

# Adaptive Design of Large Prefabricated Concrete Panels Collective Housing

Daniel M. Muntean, Viorel Ungureanu

**Abstract**—More than half of the urban population in Romania lives today in residential buildings made out of large prefabricated reinforced concrete panels. Since their initial design was made in the 1960's, these housing units are now being technically and morally outdated, consuming large amounts of energy for heating, cooling, ventilation and lighting, while failing to meet the needs of the contemporary life-style. Due to their widespread use, the design of a system that improves their energy efficiency would have a real impact, not only on the energy consumption of the residential sector, but also on the quality of life that it offers. Furthermore, with the transition of today's existing power grid to a "smart grid", buildings could become an active element for future electricity networks by contributing in micro-generation and energy storage. One of the most addressed issues today is to find locally adapted strategies that can be applied considering the 20-20-20 EU policy criteria and to offer sustainable and innovative solutions for the cost-optimal energy performance of buildings adapted on the existing local market. This paper presents a possible adaptive design scenario towards sustainable retrofitting of these housing units. The apartments are transformed in order to meet the current living requirements and additional extensions are placed on top of the building, replacing the unused roof space, acting not only as housing units, but as active solar energy collection systems. An adaptive building envelope is ensured in order to achieve overall air-tightness and an elevator system is introduced to facilitate access to the upper levels.

**Keywords**—Adaptive building, energy efficiency, retrofitting, residential buildings, smart grid.

## I. INTRODUCTION

THE industrialization period during 1958-1965 created the need for new dwellings for workers coming from rural to urban areas hoping for a better life. This process led to massive modifications in urban space design and created wounds yet to be healed. The necessity to rapidly build new homes lead to implementing standard architecture projects using prefabricated concrete panels built into repetitive modules which could be put together in various ways according to existing urban limits [1].

After the fall of the Communist regime, residents became owners by purchasing the apartments. The decrease of the national currency value and changes after 1989 lead to a series of alterations made to buildings - changing the exterior layer, building attics, and thermal insulation.

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In Eastern Europe, the building technology with large reinforced concrete prefabricated panels (LRCP) has been used since 1970, at a large scale, on most of the large collective housing projects. It has been applied also in northern European countries, although similar in technology, these have managed to optimize their buildings regarding sustainability [2]. The topic of buildings retrofitting of the east-European block has become a world-wide concern, as well as a necessity in order to ensure optimal parameters for sustainable development. Moreover, due to the widespread use and sheer number, retrofitting these buildings to meet the current standards, and not demolish them, is the most economical solution [3].

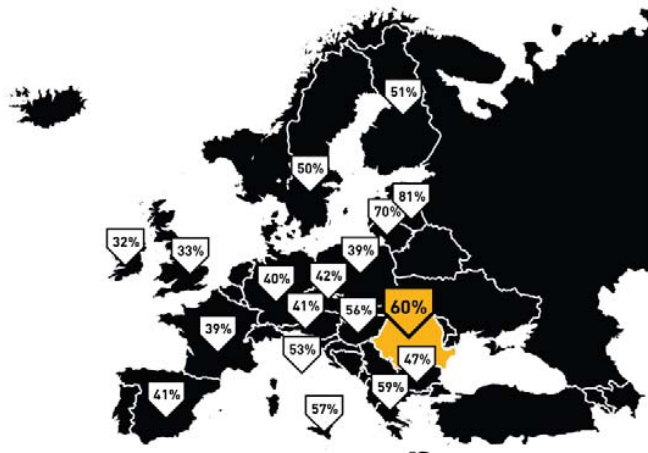
Now, more than half of the Romanian urban population lives in so called "match boxes" because of their small dimensions. Despite the fact that there are similarities between these constructions and several dwellings from the Western Europe, the Romanian blocks of flats have different characteristics and origin. For example, they were not designed for a category of disadvantaged people; they simply represented the only type of new dwellings. Besides, the urban development and the architectural operations were part of a system which dealt with the general planning. This includes the economic aspect as well as the intention of creating a new society

The overall quality of these constructions has degraded, leading to a decrease in the prices of each apartment. In the long term, this might mean considerable social and economic issues. In order to prevent this, several measures have been taken, such as rehabilitation programs, which are very few in number and only bring partial and uncoordinated solutions [4]. It is important to realize that the rehabilitation of these neighborhoods cannot rely only on solving some technical issues. Instead, it should be based on a holistic approach so that the final outcome would be a complex and efficient regeneration program which takes into account all aspects: spatial, social and economic.

The highest percentage of residential constructions built between 1961 and 1990 was reached by Estonia with 81% and the lowest by Ireland (32%), while Romania's percentage is rather high (60%). In addition, when it comes to the number of apartments inhabited by owners, Romania is placed first with approximately 96%. This means that only 4% of the inhabitants are tenants, whereas in Switzerland the percentage of tenants is 65%, as shown in Fig. 1. Above all, when it comes to the ratio between the square meter allocated to each person, Romania finds itself at the lower end of the list with

only 20 m<sup>2</sup>/person, with South Europe providing 31 m<sup>2</sup>/person and North-West Europe leading with 36 m<sup>2</sup>/person [5].

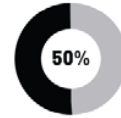
#### APARTMENTS BUILDINGS IN EUROPE



#### Europe

**30m<sup>2</sup>**

Average residential floor space capital per apartment in the EU.



Believe that dwelling is important for the quality of life.



Of the inhabitants in EU are the tenants of their flats.



Of the heating energy is saved by optimization.

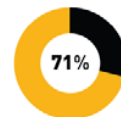
#### APARTMENTS BUILDINGS IN ROMANIA



#### Romania

**20m<sup>2</sup>**

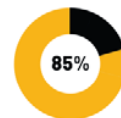
Average residential floor space capital per apartment.



Believe that dwelling is important for the quality of life.



Of the inhabitants are the owner of the flats.



Of the heating energy is saved by optimization.

Fig. 1 Statistic comparison of the collective housing stock between Europe and Romania

Buildings are great energy consumers, thus contributing significantly to the greenhouse effect and climatic change. Heat protection of the building during winter, as well as in summer must be ensured, using modern techniques that are applied to the outer envelope of the buildings in order to provide adequate insulation and overall air tightness of the buildings and their openings.

Retrofitting older buildings is one of the most important issues in Europe towards having CO<sub>2</sub> and GHG emissions reduction and energy efficiency. According to European statistics, in 2009 European households were responsive for around 70% of the total final energy use in buildings, where space heating having the highest end-use consumption mark in EU houses [6]. It is clear that the policies and strategies

addressed to the retrofitting of this stock segment are essential. Currently one of the most debated issues is to find locally adapted strategies that, considering the 20-20-20 EU policy can be applied on the existing building stock [7], thus offering alternative and innovative solutions in order to achieve cost-optimal energy performance of buildings adapted to the current market [8].

Regarding the CO<sub>2</sub> emissions per useful built area, Romania is placed somewhere at the middle of the list, producing around 57 kg CO<sub>2</sub>/m<sup>3</sup>. The lowest quantity of CO<sub>2</sub> emissions is given by Norway with 5 kg CO<sub>2</sub>/m<sup>3</sup>, while Ireland is the highest (122 kg CO<sub>2</sub>/m<sup>3</sup>). The paper is focused on a possible adaptive design scenario of the block of flats having one of the most used large prefabricated concrete

panels building typologies as background. First, some details regarding the existing housing stock in Romania and the chosen building model are presented. Then the adaptive design concept is presented, referring to the problems that the building user are facing and how the adaptive scenario is implemented starting from the apartment level, to the building and finally to the surrounding district. Finally, Life Cycle Assessment possibilities are addressed.

## II. THE COLLECTIVE HOUSING STOCK IN ROMANIA

In Romania, the buildings represent 1.8% of the existing building stock and house 52.8% of the total urban population (Fig. 2). Even though they buildings have only reached half of their intended lifespan, they no longer meet the current living standards [9].

At a national level, the most common project types were [10]:

- P+4: project types 770, 744, 994, 1,013-1,168, 1,340, 1,586, 2,926; 1,399;
- P+8: project type 772.

In Timisoara these typologies were built at the course of three stages of urban development [11].

- First stage: 1962-1975 – most common project type: “T744R”;
- Second stage: 1975-1982 – most common project type “770”;
- Third stage: 1982-1989 – most common project type “1340”;

Every project typology was designed from precise and rationally dimensioned precast building parts that would be shipped to the building site and assembled in the shortest time possible.



Fig. 2 Example of collective housing



Fig. 3 Project types distribution in Timisoara: 1962-1975, 1975-1982, 1982-1989



Fig. 4 Example of T770 distribution in major cities of Romania - Arad and Bucharest



Fig. 5 Example of model T770 distribution in Timisoara



### A. The T770 Typology

The 770 is one of the most common typology of five-storey residential unit in Timisoara. It has been built extensively throughout the entire country during the 70s and the beginning of the 80s and offered the lowest building standards. This model can be found in almost all the neighborhoods, built during that period in major cities of Romania: Arad, Cluj, Brasov, Bucharest, Iasi and Ploiesti (Figs. 4 and 5).

The model was designed to withstand high level seismic activities and could be combined in different ways in order to obtain a variety in the planning and building of new neighborhoods. However, the repetitive pattern can still be

perceived, producing a sense of confusion, as the neighborhoods have no visual identity.

In the case of the 770, 68 different components were used, ranging from vertical exterior and interior walls, ceilings, staircases and even bathroom units. The particularity of this model is represented by the five possible bay dimensions measuring 2.40, 3.00, 3.30, 3.60 and 5.40 meters.

The 770 is based on three main subtypes: Pa, Pb and Pc (Fig. 7). Out of these the Pa subtype is most present in the West and Center of the country, while the Pb in the South and East. The Pc subtype is spread across the country, but less compared to the other two subtypes.



Fig. 6 Model T770 subtypes

Each of the twelve subtypes represents one block of flats ranging from 10 apartments to 20 apartments that are bound together to form a building row. Several connection types are defined, determining different positions of the blocks in the row. The connections imply changes in the position of the balconies and in a few cases, modification of the floor plan (D and F, for Pc1 and Pc2 subtypes). Thus, there are blocks that can function as individual buildings (CC 'end-end'), blocks that represent the end of a building row (MC, CM 'end-middle'), intermediary blocks (MM 'middle-middle') or corner continuation of the rows (LM, LC) (Fig. 7).

Connections	Code	Description
End	O,F	Mark the beginning/end of a row
Attached	M,R	middle connection- blocks of flats continue aligned one next to another R-with a structural joint between the blocks
Corner	D,L	90 degree angle corner

Fig. 7 Model T770 connection types

By taking into account all possible types of connections that can be applied to the 12 subtypes, we get 88 different blocks of flats, all starting from the same 68 prefabricated building components.

### III. ADAPTIVE DESIGN CONCEPT

Due to the large number of existing collective dwellings and since new constructions represent less than 10% of the total building stock [12], we considered our approach more important because of the greater impact it can have on the CO<sub>2</sub> and other green-houses gas emissions.

Stating from the improvement of the quality of life, the project generates a sustainable future for the blocks of flats. It targets a minimum CO<sub>2</sub> emission level for the whole project, so as to value most the idea of retrofitting.

It is not only about creating something new, but also taking something old and using it in a new and improved way, extending the lifespan of existing buildings. From the social perspective, a solution that could fit the inhabitant's exact needs can be developed. The design intends to improve the overall quality of life not only at the apartment level, but also on a larger scale, on the district level (Figs. 8-10).



Fig. 8 Existing collective housing - District view

An active core element is placed in the upper newly created level that acts as a distributed power plant. Highly efficient thermal collectors are introduced to enable a solar cold system to be fed. The system feeds an absorption machine with heat, which in turn produces cold water that flows through an integrated circuit in a false ceiling (cold ceiling). This is rounded off with a photovoltaic network of the façade and a hybrid system on the roof.

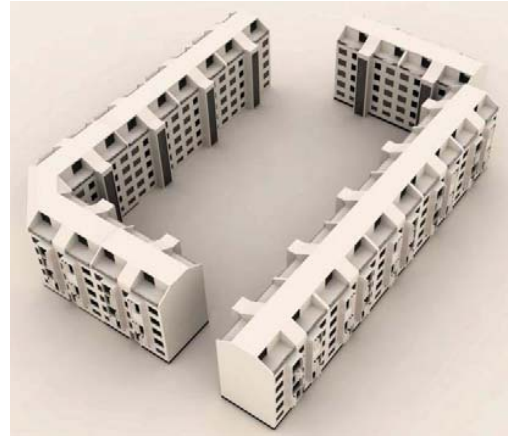


Fig. 9 3D model of the new district



Fig. 10 3D Rendering street view

An integrated "smart grid" connection is introduced. The building connected to the new power network becomes both a receiver, as well as energy distributor. Today, governments and power companies across the world have recognized that the traditional grid, which has not significantly changed over the last decade, must be replaced by more efficient, flexible and intelligent energy-distribution networks, called "smart grids" [13]. These are digitally monitored/controlled, self-healing energy systems that deliver electricity or gas from generation sources, including distributed renewable sources, to the consumers. By optimizing power delivery and facilitating two-way communication on the grid, the introduction of these networks enables end-user energy management. The power disruptions are minimized and only the required amount of power is transported. The results are a lower cost to the utility and the customer, more reliable power, and reduced carbon emissions [11].

Air tightness and insulation are two aspects helping to reduce operating costs and save energy. Therefore, a special

focus is laid on those aspects for the project. The entire building fulfills all thermal requirements and is absolutely tight. The openings consist of triple layered glass panels facing the south and double layered towards the east and west to assure additional air-tightness and to remove any thermal losses. The idea uses two different types of insulation in dissimilar layers. One layer of insulation is located within the

existing prefabricated concrete panels. In order to enhance the air-tightness, as well the heat transmission coefficient, a second layer of insulation is wrapped all around the outer shell. This layer is made of mineral wool. These two, combined with carefully selected materials offer the following intended heat transmission coefficient (Figs. 11 and 12):

## Exterior Wall

Exterior wall,  $U=1,34 \text{ W/m}^2\text{K}$   
created on 28.10.2016

### thermal protection

$U = 1,34 \text{ W/m}^2\text{K}$

EnEV Bestand\*:  $U < 0,24 \text{ W/m}^2\text{K}$

excellent insufficient

### Moisture proofing

Dries 35f days

Condensate:  $61 \text{ g/m}^2$

excellent insufficient

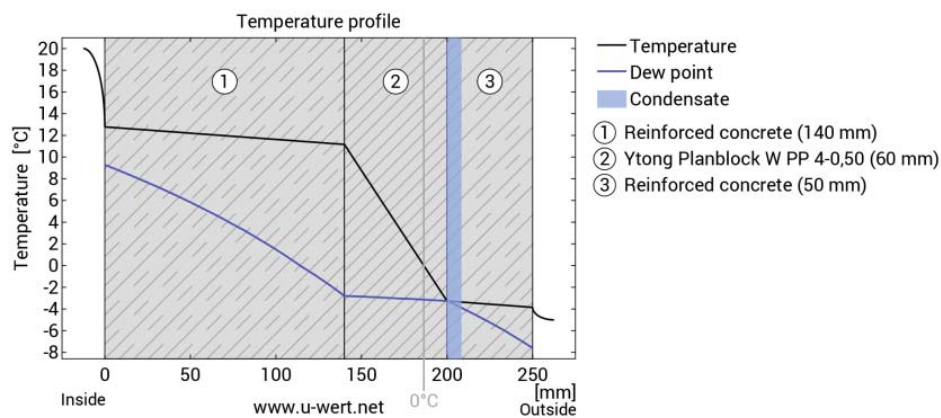
### Heat protection

Temperature amplitude damping: 12

phase shift: 7,5 h

Thermal capacity inside:  $220 \text{ kJ/m}^2\text{K}$

excellent insufficient



Temperature and dew-point temperature in the component. The dew-point indicates the temperature, at which water vapour condensates. As long as the temperature of the component is everywhere above the dew-point temperature, no condensation occurs. If the curves have contact, condensation occurs at the corresponding position.

### Layers (from inside to outside)

#	Material	$\lambda$ [W/mK]	R [m <sup>2</sup> K/W]	Temperatur [°C]		Weight [kg/m <sup>2</sup> ]
	Thermal contact resistance*		0,130	min	max	
1	14 cm Reinforced concrete (2%)	2,500	0,056	12,8	20,0	336,0
2	6 cm Ytong Planblock W PP 4-0,50	0,120	0,500	-3,3	11,2	30,0
3	5 cm Reinforced concrete (2%)	2,500	0,020	-3,8	-3,3	120,0
	Thermal contact resistance*		0,040	-5,0	-3,8	
	25 cm Whole component		0,746			486,0

Fig. 11 Existing building envelope



## Exterior wall

Exterior wall,  $U=0,188 \text{ W/m}^2\text{K}$   
created on 28.10.2016

### thermal protection

$U = 0,188 \text{ W/m}^2\text{K}$

EnEV Bestand\*:  $U < 0,24 \text{ W/m}^2\text{K}$

### Moisture proofing

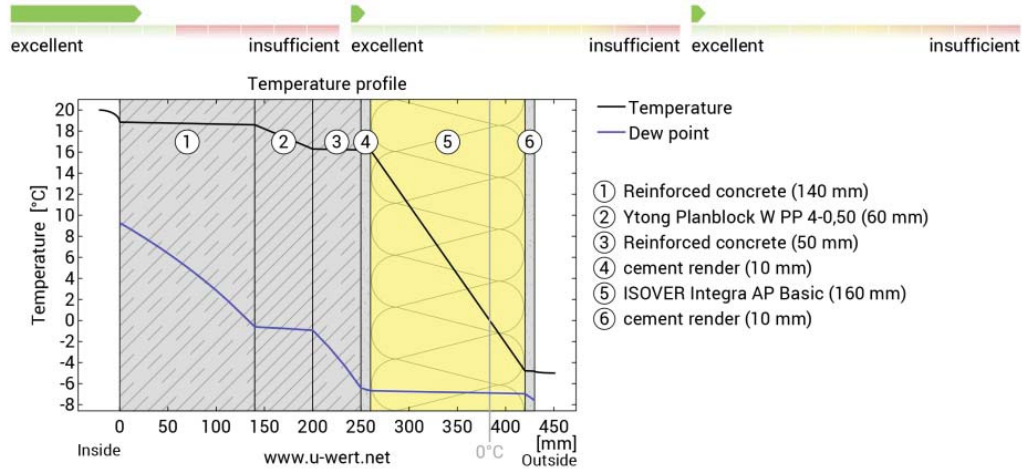
No condensate

### Heat protection

Temperature amplitude damping:  $>100$

phase shift: non relevant

Thermal capacity inside:  $416 \text{ kJ/m}^2\text{K}$



Temperature and dew-point temperature in the component. The dew-point indicates the temperature, at which water vapour condensates. As long as the temperature of the component is everywhere above the dew-point temperature, no condensation occurs. If the curves have contact, condensation occurs at the corresponding position.

### Layers (from inside to outside)

#	Material	$\lambda$ [W/mK]	R [m <sup>2</sup> K/W]	Temperatur [°C] min max	Weight [kg/m <sup>2</sup> ]
	Thermal contact resistance*		0,130	18,9 20,0	
1	14 cm Reinforced concrete (2%)	2,500	0,056	18,6 18,9	336,0
2	6 cm Ytong Planblock W PP 4-0,50	0,120	0,500	16,3 18,6	30,0
3	5 cm Reinforced concrete (2%)	2,500	0,020	16,2 16,3	120,0
4	1 cm cement render	1,400	0,007	16,2 16,2	20,0
5	16 cm ISOVER Integra AP Basic	0,035	4,571	-4,8 16,2	no information
6	1 cm cement render	1,400	0,007	-4,8 -4,8	20,0
	Thermal contact resistance*		0,040	-5,0 -4,8	
	43 cm Whole component		5,332		>526

Fig. 12 Existing building envelope



Fig. 13 The existing inner courtyards

The inner courtyards, now fully occupied by cars and garages (Fig. 13) are remodeled. The once grey, unused space

is given back to the community and transformed into a positive space (Fig. 14).

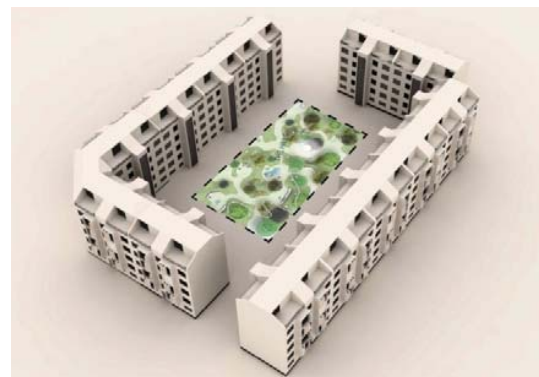


Fig. 14 Aerial view of the inner courtyard

### A. Limiting the Energy Demands

This will be accomplished by reducing the amount of energy consumed for heating, cooling and lighting. In a more specific way, for better heating and cooling energetic performance, the thermal transmittance of the existing concrete wall is improved by adding an insulating layer of mineral wool that will bring the overall U value for the full/opaque walls to around  $0.15 \text{ W/m}^2\text{k}$  – in accordance to passive renovation standards, EnerPHit [14]. By replacing the existing windows with energy efficient Low-E solutions, we will create a new thermal envelope that is also airtight. Together with this, we will enlarge the window bays in order to allow for more sunlight to come inside the apartments, this will also allow an easy connection at a further time of the extension modules. By using light-shelf's shading devices we allow a further penetration of sunlight in the rooms reducing the necessity for artificial lightning during daytime. Another passive mean to improve daytime lighting will be the use of high reflexivity materials and colors for flooring and paints inside the rooms.

### B. Active and Passive System

A passive house standard retrofitting and an improvement of the daylight conditions will lead to a consistent energy reduction. The heating is improved by reusing the District Heating System along with solar heating for domestic water. Radiant floors ensure the comfort conditions inside the apartments as well as a reduction in fuel consumption and operating price. Hybrid ventilation system that mechanically provides fresh air is also responsible for free cooling during the intermediate seasons by activating the thermal inertia of the structural concrete walls. Additionally, passive adiabatic cooling provides a new feature that the current blocks of flats do not have. Furthermore, reusing and treating the rainwater as domestic water, will reduce the overall water consumption. The top extensions are a support for hybrid thermal and photovoltaic panels, as well as the active core of the installed renewable energy distribution network (Fig 15). They can be considered as micro power plants that generate electrical energy, covering the common facilities energy yield, while the surplus is being injected into the local electricity grid.

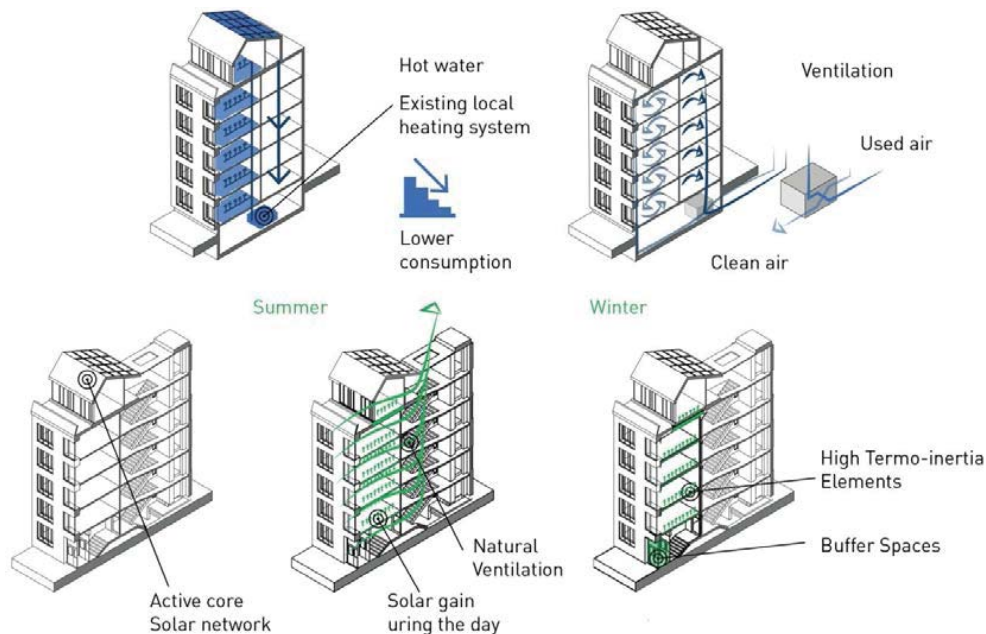


Fig. 15 Operation diagrams

By installing combined PV-solar panels, the energy requirements for both the heating system running on low temperature radiant flooring and for the electrical consumption needed for pumps and ventilators used for the ventilation system are met. The rest will be used on the common areas and by the inhabitants. To further reduce electrical energy consumption sensor controlled LED lighting devices and energy efficient appliances are to be implemented

### C. Accessibility for Disabled People

The existing staircases and access routes were not designed to accommodate disabled inhabitants. In order to allow for a

high accessibility level, a new staircase was designed. The new staircase will have the intermediary landing extended towards the outside, and an elevator added on the exterior of the building within a metallic structure with lightweight enclosures (Fig. 16).



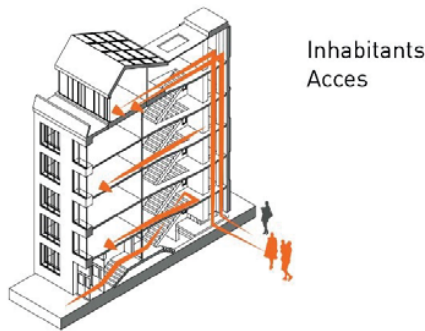


Fig. 16 New circulation system diagram

#### *D.Improving the Dwelling Unit*

In order to increase the quality of life for the inhabitants the concept plans to upgrade the apartments in accordance to contemporary living standards. This will be achieved by:

- redesigning the interior space;
- extending the surface of the apartments by resizing the existing balconies and/or using them as an extension of the apartments;
- improved natural lighting conditions;
- upgrading the existing building system services.

##### *1. Redesigning the Interior and Extending the Floor Area*

The existing dwellings are characterized by insufficient space, poor lighting, functions that are difficult to utilize and little opportunities for customizing the apartments. It can be easily noticed that people tend to use spaces in many different ways and that the final destination is never the one it was designed for. Thus, dwellings have many unused spaces that almost every time ends up as storage places. This project tries to change this through better space configuration and extra floor surface.

This floor area is extended through remodeling the existing balconies that increase the floor area of the existing rooms or create a multifunctional exterior room that increases comfort. Users try on a large scale to extend their living areas either by creating balconies (the ground floor usually did not have balconies) or by extending the existing ones or transforming them into storage area or extending the rooms by tearing down the walls between the room and the old balconies (Fig. 17). This happened due to the small size of the balcony and the need to extend the living space and use a space that is otherwise felt as unused and inefficient.

The project wants to overcome this issue by extending the existing balconies in order to provide a comfortable polyvalent outdoor room for the inhabitants of the apartments. This need was identified especially in the case of ground floor apartment owners who tried to extend their balconies or to create small individual gardens (usually without any legal formalities) in order to gain a personal outdoor space. The idea of an intermediate space/buffer zone used as a thermal regulator has been used repeatedly in traditional Romanian architecture [15]. Therefore, the existing balconies can become buffers that

can be opened/configured in various ways towards the interior or the exterior.



Fig. 17 Private ground floor extension

##### *2. Upgrading the Existing Building System Services*

One of the most foreseen factors in current rehabilitation programs available in Romania is the building services of the energy losses due to their lack of maintenance.

By reusing a large part of the existing ducting channels, we reduce the impact on the structural system and facilitate the integration in apartments that have been renovated by their owners before.

The initial ventilation system was designed to provide an efficient and continuous extraction of used air through the bathroom and kitchen via a multiple chamber extraction tubing in order to avoid contaminated air from the lower floors entering the upper levels. Bad building process and disregard of the original plans led to a single tube that was soon demolished by the inhabitants due to its inefficiency. This led to the need for a new ventilation system and ducting channels. The aluminum ducting for the new ventilation system will be integrated into a new vertical ducting channel that will pass through the stairway and distribute to the apartments at each level.

The channel will house a set of tubes for each apartment, in accordance to the total number of rooms (except the bathroom).

It will be made out of light structure walls: a thin sheet metal frame enclosed plasterboards. The same structure is used for the false ceiling that will hide the horizontal ducting in the hallway and the entry area of each apartment where the height of the room can be decreased. This system will provide fresh air brought in through the Canadian shaft and a heat exchanger to each apartment. This ducting shaft will also house the plumbing for the kitchen of the middle apartment that was relocated in order to provide a better use of interior space. The used air will be extracted through the existing ducting shafts from the bathroom and kitchen.

These shafts will also house the new plumbing system together with the grey-water recycling system. The collecting basins and filtering systems will be placed in the semi-basement; together with them will be all the technical equipment for the ventilation system and the central heating system – solar panel infrastructure and cogeneration system linked to the existing central heating network. The ducts for the heating agent will be running through the newly created

shaft. The inverters for the PV will be placed in the extension module on the terrace in a specially designed niche dissimulated in the furniture.

#### IV. LIFE CYCLE ASSESSMENT

In order to maintain the environment for future generations makes it is not only about considering the emerging environmental issues, but also to make progress in defining cost-effective strategies that are environmentally adaptable and to take actions to apply or enforce the from such discussion resulting measures.

Protecting the environment has become a strategic issue of constant increasing importance for the present industry and the business sector. Industrialists are increasingly more interested towards being able to look holistically at consequences that their operations might affect the surrounding environment.

Life-cycle assessment generates concepts for dealing with the future complex environmental issues [16]. Today new generation Green Building Standards offer alternative guidelines and codes to future new building [17].

In ordinary cases the existing building blocks will degrade in time, their inhabitants will commute and the buildings will become empty shells. The adaptive design concept however, improves the quality of life inside them, and thus, the buildings themselves, making them better from most points of view and lastly and most important, it prolongs a buildings lifespan considerably.

#### V. CONCLUSIONS

Although the buildings made out of large prefabricated concrete panels are now outdated they can be improved in order to ensure a better quality of life for the inhabitants within. Also, as shown in Fig. 1, they have a huge energy savings potential. The high thermal mass of these buildings can be exploited in order to further reduce the overall energy consumption.

Also due to today's massive evolution of technology and the increased connectivity has led to a change in social routines. Social interaction leaves the apartment premises and develops inside restaurants, cafes, or similar. Therefore, block neighborhoods become sleeping neighborhoods which require increased comfort conditions. By freeing the inner courtyards, now entirely occupied by cars, and transforming them into a positive space, social interaction is brought back to the community.

These buildings had a major impact on the urban environment planning and development we see today. Due to their wide spread and construction similarities, standardized adaptive design strategies are an efficient ways to make them better overall.

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