REFURBISHMENT OF THE EXISTING MULTI-FAMILY HOUSING STOCK FROM THE PERIOD OF POST-WAR MASS CONSTRUCTION: SPATIAL AND ENERGY BENEFITS

DOI: https://doi.org/10.18485/arh_pt.2024.8.ch40

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ABSTRACT

The most represented multi-family housing stock within the cities of Serbia was built in the period from 1946 to 1970. 25% of the total multi-family stock of Serbia consists of buildings built in that period. This multi-family housing stock is at the centre of discussion due to its energy, functional and spatial-organisational obsolescence. Designed with the aim of providing apartments for as many people as possible in the short term, these buildings are characterised by small apartments, outdated and rigid spatial organisation, inadequate dimensioning of spatial units and small window openings on the facades. In addition, these buildings have a high energy consumption for heating. The subject of the research includes the analysis of the application of complex and integrated refurbishment by adding exoskeleton to existing multi-family buildings in order to achieve high energy efficiency of buildings and increase the space of residential units, as well as improve vertical communications of buildings. The exoskeleton represents a spatial structure that is added to the existing building with the aim of spatial-functional and energy improvement. The paper will present various possibilities for the position of the exoskeleton on the envelope of the existing building, based on which it can be determined which spatial-organisational and functional characteristics of the existing building are being improved. Based on the predetermined typology of residential multi-family buildings, a classification of possible positions of the exoskeleton on the envelope of each type of multi-family building will be made. The goal of the research is to review the advantages and limitations of exoskeleton application in different types of multi-family residential buildings and to determine the possibilities of improving the spatial-organisational, functional and energy performance of existing multi-family buildings by applying complex and integrated refurbishment using exoskeleton.

KEYWORDS _ *Multi-family housing stock, refurbishment, exoskeletons, energy efficiency, spatial comfort*

INTRODUCTION

The energy renovation of the existing building stock is becoming a current topic in Europe. The renovation of the existing housing stock is a key factor in the task set by the European Commission for the period up to 2050 because the share of existing buildings is much higher than that of newly designed ones in the total building stock of the European Union. Many renovation strategies are based on energy-saving measures, such as retrofitting existing buildings to improve the building's thermal envelope and implementing efficient heating, ventilation, and air conditioning systems (European Commission, 2020).

Multi-family residential buildings built in the period from 1946 to 1970 make up one-quarter of the total multi-family stock in Serbia (Jovanović et al., 2013). Most of these buildings are characterized by high energy consumption for heating due to the poor thermal performance of the building envelope. Created according to the design regulations valid at that time, according to today's user requirements, they have major spatial and organizational deficiencies, such as small apartments, outdated and inflexible spatial organization, and small windows. The absence of elevators in many multi-family buildings from that period also reduces their comfort of use. The subject of the research includes the application of refurbishment methodology by adding an exoskeleton, as a constructive-functional element, to existing multi-family buildings with the primary goal of achieving high energy efficiency of buildings with remodelling and modernization of residential units, and improving vertical building communications. The paper shows the different uses of the exoskeleton and the positions of the exoskeleton on selected types of multi-family residential buildings in Serbia. The goal of the research is to review the advantages and limitations of exoskeleton application in different types of multi-family residential buildings and to determine the possibilities of improving the spatial-organizational, functional and energy performance of existing multi-family buildings by applying complex and integrated refurbishment using exoskeleton.

STRATEGY OF VOLUMETRIC ADDITION TO AN EXISTING BUILDING

For the refurbishment of buildings, it is important to apply the principle of adaptability. The concept of sustainable buildings requires an adaptive, integrated renovation in order to improve the existing buildings from multiple aspects, simultaneously. One such approach is the strategy for adding a so-called exoskeleton as a spatial-functional prosthesis to the existing building. This method represents a three-dimensional reconstruction of the existing building, which consists of volumetric additions that provide a structural, energy, and functional upgrade. This method can be performed if there is a possibility of extending the facade or upgrading the existing roof (Guidolin, 2018).

The approach to renovating existing buildings by adding new structures has significant functional advantages that set it apart as one of the more significant approaches 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 spatio-functional quality, as well as the comfort of its users. The exoskeleton system enables functional upgrades and an overall reorganization of a building's spatial structure, with improvements on many levels (Guidolin, 2018).

RESEARCH METHODOLOGY

The research methodology includes several analyses. First, the study examines the types of multi-family housing constructed after World War II, as well as their spatial organization and functional characteristics. Then, an existing multi-family free-standing building is chosen for the research, and its spatial organization and functional characteristics are analyzed. The energy performance of the selected building is evaluated using the Knaufterm software[1]. Next, the energy improvement

[1] 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.

achieved by applying the volumetric addition is analyzed. Finally, the advantages and limitations of applying the volumetric addition strategy to the existing building to improve its energy performance are determined.

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 (Jovanović et al., 2013). This period is characterized by intensive housing construction, the dynamic growth of cities, the development of new settlements, and block construction.

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

- A 5-storey free-standing building, on a separate plot, does not border neighboring buildings on any side,
- A 5-storey free-standing building consisting of two or more identical units with the separate entrances, in an open city block,
- A 5-storey 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 (Jovanović et al., 2013).

The buildings built in this period have common characteristics; the architectural form of the buildings was compact and geometrically regular, the facade was simple, and the windows were 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: the kitchen includes a dining space, and there is no separate dining room. The central position of the entrance to the building, the position of the staircase, the absence of an elevator, and the interior and exterior finishes are also consistent in these types of buildings and represent their common characteristics. Such similarities between the types, which do not exist in any other period, derive primarily from the post-war housing 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 (Jovanović et al., 2013). 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 (Official Gazette of SFRJ 45/67, 1967). 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 relatively simple materialization of the building envelope make them extremely suitable for energy renovation because significant improvements can be achieved with relatively simple measures (Jovanović et al., 2013).

VARIOUS ASPECTS OF THE COMPLEX AND INTEGRATED 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. Various parameters affect the heating energy calculation: the building envelope, the ratio of the volume of a building to the area of the building envelope, the total usable heated area, and a building's compactness (Ministry of Environmental Protection, Government of the Republic of Serbia, 2011). Volumetric additions to the facades of a building would increase the total usable surface of a building and its volume. As the area of the building envelope would increase by a smaller percentage in relation to the increase in volume, that would increase the possibility of achieving greater energy savings.

As the application of volumetric additions to the facades of a building increases its useful living space, apartments of minimal dimensions and outdated and rigid spatial organization, typical for the post-war multi-family housing stock, could be improved. A volumetric addition to an open space enables the creation of balconies and loggias that do not exist on these buildings. The functional characteristics of the building, such as vertical communications, can be improved by applying volumetric additions. A volumetric addition on the roof of a building increases its useful living space (Fig. 1). An increase in the number of storeys of a building is possible if the static calculations show that a building is suitable for such an intervention.

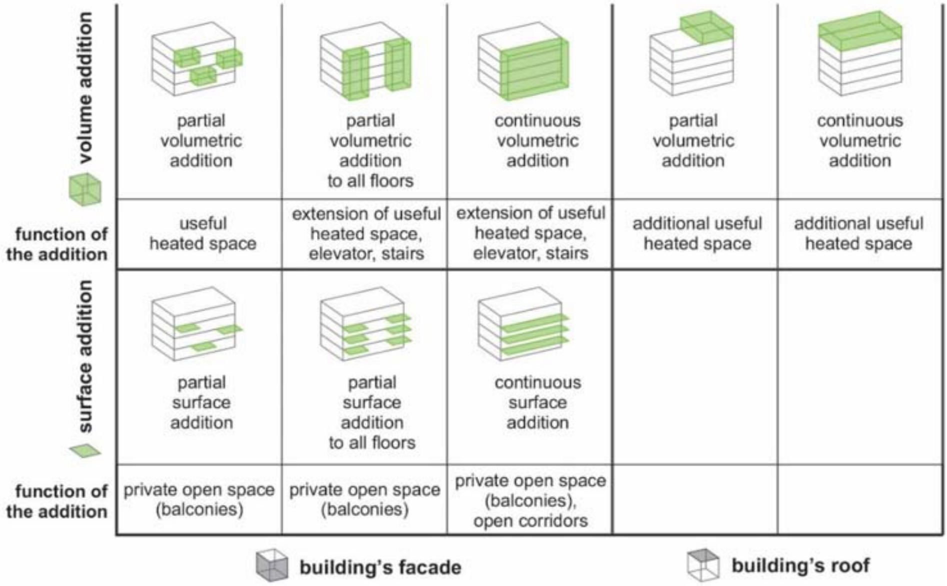

Figure 1: Variants of volumetric addition to an existing building (Image by authors)

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 on a building type, structural strength (of all described building types), and the construction site 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. Regarding *free-standing buildings consisting of two or more identical units*, it is not possible to apply this strategy to dilatation spaces and walls between them. On such buildings, there is a possibility of volumetric addition to the side facades of its end units. As these buildings were also built in an open city block, there is free space around them. In the case of *buildings in a row in a closed city block*, two facades are free, but in general, as these buildings were built on the regulation line, extension on the street facade is not allowed. Interventions to increase the volume of such a building are possible on the courtyard façade. Depending on the structural strength of such a building, an extension on the roof is 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 small.

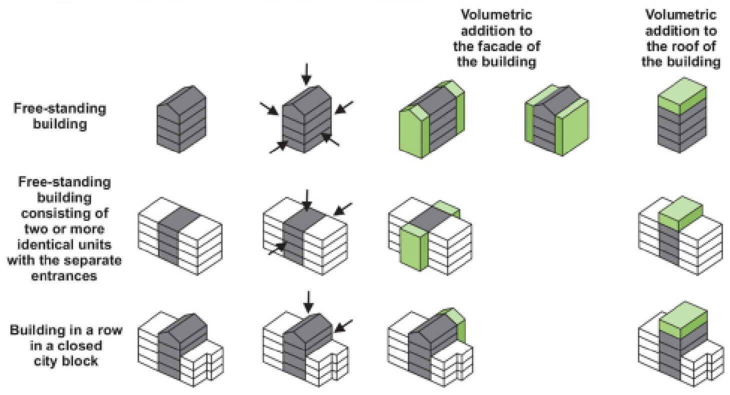

Figure 2: Possible directions of volumetric addition according to types of multi-family residential buildings (Image by authors)

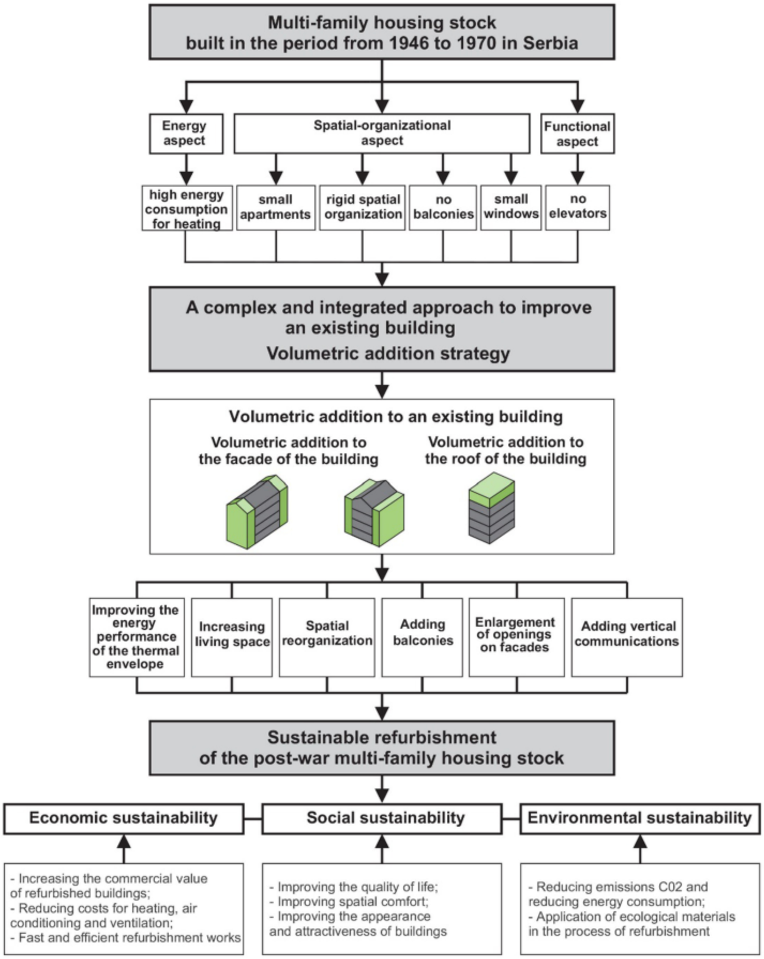

Figure 3: The research methodology (Image by authors)

THE SELECTED MULTI-FAMILY RESIDENTIAL FREE-STANDING BUILDING

The selected free-standing multi-family residential building is located in New Belgrade and was built in 1961. Within an open city block, 16 identical residential buildings were built, each with 20 apartments. By multiplying one typical building in the city block, a total of 320 apartments were obtained (Fig. 4).

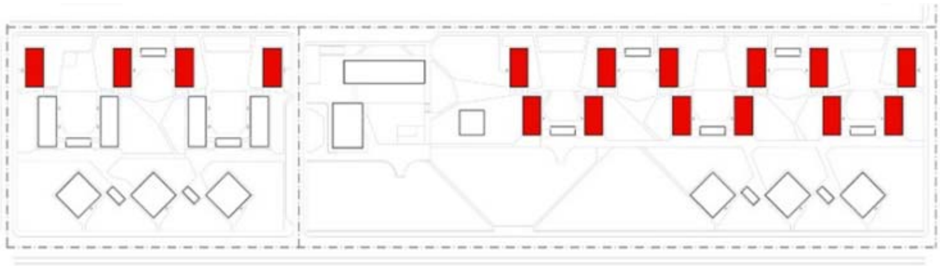

Figure 4: Grouping of 16 identical multi-family residential buildings (Image by authors)

The multi-family residential building form is a rectangular prism. The building has a basement and five original storeys. The basement of the building is used as storage space, and all other floors are for residential purposes.

On all the floors, the spatial arrangement of four apartments, two smaller with a usable area of 50,81 m2, and two bigger with a usable area of 56,13 m2, is repeated. The apartments are grouped around a centrally located staircase. Both types of apartments contain an entrance hallway, a bathroom, a kitchen, a living room, and two bedrooms. The only difference is that larger apartments also have a separate dining area. The building does not have balconies or loggias. (Fig. 5).

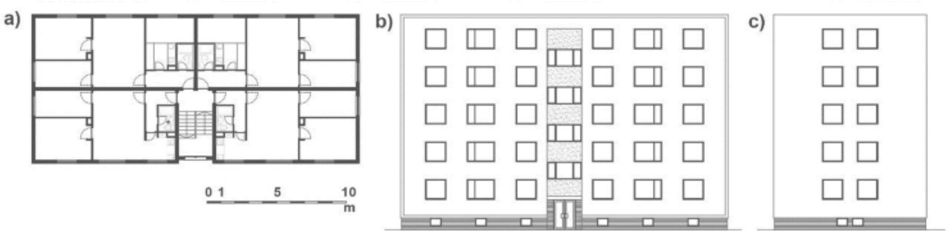

Figure 5: a) Typical floor plan; b) side façade; c) longitudinal facade of the selected multifamily housing building

The heated area includes the apartments on all floors, while the stairwell and basement are not heated. The heating system is based on electric energy. None of the positions of the building envelope meet the criteria from the Regulation on Energy Efficiency of Buildings for maximum values of the heat transfer coefficient. Based on this important finding, the selected building is a good example for research on the building's envelope to achieve better energy results. It is noticeable that some tenants have independently implemented certain energy improvements, but the study will consider the original condition of the existing building without subsequent interventions.

Based on the KnaufTerm calculation, the building belongs to the F energy efficiency class, which is one of the lowest on the scale of energy efficiency classes for residential buildings. It can be concluded that it would be extremely desirable to carry out energy efficiency renovation to reduce the total energy for heating and, therefore, improve the energy efficiency class.

ENERGY EFFICIENCY/SPATIAL/FUNCTIONAL RETROFIT OF THE EXISTING BUILDING WITH VOLUMETRIC ADDITIONS

The research represents the complex and integral refurbishment of the existing building by proposing volumetric additions on longitudinal facades, which would increase the usable living space of residential units; the addition of loggias, from a spatial and organizational aspect; and the addition of an elevator, from a functional point of view (Fig. 6).

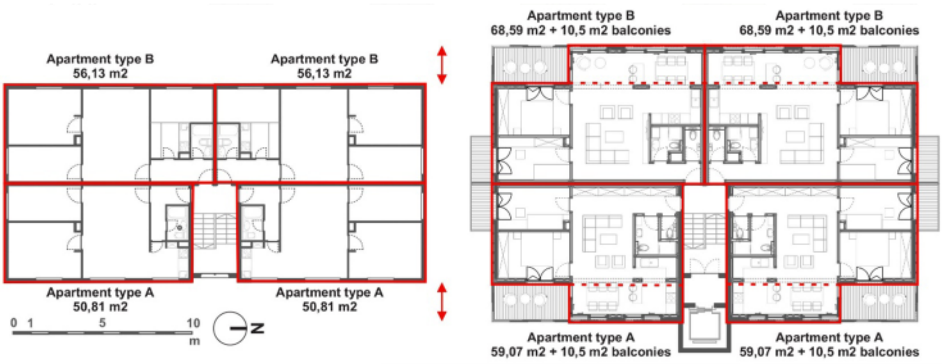

Figure 6: Spatial organization of apartments in the existing state of the building (left) and spatial organization of apartments through energy efficiency/spatial/functional retrofit of the existing building with volumetric additions (right) (Image by authors)

The solution envisages adding an elevator to the building to enable and facilitate vertical communication for its users and to make the building accessible to people with disabilities, the elderly, and families with small children. This intervention directly increases the users' comfort and the market value of the building. The solution also envisages increasing the useful living space of all residential units by adding volumes to the longitudinal facades, thus enabling the extension of the apartments on both sides. By increasing the useful space, a better organization of all housing units, greater comfort, and the possibility of reorganizing rooms in each housing unit would be possible (Fig. 6).

The conceptual solution proposes the continuous volumetric addition on the roof of the building. The spatial organization of the upgraded floor would be the same as the typical floor.

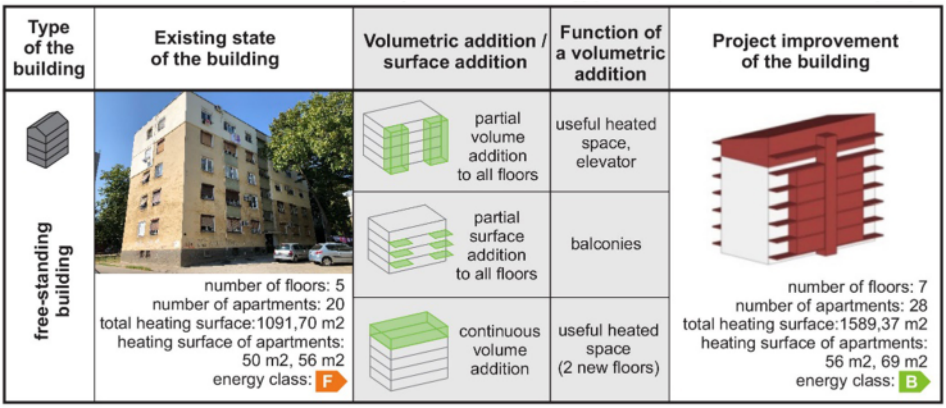

Figure 7: A comparative analysis of the energy efficiency/spatial/functional aspects of the existing state and a complex and integral refurbishment of the existing residential multi-family building (Image by authors)

Based on the interventions in all positions of the building envelope and by adding new positions in the building envelope, significant results were achieved in terms of reducing heat losses and the energy required for heating. Based on the KnaufTerm calculation, this variant of improvement of the building belongs to the B energy efficiency class.

CONCLUSIONS

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 suitable for free-standing buildings as well as free-standing buildings consisting of two or more identical units because these buildings are mostly placed in open city blocks and have facades that can be easily approached. This strategy is not easily applicable to a row of buildings within a city block due to space limitations, walls next to neighboring buildings, street facades that are placed on the regulation line, and courtyard facades that are inaccessible in closed city blocks. Further research and static calculations of the stability of the existing buildings are needed to verify whether this kind of intervention is feasible. This strategy represents a hypothetical intervention that raises numerous questions of feasibility in practice. The problems accompanying complex and integrated refurbishment would be the duration of the works and the accommodation of tenants in the meantime, the issue of ownership relations, and the consent of the housing community for such works to be carried out. Complex and integrated refurbishment that includes energy efficiency improvement and spatial expansion with the improvement of functions can be recognized as an adaptable method for future uses from the perspective of the resistance and adaptability of the already built context. On an urban scale, this method of retrofit can be introduced as a strategic approach for improving the energy efficiency of existing buildings.

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