IOP Conference Series: Earth and Environmental Science

**PAPER** • **OPEN ACCESS**

# Strategy of integrated refurbishment of post-war housing stock in Serbia using exoskeletons

To cite this article: B Levic and Lj Djukanovic 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1123** 012022

# Strategy of integrated refurbishment of post-war housing stock in Serbia using exoskeletons

**B Levic[1] and Lj Djukanovic[2]**

[1] Teaching Assistant at Faculty of Architecture, University of Belgrade, Belgrade, Serbia,
[2] Associate Professor at Faculty of Architecture, University of Belgrade, Belgrade, Serbia,

bojana.levic@arh.bg.ac.rs

**Abstract**. The functional and architectural obsolescence of the post-war multi-family housing stock, and high energy consumption of the buildings, are characteristics that require complex and integrated renovation. The research problem is the high energy consumption for heating the existing multi-family residential buildings built in the period 1946-1970. Those buildings are one quarter of the total multifamily housing stock of Serbia. The approach of renovating existing buildings by adding exoskeletons has its functional advantages that set it apart as one of the more significant approaches to complex building renovation. The subject of the research includes the analysis of the application of the exoskeleton addition strategy to existing multi-family buildings in order to achieve high energy efficiency of buildings and increase the space of residential units, and improve vertical communications of buildings. The aim of the research is to examine the advantages of the approach to integrated improvement of existing building by applying the strategy of exoskeleton addition, which includes energy, spatial and functional improvement of the existing building. The paper will define the methodological procedure of exoskeleton application from the initial idea, identification of the research problem, strategy of its application, to the results that can be achieved by such a procedure.

## 1. Introduction – Motive for the research

The current targets presented in the Energy Efficiency Directive (DIRECTIVE (EU) 2018/844) and the Energy Performance of Buildings Directive (EPBD) relate to the long-term building stock renewal strategies in Europe. The directives envisage that the long-term strategy of renewal of the existing building fund will achieve a highly energy efficient (energy class A and B) and decarbonized (reduction of gas emissions by 80-95% compared to 1990) building fund by 2050, enabling economical transformation of existing buildings with the aim of achieving zero energy consumption for heating. One of the guidelines of the European Green Agreement refers to the renewal of the existing building fund in order to reduce energy consumption. Considering that according to Eurostat statistics from 2015, energy consumption is the main source of greenhouse gas emissions, and energy consumption in the construction sector accounts for about 40% of total energy consumption in the European Union [1]. In addition to the use of energy in existing buildings, the construction of new buildings also has a large share in energy consumption, which influenced the formation of A Renovation wave for Europe Strategy, which emphasizes that sustainable architecture should take into account design and renovation. Using methods and materials that will not endanger the environment and the health and well-being of the building's occupants, construction workers, the general public and future generations, and that the built environment is very important for sustainability [2]. Given the importance of existing buildings, sustainable renovation has the task of achieving sustainable development goals by addressing environmental, social and economic aspects. Renovation of the existing housing stock is a key factor in the task set by the European Commission for the period until 2050, because the share of existing buildings is much higher than the newly designed ones in the total building fund of the European Union. The current rate of energy renovation of existing buildings in Europe is only 1-2% per year, which is very low [3][4]. The European construction sector is still not able to devise large-scale structural reconstruction processes and a systematic approach to the energy renovation of the existing housing stock [5]. Many renovation strategies are based on energy saving measures, such as renovations of existing buildings in order to improve the thermal envelope of the building and the implementation of efficient heating, ventilation and air conditioning systems. However, these measures currently apply to only 1% of European buildings per year. The current renovation rate of 1-2% will take almost an entire century to decarbonise the entire building stock[3][4]. Moreover, it is estimated that 90% of today's buildings will continue to exist in 2050, and 75% of them have unsatisfactory energy performance. Improving the intervention rate by up to 3% per year, which means the need to promote renovation actions, will increase the quality of the building stock, especially in terms of energy neutrality and high efficiency [2].

## 2. Identification of research problems

The multi-family housing stock of the post-war years was chosen for the research, which is today at the centre of the discussion about its functionality, security and typological obsolescence. Across Europe, much of the existing multi-family housing stock is no longer acceptable for energy, structural, architectural and functional reasons [6]. It can be concluded that this is the situation in Serbia as well, and that the post-war housing stock is in a very bad condition from all the above aspects, and its share is one quarter in the total multifamily housing stock in Serbia [7]. Spatial and temporal determination of types of residential buildings for complex and integrated renovation stemmed from the percentage of buildings in the entire housing stock of Serbia, their existing energy and functional performance and the possibilities of energy rehabilitation and reconstruction. The time determination of the types of residential buildings is defined on the basis of relevant data on the application of insulating materials in the thermal envelope of buildings. For the research work, it was important to choose the construction period in which there were no regulations in the field of energy efficiency, nor were insulation materials used in the thermal envelope of buildings. Also, it is important to choose the housing stock where it is possible to make the greatest energy savings by interventions on the thermal envelope of existing buildings, and this is most feasible to report on those examples of residential buildings where thermal insulation materials are not applied, so they can be implemented in interventions. At the end of the 1960s, the first regulations in this area appeared. Therefore, the construction period of 1946-1970 represents a suitable period for the selection of residential building stock.

Another criterion for timing the types of residential buildings is the percentage of the representation of buildings in the total housing stock of Serbia. In the entire multifamily housing stock of Serbia until 2012, multifamily residential buildings built in the period from 1946-1970 years make up 25.1% of the total [7]. Considering that the application of the first regulations in the field of thermal protection began after 1970, the period from 1946 to 1970 represents a good time determinant for the selection of residential buildings for research work, and also includes a significant share in the housing stock of Serbia. Therefore, the period of construction of residential buildings from 1946 to 1970 was chosen for the time determination of the types of residential buildings for research work.

The problem that the research will deal with is the high energy consumption for heating the existing residential multi-family buildings built in the period from 1946 to 1970, due to the poor energy characteristics of the thermal envelope of those buildings.

Designed with the aim of providing apartments for as many people as possible in the short term, these buildings are the result of extreme rationalization and simplification of pre-war experiences in housing construction in Serbia [7]. Uncomfortable and small apartments with outdated and rigid spatial organization, lack of spatial flexibility, inadequately dimensioned spatial units, no terraces, with small window openings on the facades, no elevators and with dilapidated materials of thermal envelope and uniform facades - multi-family buildings are relevant for researching the possibilities of complex and integrated refurbishment.

## 3. Exoskeleton addition strategy

The challenge for renovating existing buildings is to identify an appropriate strategy to improve the performance of the building. In order to improve the existing buildings not only from the energy, structural and architectural point of view, but also from the functional and social aspect, the research will apply a complex integrated renovation using exoskeletons. This method represents a three-dimensional reconstruction of an existing building, consisting of volumetric additions, which provide structural, energetic and functional upgrades.

This method can be reported if there is a possibility of expanding the facade or upgrading to the existing roof. The approach of renovating existing buildings by adding new structures has its significant functional advantages that set it apart as one of the more significant approaches to complex building renovations. This primarily refers to the possibility of adding certain functional elements to the existing building that it lacked, such as elevators, fire escapes or terraces, which can greatly improve the spatial and functional quality of the building, as well as improve the comfort of building users. Spatial-functional upgrades are achieved by adding vertical and horizontal communication spaces (stairs and elevators, additional exits or stairs for evacuation), additional apartments on the roof, private spaces within apartments or collective in other parts of the building (housing services, common areas), with energy and structural improvements to the existing building [6]. The structure of the exoskeleton is technologically composed of a structural system and lining. According to the structural system the exoskeleton can be a completely independent structure that relies on its supports on the ground; then partially dependent, where one part of the structure rests independently of the existing object on the ground, and the other part is connected to the existing building; and completely dependent structure – connected to the existing building [8].

To research this topic, it is necessary to consider a large number of criteria that relate to the characteristics of the existing building fund and the possibility of its refurbishment. In refurbishment of existing buildings, it is important to apply the principle of adaptable building so that changes in its use or expansion of space can be adjusted to the minimum consumption of resources. Renovation of existing buildings should provide the spatial capacity to install additional functions. The basic elements that can be used to define a building are construction, communications and living space. The construction and communication spaces of most buildings can be considered constant until the end of the life of the building [9]. When it comes to strategies for designing the adaptability of existing buildings, we can talk about three design strategies: a) flexibility or enabling minor shifts in space planning, b) convertibility or allowing for changes in use within the building; c) expandability or facilitating additions to the amount of scape in an existing building [9]. Criteria that are taken into account for assessing the potential for adaptation of existing buildings are external space (construction site); interior space (size of space / rooms, relations between them and communication paths in the layout); availability of construction sites and existing infrastructure; spatial and structural characteristics [9]. These criteria are important in order to assess the possibility of applying exoskeletons to the existing post-war housing fund, to select the types of existing buildings where it is possible to perform interventions using the exoskeleton addition strategy.

From the aspect of exoskeleton position on the existing building, different variants of exoskeletons are possible (partial volume addition to the building facade, volume addition to the building facade, continuous volume addition to the entire building facade, volume addition to the horizontal position of the building - roof) [6]. Partial volume addition in the renovation process could increase the usable space on individual housing units in the building or in order to add complementary facilities. Addition of volume to the vertical surfaces of the building, so that the exoskeleton is continuous along the vertical surface, and partial along the horizontal facade surface in the renovation process could make new communications (elevator, evacuation staircase), as well as expanding useful housing or adding new content by floors. Continuous addition of volume to the vertical surface of the building may suggest a combination of new communications and an increase in the useful space of the apartments. The addition of volume to the horizontal surface of the building, on the roof, could make new housing units or introducing complementary contents in the residential building. The most complex variant of exoskeleton addition would be the treatment of both horizontal and vertical surfaces of the existing building, so that volumes are added to the facades of the building, as well as to the roof.

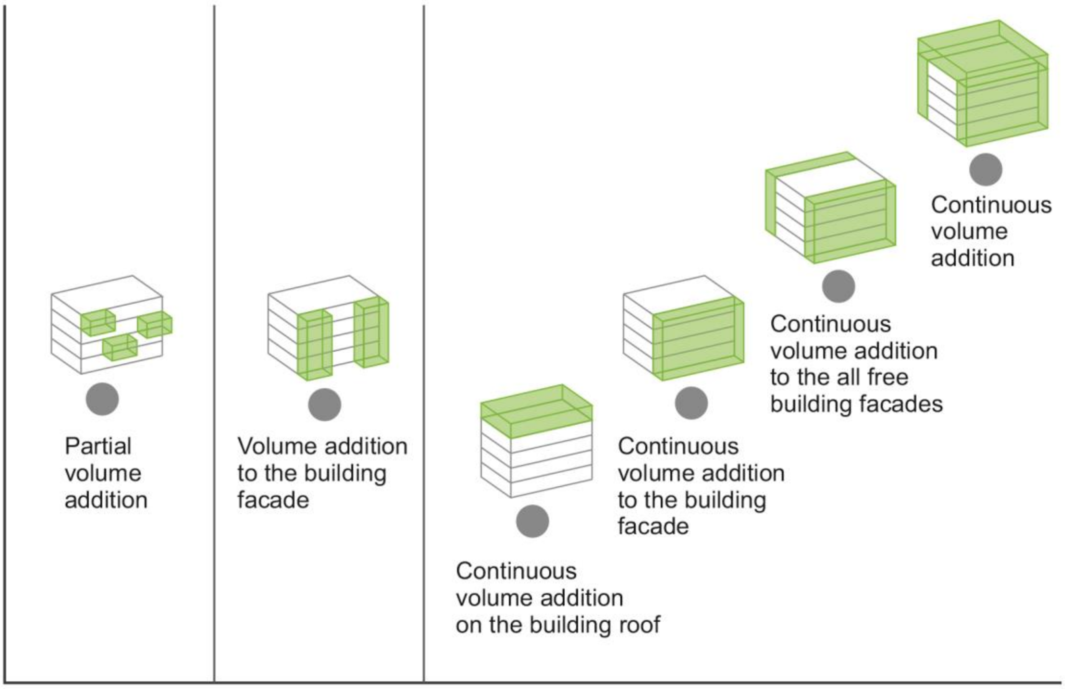


**Figure 1.** Diagram of different variants of exoskeleton position on the existing building (Source: author)

Based on various parameters (type of existing building, type of construction of the existing building, spatial organization, functional organization, communications, etc.) it can be determined which type of exoskeleton addition would be suitable, as well as whether the exoskeleton addition strategy is a suitable strategy for integrated energy spatial renovation of different types of existing buildings.

This methodology proposes the application of prefabricated exoskeletons with a construction of cross laminated timber and prefabricated lightweight timber panels. In the world, prefabricated technology is highly promoted due to its potential to improve the quality of building construction, as well as the reconstruction of existing buildings. Previous studies show that the application of prefabricated technology in the construction or renovation of existing buildings consumes about 20% less energy than the traditional method of construction. The use of prefabrication has shown some benefits, including a reduction in resource consumption by about 35%, a reduction in damage to user health by 6%, and a reduction in ecosystem damage by 3% [10]. In addition to the usual method of energy rehabilitation using individual layers, the application of prefabricated lightweight prefabricated assemblies for energy rehabilitation of existing buildings is becoming increasingly important in Europe and the world. With increasing work costs, lack of skilled workers for various jobs, demand for faster work, increased care for the environment, as well as achieving economic savings, the method of application of prefabricated structures is increasingly used in construction, which has certain advantages over classic construction, due to savings in construction time, application of ecological materials and reduction of financial investments [11]. A pre-developed prefabrication system results in a large number of benefits of using this construction method. A detailed design of the assembly system, with all the necessary details, connectors and elements, reduces the amount of waste of the applied material, because in the process of the project, the necessary quantities of materials for prefabricated construction can be accurately calculated. Another characteristic of prefabricated construction is the high quality of works, due to the application of automated machines, which reduce execution errors in relation to the project to millimetres. The third positive side of prefabricated construction is respect for deadlines. Based on the design specification of the segments of prefabricated assemblies, their dimensions and structure, the manufacturer can make an organizational plan with an accurate calculation of the time frame for the production of prefabricated assemblies. These characteristics affect the increasing integration of various structural systems of buildings, from facade walls, mezzanine structures, roof structures, to partition and installation walls [12].

## 4. Research results

By applying the mentioned methodology, the advantages and limitations of the approach of the complex and integrated improvement of the existing building can be examined by applying the exoskeleton addition strategy which includes energy, spatial and functional improvement of the existing building on examples of buildings of different construction and typology.

The modern view of post-war multi-family residential buildings is complex from different points of view. Loss of functional and architectural quality and increased energy consumption of buildings are characteristics that require complex and integrated renovation. Renovation is an integral part of the life cycle of buildings because components and functions become obsolete or reach the end of their life. Renovation of existing buildings is linked to sustainability in terms of environmental impact, social and economic impact [6].

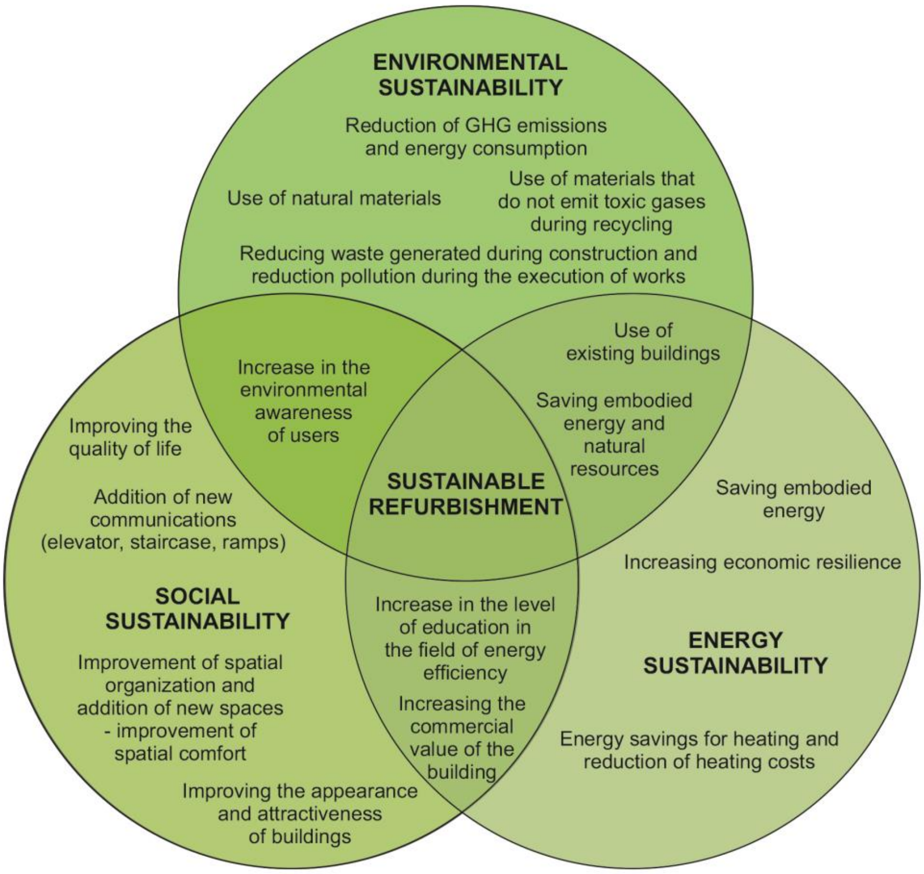


**Figure 2.** Diagram of the intertwining of environmental, economic and social aspects in the process of sustainable refurbishment of existing buildings using exoskeletons (Source: author)

The environmental aspect is primarily related to the reduction of the energy required for heating and the reduction of carbon dioxide emissions due to the improved energy performance of the building. Energy consumption is the main source of greenhouse gases, so that the energy improvement of existing buildings reduces the energy required for heating, and this directly affects the reduction of greenhouse gas emissions. Also, this methodology promotes ecological materials, which includes the use of materials of natural origin (timber, stone mineral wool), as well as products based on natural materials (wood-based products, plasterboard, etc.) because one of the goals of research is to achieve zero energy consumption for heating and reduce emissions.

The methodology proposes a strategy of the complex and integrated refurbishment using exoskeletons with structure of prefabricated lightweight assemblies, with a timber structure filled with mineral wool. In addition to the importance of applied materials and their impact on people and the environment, it is necessary to emphasize that prefabricated lightweight assemblies have additional environmental advantages over traditional, conventional construction, and these advantages primarily relate to reducing waste generated during construction and reduction pollution during the execution of works. The prefabricated system of light prefabricated construction is an environmentally cleaner approach to construction that has multiple benefits from an environmental point of view.

In addition to the main environmental motive for energy improvement - reduction carbon dioxide emissions, it is important to emphasize that the use of existing buildings and extending its life by renovation, instead of demolition and construction of new buildings, natural resources can be significantly saved. It is noticeable that today old buildings are being demolished, and new ones are being built in their place, however, due to insufficiently awakened ecological awareness, it is neglected how negative this process is for the environment. Demolition of the old and construction of a new building requires a large amount of energy that needs to be installed in the new building, natural resources are extracted, and in addition to all of the above, large amounts of waste are generated from the demolition of the old building. If in practice the environmental aspect were taken into account, as one of the most important aspects of sustainable architecture, the focus would probably be on maintaining the existing housing stock with renovations that would primarily include energy rehabilitation of buildings, as well as structural and functional improvement of existing buildings due to obsolescence.

The economic aspect of sustainable renovation is primarily a combination of reducing the cost of heating and saving energy and natural resources. The energy improvement of the existing building achieves significant reductions in energy consumption required for heating, and directly reduces heating costs, if adequate energy envelope positions are chosen for energy rehabilitation, which have the largest share in transmission losses of the building envelope and do not require large initial investment.

The economic aspect is related to the environmental aspect because the saving of energy and natural resources is significant from both points of view. Various analyzes and economic statistics have shown that the financial investments in the demolition of the existing multi-family building and the construction of a new one are far greater than the investment in the renovation of the existing building [6]. Complex and integrated renovation that includes the treatment of the entire thermal envelope of the existing building in order to achieve greater energy improvement, with the improvement of spatial organization with increasing usable space and adding communications (elevator, stairs), can increase the commercial value of the existing building. By adding exoskeletons on the free facades of the building or by forming an upgrade on the roof of the building, the useful space can be significantly increased.

Although this approach to reconstruction requires very large investments, economic analysis can calculate that such a large-scale intervention is completely profitable and economically justified. This especially refers to the construction of an upgrade, which can form additional housing units, which could be sold or rented and thus return all the invested initial investment funds. In addition to increasing the usable space, the addition of communication functions is one of the very important benefits that also requires greater investment, but allows to increase the value of the building. And the last item is to improve the appearance, attractiveness and safety of the building, which directly affects the commercial value of the building.

Improving the quality, appearance, safety and attractiveness of the building also has a positive effect on the quality of life of the building's users [9]. Also, increasing the usable area, as well as the spatial reorganization of housing units are important for improving the quality of life and comfort of users. The addition of new vertical communications - elevators, is one of the most common demands of housing communities, which significantly affects the improvement of the quality of life in the building. By expanding the volume of the building, creating more usable space, using environmentally friendly materials and products of natural origin and applying innovative construction techniques, such as prefabrication that is more efficient and environmentally cleaner than conventional construction techniques, exceptional results can be achieved in all aspects of sustainable renovation. In addition, the entire process of the complex and integrated refurbishment of buildings can be done without relocating the occupants of the building, which is a special advantage of prefabricated constructions.

In addition to the design strategy of complex and integrated refurbishment of existing buildings, it is important to emphasize the importance of user behaviors and opinions. Although the technical characteristics of a building have a significant impact on residential energy use, the behavior of the occupant is also crucial [6]. In the list of factors influencing energy consumption in residential buildings is the number of occupants, the household income and indoor temperature. All of them being positively correlated with energy consumption. The energy behavior of the occupants is also important. Energy behavior is influenced by a number of different socio-cultural and psychological factors, including human values and beliefs, choices and options related to energy attitudes/routine habits and practices, knowledge of energy issues as well as strategies for energy behavioral change. [6]. According to the research study conducted in Athens, which examines the relationships between energy use in residential buildings, the behavior of occupants and their sociodemographic characteristics, it can be concluded that an increase in the level of education in the field of energy efficiency is needed, as well as an increase in the environmental awareness of users and financial incentives for the improvement of energy saving devices for citizens with lower revenues [6].

A complex and integrated refurbishment that includes energy improvement of the building and spatial expansion with the improvement of building functions is a technological strategy that is adaptable for future applications, from the perspective of resilience and adaptability of the built context [9].

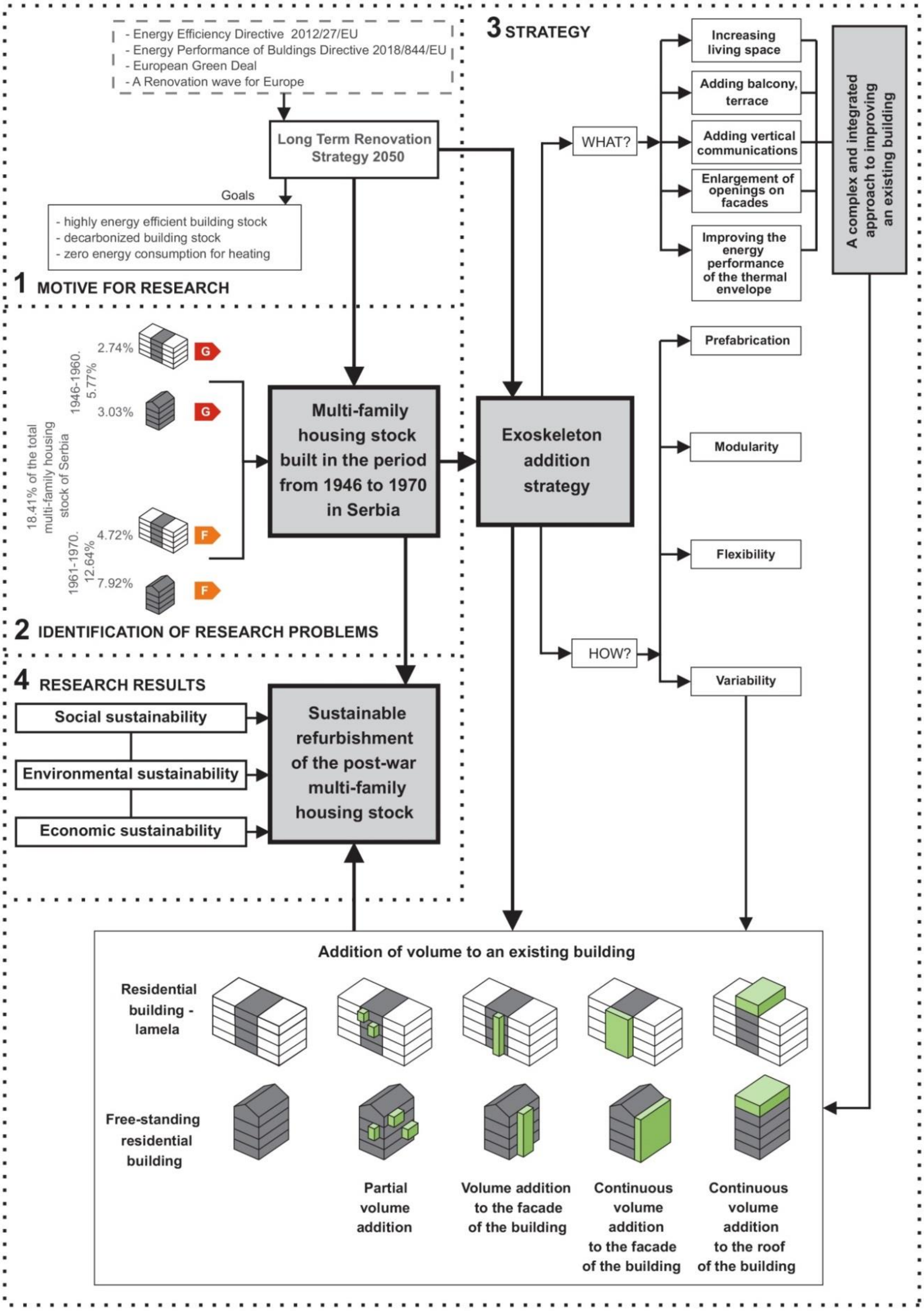


**Figure 3.** Scheme of methodological procedure for application of the strategy of the complex and integrated refurbishment of post-war housing stock in Serbia using exoskeletons (Source: author)

## 5. Conclusions

The paper defines the methodological procedure of exoskeleton application from the initial idea, identification of the research problem, strategy of its application, to the results that can be achieved by such a procedure. On an urban scale, this method of renovation can be introduced as a strategic approach to the renovation of existing buildings in Serbia and the region. This paper proposes integrated reconstruction techniques to encourage holistic and sustainable renovation of obsolete housing stock, which would increase the current rate of renovation of buildings. This research work could present an initiative for an integrated and more complex approach to the renovation of the existing housing stock, to identify all the shortcomings of existing multi-family buildings from the post-war period, preserve their qualities and consider user requirements, and then to improve the building from a functional, spatial and energy point of view, by applying a technical solution similar to a prosthesis, respecting all three aspects of sustainability.

## References

[1] European Commission, Eurostat [CrossRef]
[2] European Commission, Renovation Wave Strategy [CrossRef]
[3] EC Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings, Official Journal of European Union 16.12.2002L1/65 [CrossRef]
[4] EU Directive 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, Official Journal of the European Union 19.6.2018 L156/75-91[CrossRef]
[5] Kalamees T, Pihelo P, Kuusk K. 2017 Deep energy renovation of old concrete apartment building to nZEB 23. Internationales Holzbau-Forum IHF [CrossRef]
[6] Guidolin F 2015 Adaptive Socio-Technical Devices - Social Inclusion as a Rehabilitation Tool *Sustainable and Resilient Building Design, Approaches, Methods and Tools* (TU Delft Open) p 229 [CrossRef]
[7] Jovanović Popović M, Ignjatović D, Radivojević A, Rajčić A, Đukanović Lj, Ćuković Ignjatović N and Nedić M 2013 *Atlas of multi-family buildings in Serbia* Faculty of Architecture, University of Belgrade [CrossRef]
[8] Samardžić M 1991 *Flexible constructions in housing*, Belgrade
[9] Konstantinou T, Dimitrijević B. 2018 Sustainable Refurbishment for an Adaptable Built Environment *Sustainable and Resilient Building Design, Approaches, Methods and Tools*. (TU Delft Open) p 205 [CrossRef]
[10] Cao X, Li X, Zhu Y, Zhang Z 2015 A comparative study of environmental performance between prefabricated and traditional residential buildings in China, *Journal of Cleaner Production* [CrossRef]
[11] Ankit S 2015 Role of Prefabrication in the Construction Industry to improve sustainability and economy of Civil Engineering projects, University of Illinois [CrossRef]
[12] Björnfot A, Sardén Y. 2006 Prefabrication: a Lean Strategy for Value Generation in Construction. Prefabrication, assembly and open building Proceedings IGLC-14 p 265 [CrossRef]
[13] Vogiatzi C, Gemenetzi G, Massou L, Poulopoulos S, Papaefthimiou S, Zervas E. 2018 Energy use and saving in residential sector and occupant behaviour: A case study in Athens, *Energy and Buildings,* Volume 18,. Elsevier, p 1-9 [CrossRef]