Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 161 (2016) 1076 – 1083

Procedia Engineering

www.elsevier.com/locate/procedia

World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium 2016, WMCAUS 2016

Steel Structure Apartment Extensions for Existing Large Prefabricated Panel Collective Dwellings

Miodrag Popov[a,]*, Adrian Dogariu[b], Daniel Grecea[b], Viorel Ungureanu[b], Mircea Georgescu[b]

[a] *Politehnica University of Timisoara, Department of Architecture, No. 2/A, Traian Lalescu Street, 300223 Timisoara, Romania*

[b] *Politehnica University of Timisoara, Dept. of Steel Structures and Building Mechanics, No. 1, Ioan Curea Street, 300224 Timisoara, Romania*

Abstract

The Romanian existing building stock of collective dwellings is in a vast majority composed of reinforced concrete large prefabricated panel blocks of flats, erected during Communism. According to the 1992 Census, these standardized and widespread buildings housed almost 60 percent of the urban population of the country.

Due to the small, inflexible apartments on one hand and the changing living conditions of the contemporary Romanian society on the other, a need for extending the inner surface of the existing flats has been identified. This situation led to the adoption of technically restrictive ground-floor spatial additions and other vernacular solutions that are being applied to upper stories, some of them not being able to provide, in many cases, any forms of long term structural guarantee to their users.

The present paper describes a prefabricated steel structure solution for cantilevered apartment extensions that can be independently attached to the façade, as well as some technical connecting details to the existing building. A global structural analysis performed on a virtual model depicting a widespread type of block of flats (Model 770) proves the non-intrusive influence the cantilevered apartment extensions have over the existing buildings, in multiple different scenarios of attachments. Moreover, a FEM analysis of the proposed details further shows the reliability of the examined solution.

Peer-review under responsibility of the organizing committee of WMCAUS 2016

Keywords: existing buildings; large prefabricated reinforced concrete panels; collective dwellings; steel structures; owner-based interventions; independent prefabricated apartment extensions; FEM analysis;

* Corresponding author. Tel.: +4-074-554-7030.
E-mail address: miodrag.popov@up-tim.org

Peer-review under responsibility of the organizing committee of WMCAUS 2016
doi:10.1016/j.proeng.2016.08.851

1. Romanian urban collective housing

1.1. Statistics and particularities. Project 770

An appreciation of the existing building stock in most of the European countries indicates that more than 90% of the buildings are erected after the Second World War [1]. In Romania in particular, almost half of the built stock has been constructed between 1961 and 1980, out of which more than 75% are collective dwellings [2]. This particular architectural program, developed during the Communist regime as a response to the housing crisis generated by the increasing industrialization process, completed the vision of a new urban society.

Although the 1992 National Census showed that 1,8% of the total buildings are collective dwellings [3], these specific buildings house approximately 37% of the total apartments of Romania. A popular constructive system in the 70s in Europe for erecting the collective dwellings, the large prefabricated reinforced concrete panels (LPRCP) have by far proved to be the fastest and cheapest available technology at the time [4]. Based on standardized architectural projects, these offered standard interior configuration of the apartments in 4 main types imposed by the legislation as a mean to facilitate state-credit financing, project 770 being one of the most widespread models throughout Romania.

After 1989, specific economic factors led the initially State-owned apartments to become affordable for the people, determining the government to massively sell them. Being at only half of its intended lifespan, this typology of existing buildings is still in use today, currently providing accommodation for almost 60% of the urban population of our country, out of which 96% own the apartments they live in, as estimated in 2006 [2].

1.2. Improving the quality of life. Individual owner-based interventions

With a new Romanian society reshaping its social, economic and political path towards democracy and capitalism, the contemporary standard of living would not correspond anymore to the one set during the 70s.

When defining the quality of life, the 2011 BPIE study reveals that 71% of Romanians think the dwelling where they live is important [2]. However, the average surface per capita of 20 m2/person in Romania is one of the lowest, compared to the European average of 30 m2/person, bringing to light critical living conditions in terms of space. This is also underlined by the subjective perception the inhabitants have when it comes to the means of improving their apartments [5]. In their view, solutions regarding the interior comfort (thermal insulation of the facade, fixing the plumbing) and apartment extensions are a necessity.

At the same time, in the midst of the existing global energy crisis, considering the abovementioned impact of the blocks of flats over the urban population and the energy consumption, some of the Romanian efforts towards achieving the EU 20-20-20 goals were directed to thermally retrofitting these buildings through partnerships between the authorities and the inhabitants. This program tackled mostly the economic and environmental aspect of sustainability, focusing only on the thermal envelope improvement and reduction of heating energy costs and losses during winter. Few of these measures tackled the priorities identified by the local communities. For that reason and due to the high level of ownership, a handful of people who refuse to invest in the thermal retrofitting can easily generate an administrative/legal deadlock, denying all forms of intervention on the building. Since the beginning of the program in the early 2000s, only 24% of the blocks of flats from Timisoara were retrofitted [5].

As a possible consequence of the low number of achieved global retrofitting upgrades, individual interventions started to be applied by the inhabitants with the purpose of improving their living conditions which no longer correspond to those of the 70s, ranging from the occupation of public space around the blocks with private gardens, window enlargements, roof additions, to unauthorized interventions on the interior structural elements.

Assessing the degree of structural interventions that the blocks of flats were submitted to is only intuitive in the absence of authorized projects and without a real possibility to conduct a structural survey. However, we can define some tendencies of spatial reconfiguration that people used to resonate with, these mainly being rooted in the cultural models of the last 25 years.

Apart from the common renovation of the flats respecting the initial room configuration, some of the most common interventions presumed enclosing the balconies with windows, moving or adding partition walls to accommodate storage room and opening the kitchen to the entry lobbies of the flats.

Fig.

Fig. 1. Independent apartment extensions in Ferentari neighborhood, Bucharest (source: Google Street View).

The dense structural elements make room connections possible only with serious structural reinforcement. Research studies have shown that there are possible means of intervening on the structural levels for connecting two adjacent rooms (vertically or horizontally) by introducing new openings at wall or slab level [6]. Another current structural intervention refers to enlarging the openings in the façade, specific to ground-level apartment extensions, possible by means of TRM strengthening [7].

One of the most extreme and highly present individual owner-based interventions are the horizontal cantilevered extensions of the apartments with the aim of increasing their interior surface. As a result of the owners' initiative, different structural solutions have been used, as shown in Figure 1. A typology of the adopted solutions, shown in table 1, describes the constructive system adopted in the four different cases of extensions.

Whereas some of these interventions respect a professional design process and are approved by the governing authorities, the vast majority are the result of unauthorized construction works. We can, therefore, conclude that it is not clear whether these solutions could offer any kind of structural warranty for the users (e.g. withstand the seismic threats, specific to Romania). In light of the abovementioned context and the clearly identified need for a larger apartment, the present paper describes an architectural solution for a prefabricated steel module, based on the standard dimensions of the LPRCP used in model 770, capable of being independently attached at the façade level at any height, in order to increase the gross surface of the flats. A global structural analysis has been conducted in order to identify the impact the attached prefabricated modules have over the existing building. At the same time, two connection details are evaluated with the purpose of determining whether the proposition is structurally feasible.

Table 1. Typology of the individual owner-based apartment extensions.

Extensions	Floor	Synergy with existing block	Structure	Enclosure	Windows (glass; frame)	Authorized works
1. Concrete Ground floor	GF only	isolated foundation	cast-in-place concrete slab	masonry	double glazing; PVC	yes
2. Steel Supported	GF, 1st	pinned at the façade level	CHS200 steel columns	metal sheets	single glazing; steel frame	no
3(a) Steel cantilevered	1st-4th	in cased into façade/slab	steel beams (tram tracks reused)	metal sheets	single glazing; steel frame	no
3(b) Steel cantilevered	1st-4th	pinned at the façade level	steel profile for cantilevers	metal sheets	single glazing; steel frame	no

Fig. 2. Dimensions of the prefabricated modules, structural elements and the enclosed volume.

2. Prefabricated steel structure apartment extensions

The extension module represents a local intervention, with spatial implications at apartment scale, with controlled variations and positioning within the façade. Therefore, its dimensions are given by the height of the storey (2.70 m), the bay openings (2.40-3.60 m) and the functionality of the space it comprises (2.00 m), such as hobby areas, lounge spaces e.t. Moreover, the extensions become intermediate spaces, gradually connecting the interior space of the inhabitant with the surrounding environment, a common pattern found in traditional architecture of all cultures. Besides the importance of the intermediate space at a phenomenological level, traditional architecture in the Romanian climate repeatedly used this space as a thermal self-regulator of the heat gains from the sun. In our case, the thermal envelope of the prefabricated modules doubles the one from the existing building, creating a buffer space, that can be opened in various ways either to the interior, or the exterior (Figure 2). In certain configurations and orientations towards the sun, the buffer space enhances solar passive heating, leading to a decrease in energy needs in winter [8]. In summer, it provides shading and prevents heat gains to increase the cooling energy demands.

In order to provide a relevant structural analysis for cantilevering the prefabricated apartment extensions, we have applied our proposals to one of the mostly widespread sub-type of project 770, the Pa2 variation. The constructive solution of the prefabricated extension is presented as follows, as well as two connection details of attaching the extensions to the existing building. An adjacent steel frame consisting of HEA180 columns and beams composes the rigid box, having a large glazed surface and light steel enclosures as shown in Figure 2, to ensure both technological and aesthetical aspects. Prefabricating the extensions offers advantageous production costs of the module and minimizes the in-site fitting time. Moreover, the same prefabricated module solution (with variations only in size) can be used in both of the attaching solutions treated hereafter.

The permanent loads were composed as follow: floor slab (62 kg/m2), roof (42 kg/m2), opaque wall (39 kg/m2), glazing (21 kg/m2). Regarding the live load, a value of 200 kg/m2 was considered according to EN1991 [9] (this extension has to be regarded as a room, not a balcony). The total weight of such an extension is of 1.2 tonnes, less than 0.1% of the whole building weight. The only concern is the connecting technology used for the extension. Load combinations were compliant to EN1990 [10], including vertical earthquake forces used in the following structural simulations.

3. Analysis of structural feasibility

3.1. Attachment scenarios. Synergy with the existing building

The proposed solution for the prefabricated extensions considered the hypothesis of independently attaching the modules at any level of an existing block of flats. The proposed structural solution, therefore, will take into consideration the characteristics of the LPRCP used in the case of model 770. The 770 Pa2 sub-type is made out of two-way prefabricated reinforced concrete panels, with three bay dimensions: 3.00 m, 3.30 m and 3.60 m. The strip foundation under the structural walls is made out of concrete B75 (C4/5). The width of the foundation varies depending on the block typology, because the conventional pressure is different in all zones. Foundation elevations (basement) are made of 20 cm thick cast-in-place reinforced concrete B150 (C8/10) [11].

Concerning the superstructure, made entirely of precast panels, the 14 cm bearing reinforced concrete B200 (C12/15) panels used in the interior upper storeys respect. a maximum weight of 5.1 tones because, a lifting restraint of the used crane model MT110 at that time. The exterior wall panels are made of 2 layers of concrete B250 (C16/20) and a thermal insulation layer of CBA, all within a total width of 30 cm. The slabs are made of reinforced concrete panels and have a width of 13 cm. The wall reinforcement consists of PC52 type (S355 grade) for 10 mm longitudinal bars and for 14 mm vertical continuity bars and STPB type (S490) for 4 mm welded wire mesh. The ultimate cubic compressive strength of concrete for the tested and modelled wall panel is 17.5 MPa [7]. Joints between the panels were assured by welding the concrete steel reinforcements and B300 (C18/22.5) quality concrete in-place casting.

3.2. Global structural analysis

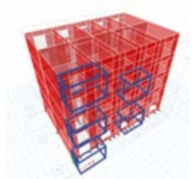
From 1965 until now, several changes in the structural design codes and the codes for actions (especially the seismic one) were adopted. It is, therefore, necessary to conduct a structural analysis of the existing building in order to prove the structure capability to comply the actual building codes and only then to establish the impact the extensions would have over the block of flats.

An example of such analysis is given below by considering 3D analyses using ETABS computer code in the case of building type 770 Pa2. Shell finite elements for simulating the concrete panels (both horizontal and vertical) and beam elements for the proposed steel-frame solutions have been used. A similar study applied to other subtypes of the 770 model (Pb2) has been conducted in a previous article [12].

The modules were considered pinned at the façade level, in each corner of the adjacent façade panel. The loads and combinations were detailed in the previous paragraph. The building is considered to be situated in Timisoara, which according to the Romanian seismic standard P100-1/2013 [13] has the following characteristics for the seismic motion: $a_g = 0.20\ g$ and $T_C = 0.7\ s$, and includes The behaviour factor used in the analysis was $q = 1$.

The analysis of the existing building considering the actual loads and combinations confirmed the requirements for ULS and SLS of the existing structure. The first vibration mode was on longitudinal direction with a period of 0.084 sec, close the second one (0.074 sec) which is on transversal direction. Different scenarios for the disposal of the extensions on the building façade are presented in Table 2. The main structure is symmetrical and the extensions were placed in such a way in order to introduce a large eccentricity with torsional effect.

Table 2. Global analysis. Vibration modes for different eccentric distribution of modules scenarios.

				
0. Initial building	1. 1 module	2. 3 modules	4. 5 modules	5. 10 modules
Mode 1: 0.084 s longitudinal	Mode 1: 0.082 s	Mode 1: 0.082 s	Mode 1: 0.083 s	Mode 1: 0.084 s
Mode 2: 0.074 s transversal	Mode 2: 0.072 s	Mode 2: 0.072 s	Mode 2: 0.072 s	Mode 2: 0.072 s
Mode 3: 0.058 s torsional	Mode 3: 0.055 s	Mode 3: 0.055 s	Mode 3: 0.056 s	Mode 3: 0.056 s

After the analysis of the structure including the extensions, one can observe that due to the very small module mass, the dynamic characteristics of the buildings remain almost unchanged. The first and second vibration modes remain longitudinal with a period of 0.084 sec for the initial building with up to 10 extensions placed on one single facade, and slightly decrease at 0.072 sec for the transversal. These facts underline the insignificant changes, introduced by the extension, in the dynamic characteristics of the buildings, extremely important features in case of an earthquake. At the global level, the un-intrusive character of the intervention is once again proved by the small changes (around 2%) in the overall base reactions. It has been proven [5] that the modules respect admitted values for ULS and SLS relative displacements and that there are no supplementary loads on the reinforced concrete shear walls of the existing building. Locally, extension may introduce most unfavourable pairs of forces, with pulling forces up to *5 kN* and shear forces of *12 kN*. This level of forces may be easily accommodated by the connection detail, accompanied or not by complementary local strengthening intervention. As recent experiments have shown, steel frame strengthening solutions can be applied, based on discrete connections with the existing structure [14].

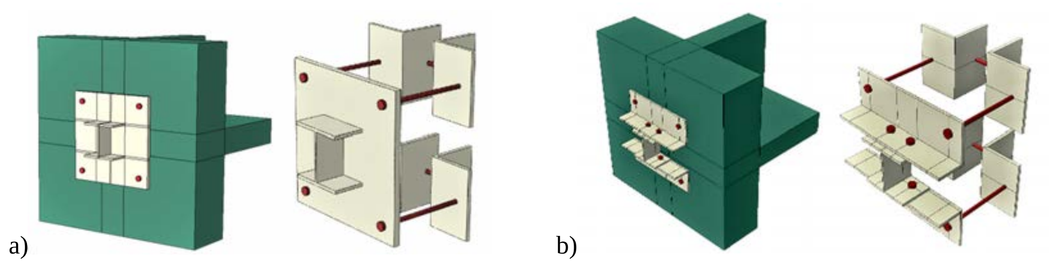


Fig. 3. (a) Semi-rigid connection (welded extended header plate) and (b) pinned connection (bolted seating angles).

3.3. Connection analysis

The global analysis of the intervention has proved the solution feasibility, but the connection detail still represents a critical aspect of the intervention. The independent connections were analyzed, being considered more intricate. Within the study have been proposed three connections typologies (see Figure 3) to fulfil the semi-rigid and the pinned behaviour requirements. All the proposed solutions should respect the anchors geometry (360 by 360 mm distance) imposed by the prefabricated concrete slab and wall thicknesses in order to avoid the penetration through in-situ cast concrete joints.

First connection is based on a welded extended header plate of 460 by 460 mm without any additional stiffeners (Figure 3a), the second one is made by means of two seating angles bolted connected with the extension beam flanges (Figure 3b) and the third one is a classical fin plate connected on the extension beam web by shear bolts. The fin plate connection is a simple connection with very clear analytical procedures for design available in EN1993-1-8. The design of the other two connections is not covered entirely by the code provision, only some of the components, and consequently were numerically investigated using ABAQUS software [15]. Each connection presents specific technological aspects, but it is believed that the one based on angles is more appropriate from the easiness of handling on the construction site. In both the detailed numerical models hexahedral solid elements C3D8R have been used. The steel material from profiles, bolts and anchors have been defined as elastic-perfect plastic according to steel grade S355 and bolts class 6.6. The crushing and cracking of the concrete were considered using a concrete damaged plasticity material model. The diameter of the anchors and bolts was defined as the one's tensile stress area for obtaining a more realistic design tensile force. In order to reduce the false sliding effects due to the unrealistic tolerances, the bolt-holes diameter was defined with a very small tolerance related to bolt diameter. In case of contacts definition, only a normal "hard" behaviour was accounted; the friction effects being regarded as unimportant.

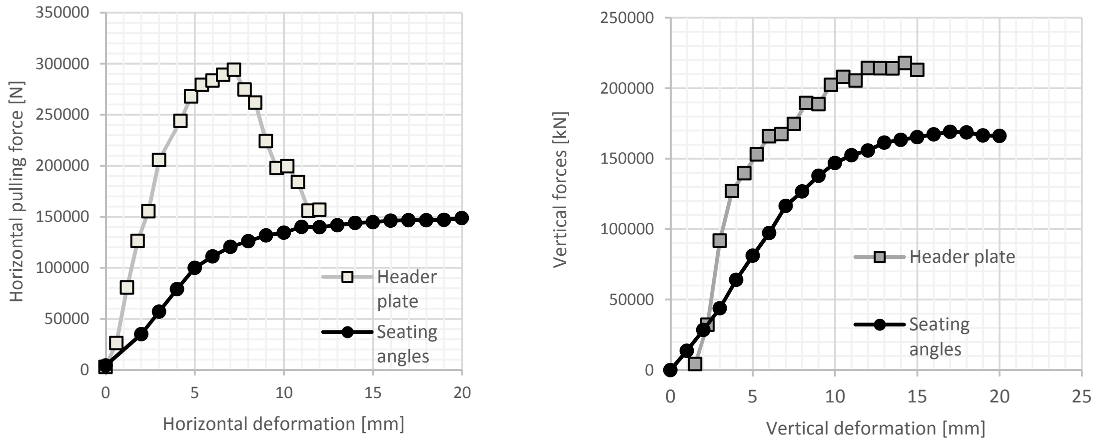


Fig. 4. Horizontal pulling forces and vertical shear forces acting on the connections.

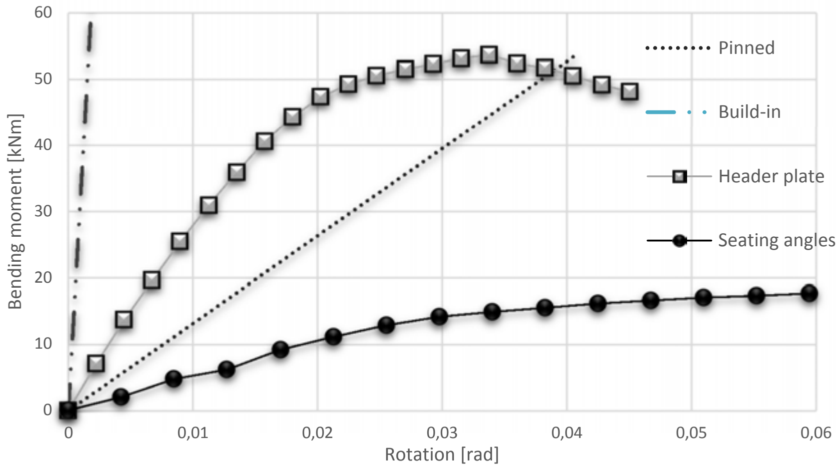


Fig. 5. Bending rigidity of the two connections.

The behaviour of each connection was analysed accounting independently for normal and vertical forces and bending moment actions. The obtained numerical behaviour is presented in the following figures (see Figure 4).

In order to establish the connection type and the behavioural parameters for global analysis, one of the most important aspect is the bending rigidity. In Figure 5 the bending behaviour is plotted showing a semi-rigid and a pin behaviour for the two types of connections. The obtained capacities of the connection exceed by far the connection design forces resulted from the global analysis, i.e $H = 5\ kN$ and $V = 12\ kN$. In order to check the safety of the connections a numerical analysis using the real design internal forces have been performed showing a quite reduced level of von Misses stresses (see Figure 6) in all the connections' components compared with the yielding limits. As one may observe, almost all the components of the connections are oversized, some of them due to constructive conditions, but for sure, in a future phase of the research, the components' geometry may be optimized. Due to the lack of an experimental campaign the numerical models are not calibrated and validated, so the simulation results should be treated only on a qualitative manner. Even so the results come to sustain the connection feasibility. Further study will be undertaken to optimize the structural performance of the details.

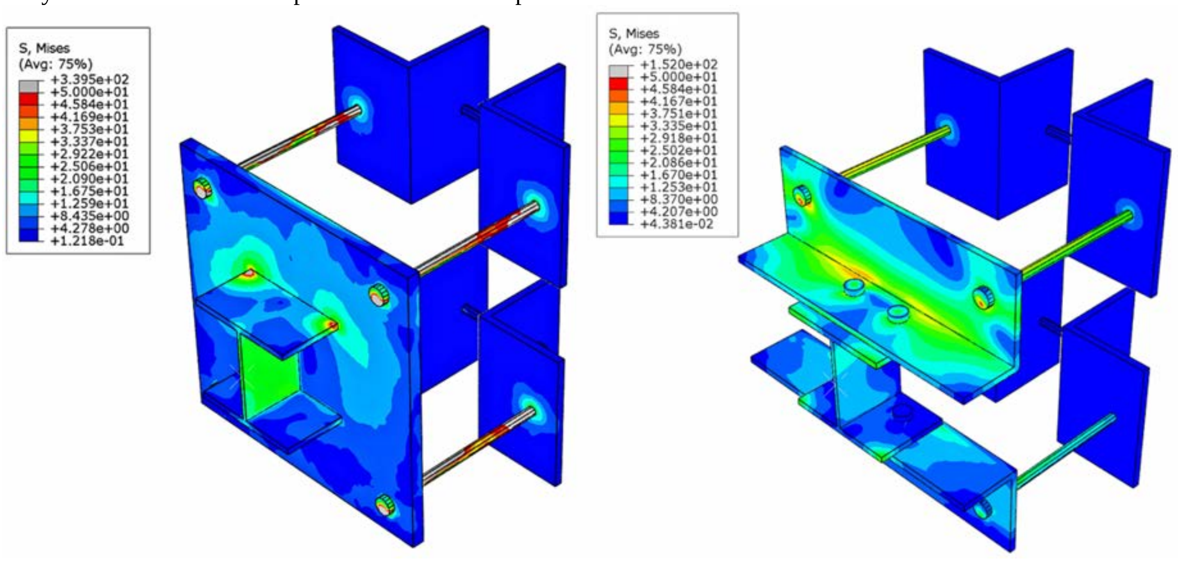


Fig. 6. FEM model and qualitative inner stress levels of the connections.

4. Conclusions

Contemporary research has proved that the quality of life is strongly connected to the built environment and, in specific, to the gross area of the houses we live in. In the specific cases of Romanian high-density collective made of LPRCP dwelling representing a repetitive building stock, the insufficient surface per capita generated a wide range of owner-based unauthorized and unsafe apartment extensions. The present paper describes a prefabricated extension module as a solution to this specific need. The global structural analysis shows the un-intrusive character of the addition of the modules in a variety of scenarios, mainly due to the small induced mass. The presented, yet un-optimized connection details were analysed in a qualitative manner, their behaviour further showing the feasibility of the solution. As a future research direction, an experimental study is needed in order to prove the model viability.

Acknowledgements

This work was partially supported by the strategic grant POSDRU/159/1.5/S/137070 (2014) of the Ministry of National Education, Romania, co-financed by the European Social Fund – Investing in People, within the Sectorial Operational Programme Human Resources Development 2007-2013.

References

[1] M. Hegger, M. Fuchs, T. Starck, M. Zeumer, Fundamentals. Energy Manual – Sustainable Architecture, Basel, Switzerland, Birkhäuser, 38-61, 2008.

[2] M. Economidou et al., Europe's buildings under the microscope – A country-by-country review of the energy performance of buildings, Building Performance Institute of Europe, 39-50, 2011.

[3] ***, Institut Wohnen und Umwelt GmbH, Use of Building Typologies for Energy Performance Assessment of National Building Stocks. Existent Experiences in European Countries and Common Approach - First TABULA Synthesis Report, 122-127, 2010.

[4] M. Popov, M. Szitar, M. Sămânţă, An Integrated Approach – Retrofitting the blocks of flats made of prefabricated panels, Romanian-Finnish Seminar on Opportunities in Sustainably Retrofitting the Large Panel Reinforced Concrete Building Stock – January 28, 2013, Timişoara, Romania, edited by Ungureanu V. and Fülöp L., Timişoara – Orizonturi Universitare, 159-175, 2014.

[5] M. Popov, Integrated Retrofitting of the Collective Dwellings Made of Large Prefabricated Panels. Structural Solutions (Reabilitarea integrata locuintelor din panouri mari prefabricate. Solutii structurale), PhD Thesis, Editura Politehnica, 2015, (in Romanian).

[6] A.A. Botici, V. Ungureanu, A. Ciutina, A. Botici, D. Dubina, Sustainable retrofitting of large panel prefabricated concrete residential buildings, Proceedings of Central Europe Towards Sustainable Building 2013 Conference - Sustainable Building and Refurbishment for Next Generations, Prague, Czech Republic, 39-42, 2013.

[7] C. Todut, V. Stoian, I. Demeter, T. Nagy-György, V. Ungureanu, Retrofitting of earthquake damaged precast concrete wall using FRP composites, fib Symposium 2013 - Engineering a Concrete Future: Technology, Modeling & Construction, 573-576, 2013.

[8] M. Pucar, Bioklimatska arhitectura – zastakljeni prostori i pasivni solarni sistemi, (Bioclimatic Architecture – Glass Spaces and Passive Solar Systems), Belgrade, SRB: Institut za arhitekturu i urbanizam Srbije IAUS, 40, 2006.

[9] .***, EN 1991-1-1, Eurocode 1: Actions on structures - Part 1-1: General actions-Densities, self-weight, imposed loads for buildings, European Committee for Standardization, 17, 2002.

[10] .***, EN 1990, Eurocode – Basis of structural design, European Committee for Standardization, 2002.

[11] *** IPCT, Cladiri de locuit P+4 din panouri mari. Proiect 770-81, Vol. D: Elemente prefabricate si armari, (Precast reinforced concrete large panel collective dwellings P+4. Project 770-81, Vol. D: Precast elements – Reinforcing), Volume D, Bucharest, Romania, 1981.

[12] M. Popov, A. Dogariu, D. Grecea, V. Ungureanu, "Seismic Behaviour Of Two Steel Solutions For Apartment Extensions In Case Of Large Prefabricated Reinforced Concrete Collective Dwellings", 8th International Conference on Behavior of Steel Structures in Seismic Areas, Shanghai, China, 1550-1557, 2015.

[13] ***, P100-1:2013, Cod de proiectare seismică", Seismic design code. Part I - Design previsions for buildings, Monitorul Oficial al României (Official Journal of Romania), Part 1, No. 803 bis., 2006.

[14] A.A. Botici, V. Ungureanu, A. Ciutina, A. Botici, D. Dubina, Structural interventions for rehabilitation of precast large concrete panels for residential buildings, Proceedings of the 2nd International Conference on Protection of Historical Constructions. 7-9 May 2014, Antalya, Turkey, 133-139, 2014.

[15] Abaqus Users Manual, 2013. Version 6.13-2, Dassault Systémes Simulia Corp., Providence, Rhode Island, USA.