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INTRODUCTION

We are delighted to present the latest issue of the Journal of the Faculty of Civil Engineering and Architecture. Established in 1980, this journal has undergone several transformations, evolving alongside the faculty's name to become the Journal of the Faculty of Civil and Architectural Engineering. As we celebrate the release of the 38th edition in 2023, we continue the proud tradition of this esteemed serial publication. However, this particular issue marks a significant departure from tradition as, for the very first time, we are publishing papers in English.

In this issue, we proudly showcase a selection of nine papers that were presented at the conference Synergy of Architecture and Civil Engineering – SINARG2023. This conference served as a platform for experts and scholars from various corners of the globe to converge and exchange insights at the intersection of architecture and civil engineering. We believe that these papers will contribute significantly to the discourse in the field and further the collaboration between these two closely related disciplines.

The papers included in this issue cover a wide spectrum of subjects, including the adaptation and transformation of abandoned industrial heritage buildings, a comparative analysis of test results for properties of concrete, innovative approaches to refurbishing sports halls, landslide stabilization and rehabilitation measures, a comparative study on architectural education in the Republic of Serbia, the role of fiber-reinforced polymer composites in civil engineering, strategies for improving the socio-demographic structure in rural areas of Serbia, possibilities for enhancing the energy efficiency of existing multi-family buildings, and an exploration of intelligent tools for large-scale 3D printing. These papers represent a valuable contribution to the ongoing dialogue in the fields of architecture and civil engineering.

The list of our dedicated reviewers is published at the end of this journal, accompanied by detailed formatting guidelines for authors. We invite researchers, both established and early-stage, to consider our journal as a platform for the dissemination of their valuable work. Today, as our journal becomes more inclusive than ever, we extend a special invitation to our younger colleagues, in the hope that our journal will accelerate the development and dissemination of their research.

Editor-in-chief,
Prof. Dr. Miomir Vasov, M.Arch.

Dean,
Prof. Dr. Slaviša Trajković, M.Eng.

CONTENTS

Tadija Vasiljević, Janusz Marchwiński, Uroš Antić
ADAPTING AND TRANSFORMING ABANDONED INDUSTRIAL HERITAGE BUILDINGS INTO CONTEMPORARY OFFICE SPACES ON THE EXAMPLE OF PGNIG IN WARSAW, POLAND 1

Marko Ćećez, Merima Šahinagić-Isović, Mili Selimotić
COMPARATION OF LABORATORY AND IN-SITU TEST RESULTS OF MECHANICAL AND DURABILITY CONCRETE PROPERTIES FOR STADIUM STRUCTURE...........13

Ruxandra Balcanu
REFURBISHING INNOVATIVE STRUCTURES: THE CASE OF ROMANIAN SPORTS HALLS 21

Sead Abazi, Bulent Suloodja
LANDSLIDE STABILISATION AND REHABILITATION MEASURES ON THE REGIONALEN ROAD R-1202 MAVROVO - DEBAR, NORTH MACEDONIA...............32

Olivera Dulić
A COMPARATIVE STUDY ON ARCHITECTURAL EDUCATION IN THE REPUBLIC OF SERBIA 41

Ivana Drobnjak
THE ROLE OF FIBER-REINFORCED POLYMER COMPOSITES IN CIVIL ENGINEERING 52

Milica Igić, Milena Dinić Branković, Đekić Jelena, Bogdanović Protić Ivana, Mitković Mihailo
IMPROVEMENT OF SOCIO-DEMOGRAPHIC STRUCTURE IN RURAL AREAS IN SERBIA – POSSIBILITIES AND CHALLENGES...64

Bojana Lević, Dušan Ignjatović
POSSIBILITIES OF ENERGY IMPROVEMENT OF THE EXISTING MULTI-FAMILY BUILDINGS FROM THE PERIOD OF POST-WAR MASS CONSTRUCTION USING VOLUMETRIC ADDITIONS 76

Milijana Živković, Maša Žujović, Jelena Milošević
INTELLIGENT TOOLS FOR LARGE-SCALE 3D PRINTING: A SCOPING REVIEW...88

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POSSIBILITIES OF ENERGY IMPROVEMENT OF THE EXISTING MULTI-FAMILY BUILDINGS FROM THE PERIOD OF POST-WAR MASS CONSTRUCTION USING VOLUMETRIC ADDITIONS

Bojana Lević[1]
Dušan Ignjatović[2]

Abstract

The refurbishment of existing buildings with the aim of spatial-material improvement combined with the reduction of energy consumption is a very contemporary topic in recent years. The interest, both of experts and the general population, in saving energy while minimizing operating costs is constantly increasing, and it is emphasized by the uncertainties of energy supply coupled with constant increase in prices. Residential buildings built in the period from 1946 to 1970 make up one quarter of the total multi-family stock in Serbia. Most of these buildings are characterized by high energy consumption for heating due to poor thermal performance of the building envelope. Created according to the design regulations valid at that time, valued by today's user requirements, they have major spatial and organizational deficiencies, notably small apartments, outdated and inflexible spatial organization and small windows on the facades. The absence of elevators in many multi-family buildings from that period also reduces their comfort of use. The subject of the research is based on application of deep refurbishment methodology by adding volumes, as a constructive-functional element, to existing multi-family buildings. Primary goal represents achieving high energy efficiency levels combined with bettering of spatial and living standards through remodeling and modernization of residential units, and improving vertical building communications. The paper will illustrate the application of the principle of volumetric addition on three typologically different multi-family residential buildings. Based on the National Typology of Residential Buildings of Serbia, the subject of research are most common building typologies: free-standing buildings, row buildings within a city block and "lamellas". The research will analyze energy performance of the existing state on representative buildings of each type, as well as performance of improved state through application of strategy of deep refurbishment by adding a volume. The goal of the research is to review the advantages and limitations of proposed method for energy and spatial improvements in different types of multi-family residential buildings.

Key words: sustainability, deep refurbishment, energy efficiency, multi-family housing stock, volumetric addition

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1. INTRODUCTION

The refurbishment of existing buildings with the primary aim of reducing energy consumption has become a very contemporary topic in recent years. The Amended Directive on Energy Efficiency and the Directive on the Energy Performance of Buildings contain clear objectives related to long-term strategies for the renewal of the building stock in Europe [1]. In addition to these documents, the European Green Deal provides guidelines for the renewal of the existing building stock in order to improve energy efficiency and reduce energy consumption [2]. Many renovation strategies are based on energy-saving measures, such as retrofitting existing buildings to improve the building's building envelope and implementing efficient heating, ventilation, and air conditioning systems [3].

The EC’s (European Community) Renovation Wave sets the objective of fostering deep energy renovations [4]. Deep Renovation represents a term that defines the process of renovation with a focus on the building shell of existing buildings that will result in achieving of high energy performance standards. The deep renovation should also deliver an optimal level of indoor environmental quality to the building occupants [4].

The approach to renovating existing buildings by adding new structures has significant functional advantages that set it apart as one of the more significant methods to the complex renovation of buildings. This refers to the possibility of adding missing functional elements to an existing building, such as elevators, fire escapes, or balconies, which can greatly improve its spatial-functional quality as well as the comfort of its users. The added volumes are enabling functional upgrades and an overall reorganization of a building's spatial structure, with improvements on many levels [5].

The research focuses on determining the approach for achieving deep renovation goals through extensive spatial interventions on building envelope in the Serbian housing stock. The most prevalent multi-family housing stock in Serbian cities was built between 1946 and 1970, with 25% of the total multi-family buildings originating from that period [6]. These buildings have functional and spatial-organizational deficiencies as a consequence of the valid laws and design principles of the time, that defined their initial design. Usually, they are described as structures with small apartments that should accommodate as many people as possible, resulting in inadequate unit dimensions, rigid spatial organization, and small windows. Moreover, these buildings are characterized with high energy consumption for heating. Therefore, this research analyses the application of the methodology of complex and integrated refurbishment by introducing the principle of volumes addition to existing multi-family buildings with the aim to achieve high energy efficiency standards, modernize residential units, and improve vertical building communications. The paper will show the volumetric addition to three typologically different multi-family residential buildings. The study includes a comparative analysis of the energy performances of existing state for three representative buildings of different types and variants for improving the energy performances through volumetric additions. The research aims to review the advantages and limitations of applying volumetric addition strategies for energy improvements in multi-family residential buildings built during the mass construction period.

2. METHODOLOGY

The research is based on several analytical methods. It starts with the analysis of the typology of multi-family housing constructed after World War II, as well as its spatial organization and functional characteristics. For further analysis, three representative buildings of different types are identified, and their spatial organization and functional characteristics are analyzed. The next step includes the evaluation of the energy performances of the selected buildings using the Knaufterm software[3]. Further, the various modalities with special attention to volumetric intervention resulting in energy improvements of the buildings are defined and analyzed. The energy performances of improved state are analyzed using the same energy calculation software. Finally, a comparative analysis of the results is conducted, and the advantages and limitations of applying the volumetric addition strategy to the existing building focused on improving its energy performance are determined.

2.1. Multi-family housing stock built in the period from 1946 to 1970 in Serbia

Of the total stock of multi-family residential buildings in the Republic of Serbia, 24.81% were built in the period from 1946 to 1970 [6]. This period is characterized by intensive housing construction, the dynamic growth of cities, the development of new settlements, and urban open city block typology.

The classification of multi-family buildings based on architectural-urban planning parameters and building characteristics includes the following types:

- A free-standing building, on a separate plot, does not border neighboring buildings on any side,
- A free-standing building consisting of two or more identical units with the separate entrances, in an open city block ("lamella"),
- A building in a row, within a series of different buildings in a closed city block, borders neighboring buildings on one or two sides,
- A high-rise free-standing building with more than 10 storeys, on a separate plot, does not border neighboring buildings on any side [7].

The buildings built in this period have common generative characteristics; the architectural form of the buildings was compact and geometrically regular, the facade was simple without decorative elements, and the windows were rather small. The buildings were built in a traditional way, in a massive construction system, with brick as the dominant material. Similarities are also noticeable in the spatial organization regardless the type of the building: central position of the entrance to the building, the position of the staircase, the absence of an elevator, and the interior and exterior finishes. Flats were characterized with rather small kitchens often encompassing a dining space so there is no separate dining room. Such similarities between the types derive primarily from the post-war housing

[3] Knaufterm is the commercial software that is the most used calculation tool for calculating energy performance and determining the energy class of a building in Serbia.

policy, which aimed to provide the minimum housing space in the shortest possible time for a large number of people using known constructive systems and traditional building techniques [6]. Rational solutions, common to all buildings, are the result of regulations for residential construction that aimed to define the minimum dimensional and technical standards. The regulation regarding thermal protection emerged only in the late 1960s [8]. Buildings from this period do not have an adequate solution for thermal conductivity from today's perspective of thermal requirements. However, the simple, cubic forms and good quality of structural elements and applied materials of the building envelope make them extremely suitable for energy renovation because significant improvements can be achieved with relatively simple measures [7].

2.2. Various aspects of refurbishment of a building using the strategy for volumetric addition

The sustainable renovation goal is to improve living conditions in existing multi-family residential buildings and achieve high energy efficiency standards. Various parameters affect the heating energy calculation: the materialization and quality of building envelope, the ratio of the volume of a building to the area of the building envelope (shape factor), the total usable heated area and the “exposure” of the building [9]. In common practice improvement measures are based on bettering the conductivity characteristics of building envelope through addition of insulation layers and windows replacement, a process which can have several qualitative levels [10]. Focus of this research investigates more complex approach based on the application of volumetric additions to the volume of a building. This method, apart from changing the thermal characteristics of envelope changes the shape factor and increases its useful living space enabling the redefinition of the existing apartments of minimal dimensions and outdated and rigid spatial organization [11]. The functional characteristics of the building, such as inadequate vertical communications, can also be improved by applying volumetric additions. A vertical volumetric addition on the roof of a building increases its useful living space (Fig. 1) which can be commercialized presenting an economic base for overall intervention. An increase in the number of floors of a building is possible only if the preliminary loadbearing analysis shows that a building is suitable for such an intervention.

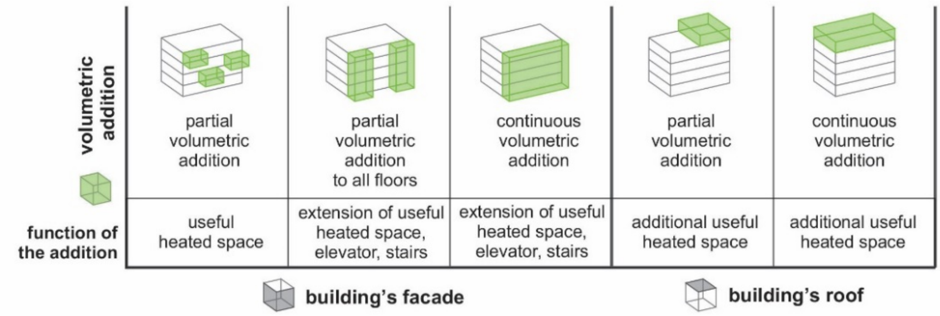


Figure 1. Variants of volumetric addition to an existing building, Image by authors

2.2. Strategy of volume addition to different types of multi-family housing buildings

The strategy for adding volumetric extensions to facades and on a roof of an existing building in a complex and integrated renovation depends firstly on urban conditions, heritage protection regime than building type, structural strength (of all described building types), and the lot size and accessibility.

As *free-standing buildings* were built in an open city block, there is sufficient surrounding space that is necessary for this renovation approach. *Free-standing buildings consisting of two or more identical units (lamella)*, can be addressed in the same way apart from dilatation spaces and walls between them. On such buildings, there is a possibility of volumetric addition to the side facades of its end units. In the case of *buildings in a row in a closed city block*, two main facades are suitable for this kind of intervention, but in general, as these buildings were built on the regulation line, extension on the street facade is only partially allowed. Interventions resulting in the increase of the volume of such a building are more applicable on the courtyard façade. Depending on the structural strength of such a building, an extension on the roof is also possible (Fig. 2). High-rise, free-standing buildings with more than 10 storeys were not taken into consideration because their percentage share in the total multi-family housing stock in Serbia is very small.

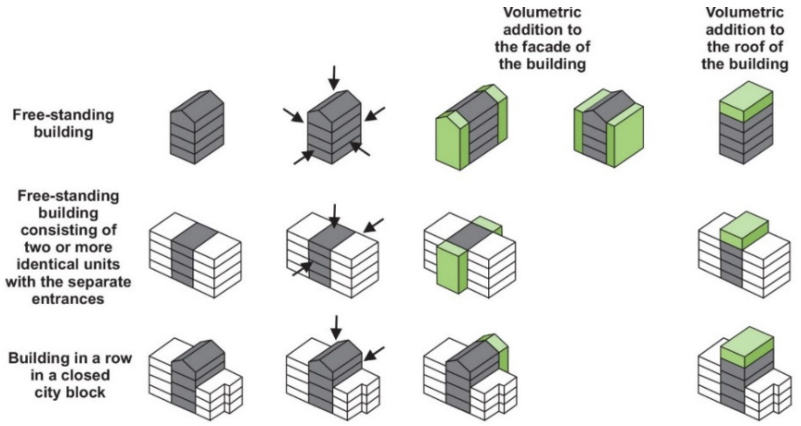


Figure 2. Variants of volumetric addition to an existing building, Image by authors

2.3. Spatial-organizational and functional aspects of the selected multi-family residential buildings

The selected buildings for the research were built in the same period in Belgrade, in a traditional way, in a massive construction system, with brick as the dominant material.

They share common characteristics in spatial-organizational and functional aspects (Fig. 3). The buildings have a basement and five or six original storeys. The basement of the buildings is used as storage space, and all other floors are for residential purposes. On all the floors, the apartments are grouped around a centrally located staircase. None of the selected buildings have elevators. All types of apartments contain an entrance hallway, a bathroom, a kitchen, a living room, and one or two bedrooms depending of usable area of the apartment.

The spatial organization of the apartments is similar in all three selected types of multi-family residential buildings. The units are designed with minimal dimensions, which was characteristic of residential buildings built in that period.

In the representative free-standing building, the spatial arrangement of four apartments, two smaller with a usable area of 50m2, and two bigger with a usable area of 56m2, is repeated on all the floors. The only difference is that larger apartments also have a separate dining area. The building does not have any balconies or loggias.

In the selected lamella building typical structural part is consisting of three units with separate entrances, on all the floors. The spatial arrangement of four apartments with a usable area of 51m2, and two apartments with a usable area of 72m2 is repeated. The apartments are grouped around three centrally located staircases. There are six apartments on each floor. The only difference is that larger apartments have two bedrooms. According to the original documentation, all apartments on the upper floors had loggias. However, in order to expand the usable heated space, many tenants closed the loggias.

In the selected building in a row in a closed city block, the spatial arrangement of two identical apartments with a usable area of 72m2 is repeated on all the floors.

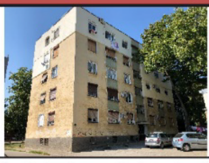
Type of the building	Free-standing building	Free-standing building consisting of two or more identical units with the separate entrances	Building in a row in a closed city block
Existing state of the building			
Location	Bežanijska kosa, Belgrade, Serbia	Profesorska kolonija, Belgrade, Serbia	Dorćol, Stari grad, Belgrade, Serbia
Construction year	1961	1950	1965
Number of floors	Basement + Ground floor + 4 floors	Basement + Ground floor + 5 floors	Basement + Ground floor + 5 floors
Purpose of floors	Basement – Storage Ground floor – Apartments Upper floors – Apartments	Basement – Storage Ground floor – Apartments Upper floors – Apartments	Basement – Storage Ground floor – Apartments Upper floors – Apartments
Number of apartments	20 (4 apartments on one floor)	36 (6 apartments on one floor)	12 (2 apartments on one floor)
Usable area of apartments	10 apartments with an area of 50 m2; 10 apartments with an area of 56 m2;	24 apartments with an area of 50 m2; 12 apartments with an area of 75 m2;	12 apartments with an area of 72 m2
Communi-cation	1 entrance and 1 stairwell, no elevator	3 entrances and 3 stairwells, no elevator	1 entrance and 1 stairwell, no elevator
Total heated area	Appartments 1091,70 m2	Appartments 2106,75 m2	Appartments 863,14 m2
Uneated area	Basement, stairwell	Basement, stairwells	Basement, stairwell
Heating system	Electric energy	Central district heating system	Central district heating system

Figure 3. Spatial-organizational and functional characteristics of the selected multi-family residential buildings, Image by authors

2.4. Energy aspect of the selected existing buildings

In all three buildings, the heated area includes the apartments on all floors, while the stairwell and basement are not heated. Calculation of heat transfer coefficients for the entire building envelope of the buildings, indicates significantly higher values than in energy efficient buildings (as required by the sub-law documents) (Fig. 4).

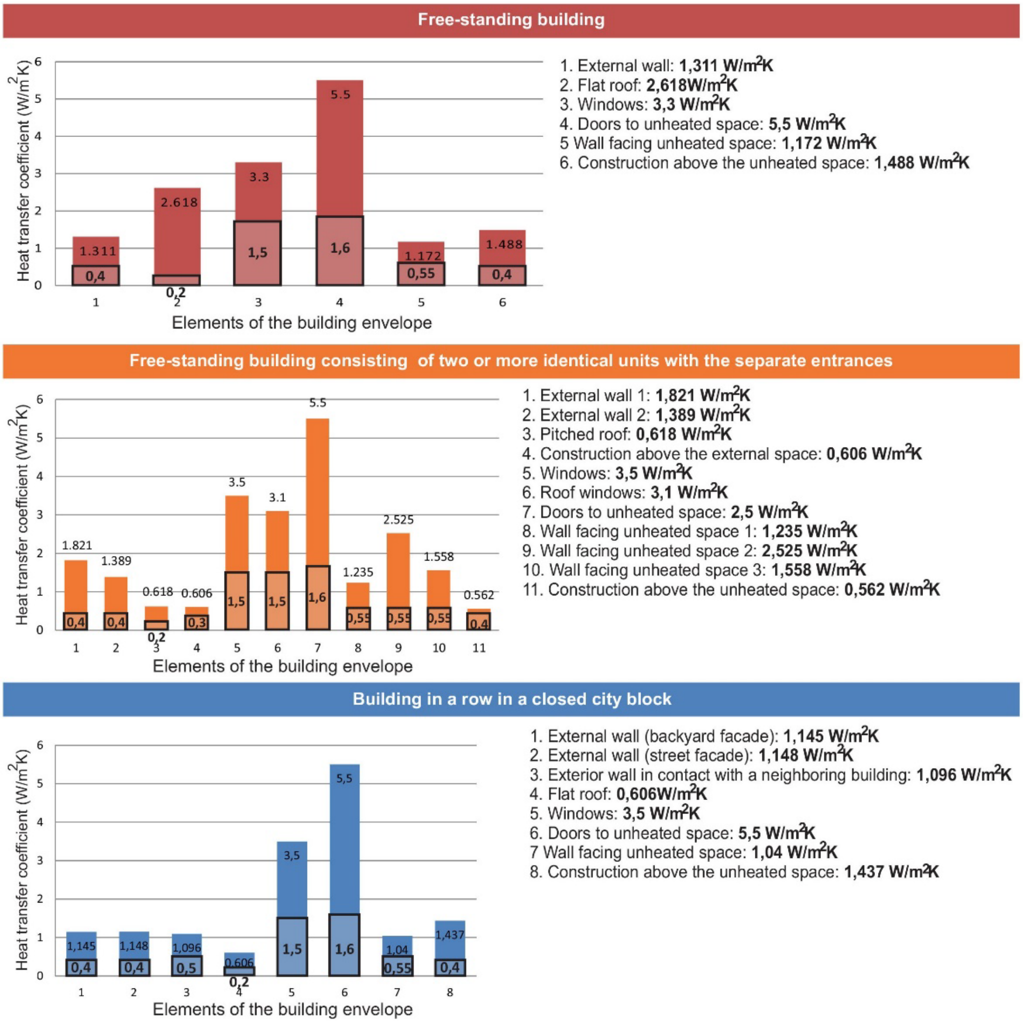


Figure 4. Comparative analysis - Heat transfer coefficients for elements of the building envelope and the highest permitted values of the heat transfer coefficient for elements of the building envelope of an existing building according to the Rulebook on Energy Efficiency [9]., Image by authors

Based on the calculation, the selected buildings have very high transmission losses and specific annual energy requirements for heating, so they belong to the lowest energy classes on the scale of energy efficiency classes for residential buildings (Fig. 5). It can be concluded that it would be extremely desirable to carry out energy efficiency renovations of the buildings to reduce the total energy for heating and, therefore, improve the energy efficiency classes.

	Free-standing building	Free-standing building consisting of two or more identical units with the separate entrances	Building in a row in a closed city block
Transmission losses	174191,31 kWh	345003,61 kWh	107674,22 kWh
Specific annual energy required for heating	163,85 kWh/m^2	193,75 kWh/m^2	135,63 kWh/m^2
Emission of CO_2	237013,16 kg	89802,05 kg	50223,32 kg
Energy class	F	G	E

Figure 5. Heat losses of the selected existing buildings, Image by authors

2.5. Energy efficiency/spatial/functional retrofit of the existing building with volumetric additions

The research represents the complex and integral refurbishment of the existing buildings by refurbishment of all elements of the building envelope according to the sub-law defined standards and by proposing volumetric additions to improve the spatial-organizational, functional, and energy performances of the buildings.

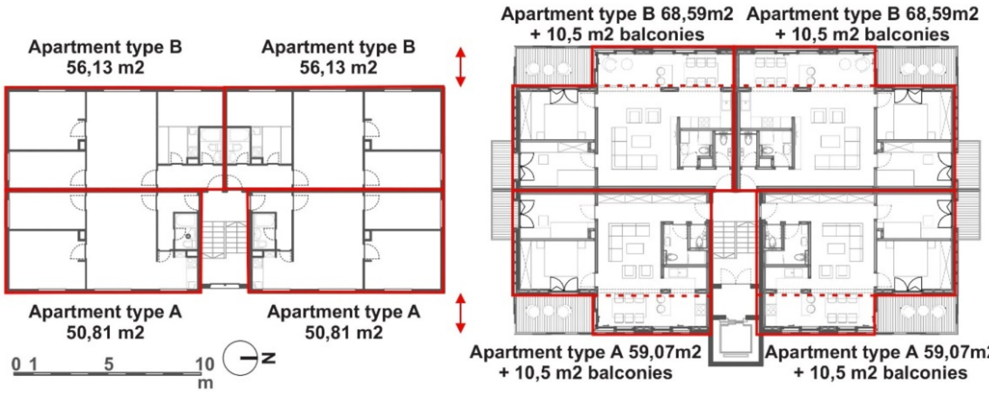


Figure 6. Spatial organization of apartments in the existing state of the selected free-standing building (left) and spatial organization of apartments through energy efficiency/spatial/functional retrofit of the existing building with volumetric additions (right), Image by authors

For the free-standing building, the conceptual solution proposes volumetric additions on both longitudinal facades, which would increase the usable living space of residential units, and the addition of loggias on the longitudinal facades and balconies on the side facades. The solution also proposes the addition of an elevator (Fig. 6). The conceptual solution proposes a continuous volumetric addition on the roof of the building. The spatial organization of the upgraded floor would be the same as the typical floor.

For the lamella building the conceptual solution proposes volumetric additions on both longitudinal facades, which would increase the usable living space of residential units, and the addition of loggias on the longitudinal facades. The solution also proposes the addition of elevators (Fig. 7). The conceptual solution proposes a continuous volumetric addition on the roof of the building. The spatial organization of the upgraded floor would be the same as the typical floor.

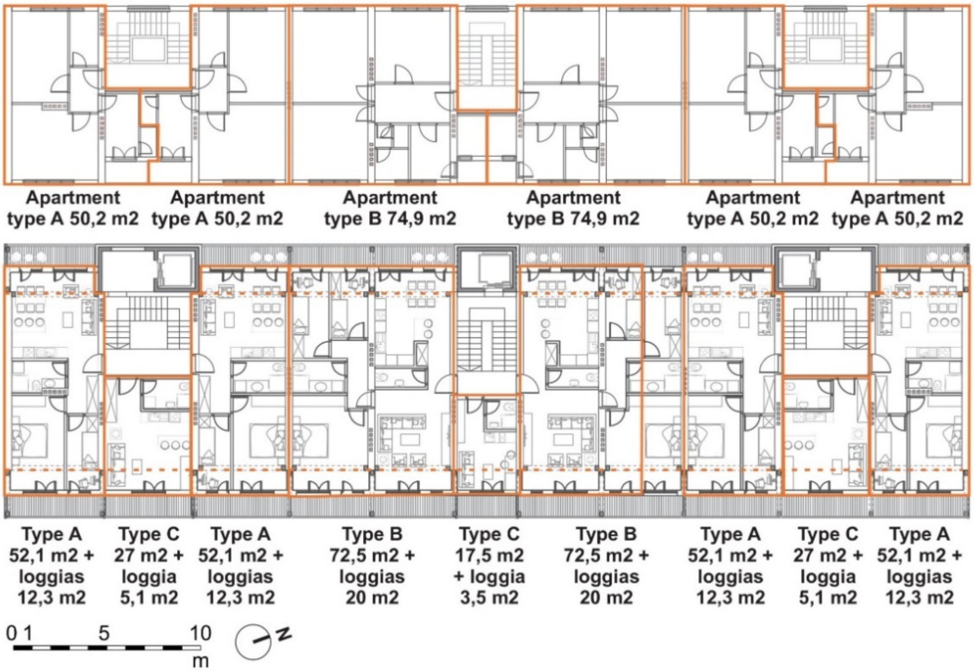


Figure 7. Spatial organization of apartments in the existing state of the selected lamella (above) and spatial organization of apartments through energy efficiency/spatial/functional retrofit of the existing building with volumetric additions (below), Image by authors

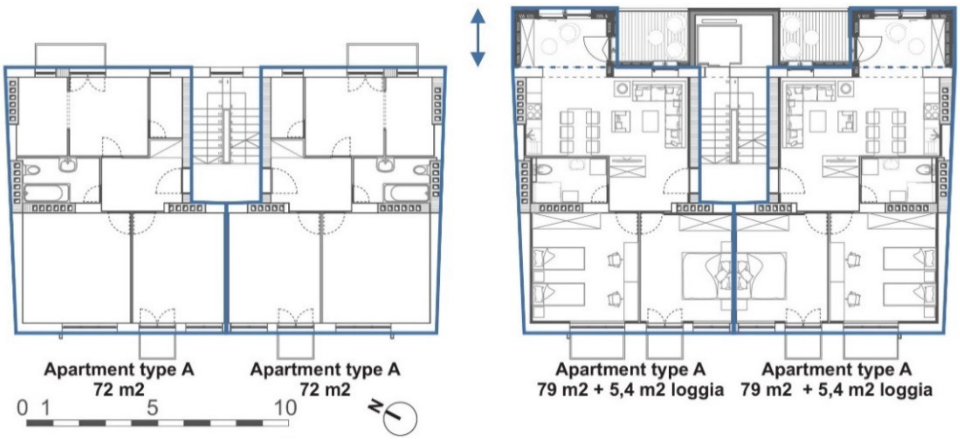


Figure 8. Spatial organization of apartments in the existing state of the selected building in a row in a closed city block (left) and spatial organization of apartments through energy efficiency/spatial/functional retrofit of the existing building with volumetric additions (below), Image by authors

The representative multi-family residential building in a row in a closed city block belongs to the spatial, cultural, and historical complex "Area around Dositej's Lyceum," which has been declared a cultural heritage of exceptional importance. Due to its protected status, interventions on the street facade and roof of this building are not allowed in order to preserve the appearance of the surrounding architectural ensemble. Additionally, this building is situated on a regulation line, making it impossible to add additional volumes. Interventions are only permitted on the courtyard facade of this building. The conceptual solution proposes volumetric additions on the courtyard facade, which would increase the usable living space of residential units, and the addition of loggias. The solution proposes the addition of an elevator (Fig. 8).

3. RESULTS

Based on the interventions significant results were achieved in spatial-organizational, functional, and energy-efficient performances in all three selected buildings (Fig. 9).

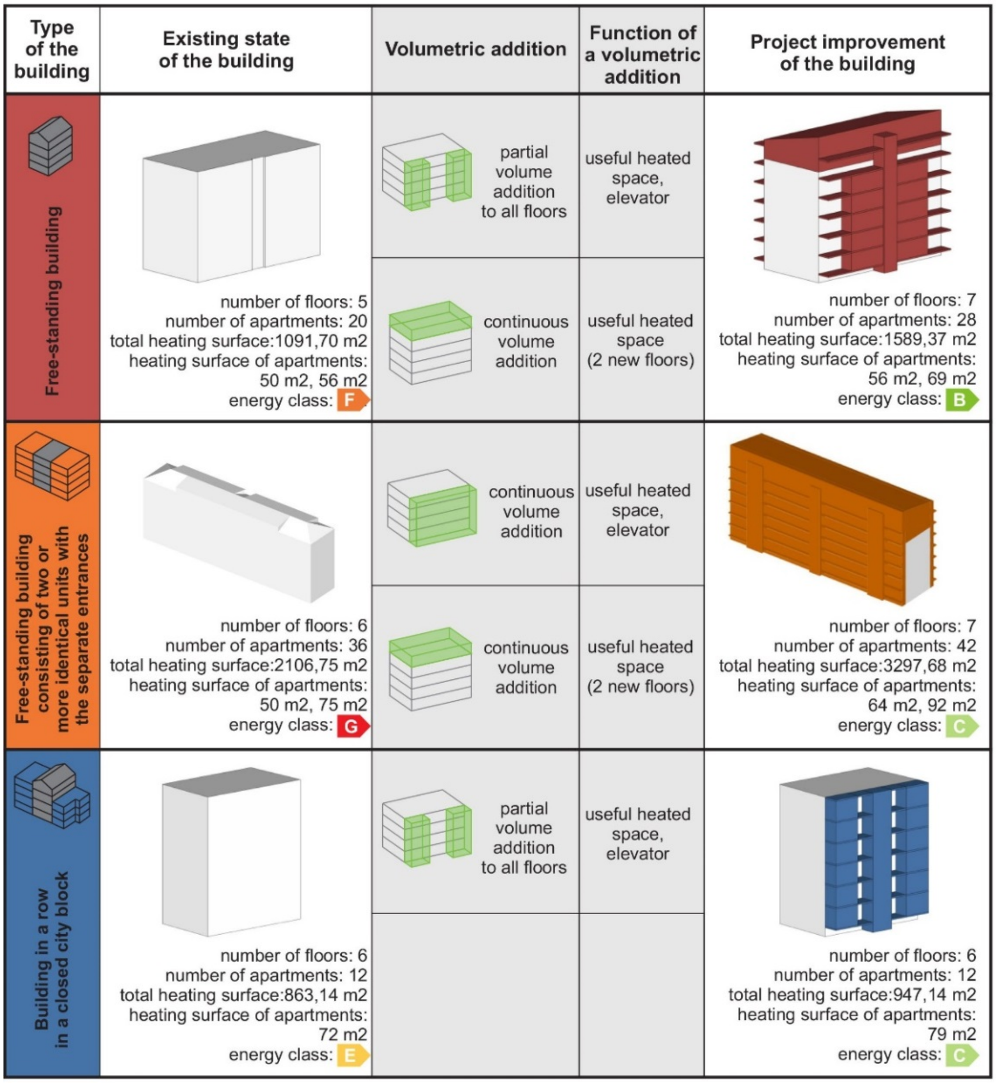


Figure 9. A comparative analysis of the existing states and the complex and integrated improvements in the selected existing multi-family residential buildings, Image by authors

4. DISCUSSION

Deep refurbishment methodology that included improvement of all elements of building envelope combined with volumetric interventions on the buildings has resulted in significant improvement of the performance of the analyzed buildings. Spatial redefinition of the units has given, at the same time, new quality to the process bringing rather outdated structures to the contemporary standards and user demands. Comparing the achieved energy levels, it is noticeable that all buildings fulfill the standards for new structures and even exceed them. As a consequence of the process significant reduction of carbon dioxide emission has been achieved (Fig. 10).

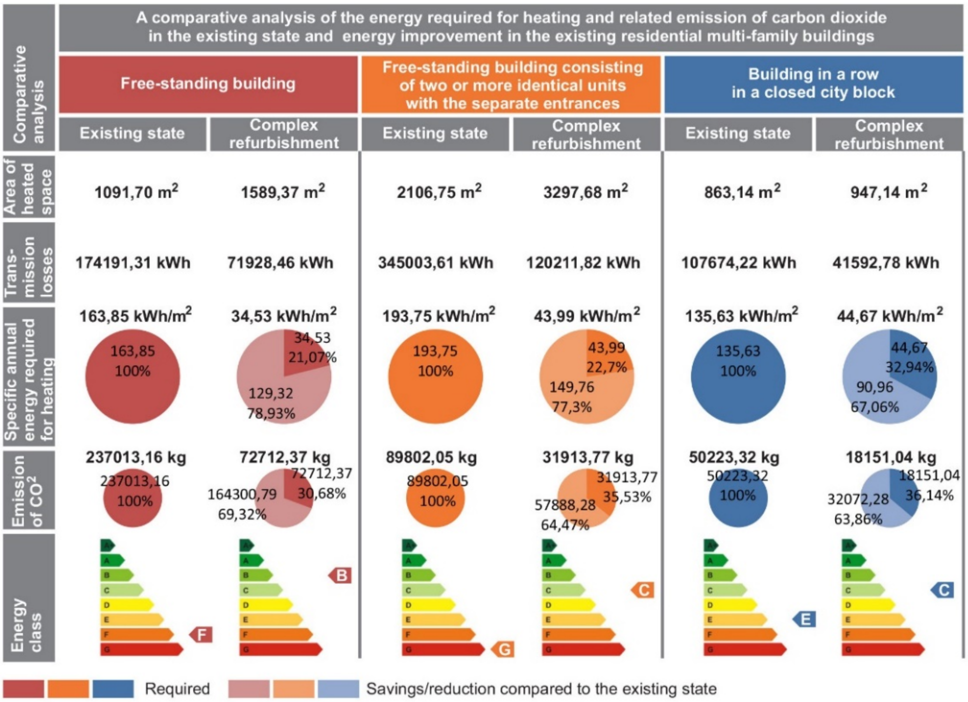


Figure 10. A comparative analysis of the energy required for heating and related emissions of carbon dioxide in the existing states and the energy improvements in the selected existing residential multi-family buildings, Image by authors

It is noticeable that the energy class of the freestanding building increased by 4 energy classes, from F to B. The same case applies to the freestanding building with three separate entrances, where the energy class transitioned from the lowest, G, to C. The reason for such significant shifts in the energy rating is due to the addition of volume to the façade walls and the entire roof surface. The usable heated space has significantly increased, along with the building's volume, and the overall building envelope has been improved.

In the case of a row building within an urban block, the energy class increased by 2 energy classes, from E to C, having smaller effect compared to the previous two cases. The reason for such a change in the energy rating is due to a smaller range of volumetric additions. Volumetric addition was applied only to one façade, while the other façade and the roof were not included.

5. CONCLUSION

The benefits that could be achieved by applying the strategy of volumetric redefinition of an existing building by addition of volumes are multiple. They are ranging from simple improvement of energy efficiency class to the redefinition of living spaces and bettering of overall performance of the building prolonging its lifespan and increasing the value. Considering that it is a very complex type of renovation that requires interventions on the entire building envelope, it can be concluded that this renovation strategy is most suitable for free-standing buildings as well as lamellas, because these buildings are mostly located in open city blocks and have facades that can be easily approached. This strategy is partially applicable to a row of buildings within a city block due to various limitations (urban, spatial, structural…). Complex and integrated refurbishment that are including the overall approach treating the existing buildings as a starting point for new design (redesign) including improving of energy efficiency but achieving, at the same time, spatial-organizational and functional improvements can be recognized as a valuable method for future practice. Having in mind modern theories of sustainable and resilient development professionals have to address the existing building fund as one of the greatest resources of a humankind and apply methodology that will enable its longevity and usefulness.

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