluations of the applied measures, to show both the good and the bad sides of certain interventions that can be implemented at the same time at a low cost. This, combined with some new methods on existing buildings, will show the full potential of this approach.

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