Opportunities and challenges in sustainably retrofitting the large panel concrete building stock

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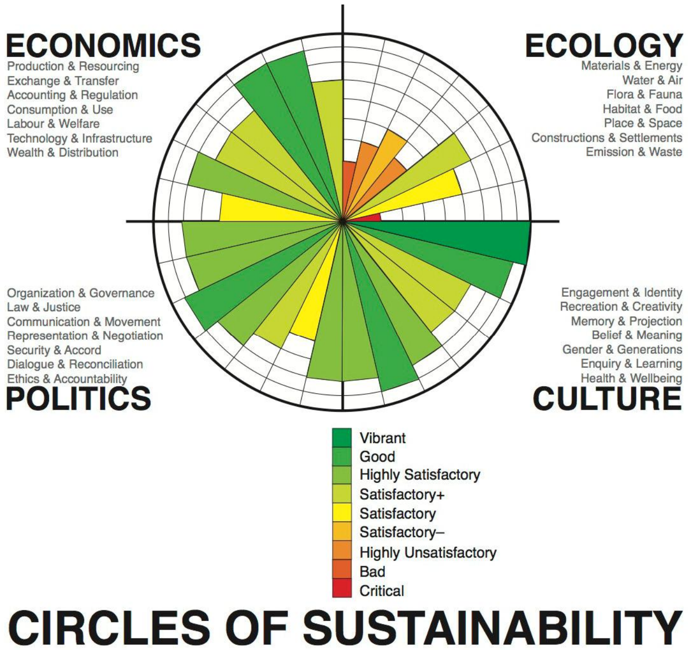
Foreword

According to *Wikipedia*, *Sustainable Development* is an organising principle for human life on a finite planet. It posits a desirable future state for human societies in which living conditions and resource-use meet human needs without undermining the sustainability of natural systems and the environment, so that future generations may also have their needs met. The term 'sustainable development' rose to significance after it was used by the *Brundtland Commission* in its 1987 report *Our Common Future*. In the report, the commission coined what has become the most often-quoted definition of sustainable development: "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*".

The concept of sustainable development has been, in the past, most often broken out into a three constituent domains: *environmental sustainability*, *economic sustainability* and *social sustainability*. However, many other possible ways to delineate the concept have been suggested. For example, the *Circles of Sustainability* approach (http://en.wikipedia.org/wiki/Circles_of_Sustainability) distinguishes the four domains of: economic, ecological, political and cultural sustainability.



A Circles of Sustainability representation - in this case for Melbourne in 2011.
(http://en.wikipedia.org/wiki/Circles_of_Sustainability)

Sustainable development is one of the greatest challenges of the modern world. Sustainability includes environmental, economic and social aspects, all contributing to a durable development of the society. From assessment like the one with the Circle of Sustainability, supported by the four pillars, it results that current focus is usually unbalanced due to the weakness of environmental component. Scores for Constructions & Settlements are average, while for Materials & Energy Emissions and Waste, both of them very important for construction, are bad or critical.

Buildings consume 40% of our planet's materials and 30% of its energy. Their construction uses up to three million tons of raw materials a year and generates 20% of the solid waste stream. If we want to survive in our urban future, there is no option but to build in ways which improve the health of ecosystems. Understanding the concept of ecological sustainability and translating it into practice as sustainable development are the key tasks for today's built environment professionals. The skill and vision of those who shape our cities and homes is vital to achieving sustainable solutions to the many environmental, economic and social problems we face on a local, national and global scale *(Peter Graham, Building Ecology: First principles for a sustainable Built Environment, 2002).*

The building industry plays an important role both in national and global economies. However, the approach on *sustainable constructions* has different priorities and purposes in various countries. According to concepts of *Circles of Sustainability*, the *sustainable construction* can be regarded as a subset of sustainable development and contains a wide range of issues, i.e.: re-use of existing built assets, design for minimum waste, reduction of resources and energy consumption and of pollution.

The *sustainability of building environment* is a larger concept than *sustainable constructions*, because it includes not only the new constructions, but also the existing ones. It is estimated that there are 25 billion m^2 of useful floor space in the EU27, Switzerland and Norway (*BPIE, 2011: Europe's buildings under the microscope*). The gross floor space could be concentrated in a land area equivalent to that of Belgium (30,528 km^2). Non-residential buildings account for 25% of the total stock in Europe and comprise a more complex and heterogeneous sector compared to the residential sector. A substantial share of the stock in Europe is older than 50 years with many buildings in use today that are hundreds of years old. More than 40% of our residential buildings have been constructed before the 1960s when energy building regulations were very limited. A large boom in construction was in the period 1961-1990, and the housing stock in most European countries more than doubled in that period. The performance of buildings depends on a number of factors, such as the performance of the installed heating system and building envelope, climatic conditions, behaviour characteristics (e.g. typical indoor temperatures) and social conditions (e.g. fuel poverty). Data on typical heating consumption of the existing stock by age shows that the largest energy saving potential is associated with the older building stock, where in some cases, buildings from the 1960s are worse than buildings from earlier decades. The lack of sufficient insulation of the envelope in older buildings was also reflected through the historic U-value data, which comes with no surprise as insulation standards in those construction years were undeveloped.

The building sector is one of the key consumers of energy in Europe, where energy use in buildings has seen overall a rising trend over the past 20 years. In 2009, European households were responsible for 68% of the total final energy use in buildings. Energy in households is mainly consumed by heating, cooling, hot water, cooking and appliances. The dominant energy end-use (responsible for around 70%) in homes is space heating. Gas is the most common fuel used in buildings while oil use is highest in North & West Europe. The highest use of coal in the residential sector is in Central & Eastern Europe, where also district heating has the highest share of all regions. Renewable energy sources (solar heat, biomass, geothermal and wastes) have a share of 21%, 12% and 9% in total final consumption in Central & Eastern, South and North & West regions, respectively (*BPIE, 2011*).

That is why transnational research projects as ***Inspire – Integrated strategies and policy instruments for retrofitting buildings to reduce primary energy use and GHG emissions***, financed by the Eraco-Build Sustainable Renovation Program are so important (*Botici et al., 2014: Sustainably challenges of residential reinforced - concrete panel buildings. Urbanism. Arhitectură. Construcţii. Vol. 5, No. 2, 2014*).

The research reports and papers collected in this volume have been presented and debated in the frame of an International Seminar entitled "***Opportunities in sustainably retrofitting of large***

panel reinforced concrete building stock". A significant part of the printed contribution summarizes the research activity developed at The Politehnica University of Timisoara, focused on the rehabilitation of prefabricated large panel reinforced concrete blocks of flats; a building configuration intensively applied in Romania and in Timisoara, in the period 1962-1989.

I am sure that the reader, either specialist in the field or not, will find in this volume a lot of interesting and useful information.

Prof. Dan Dubina, C.M. of Romania Academy

Timisoara, January 2014

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SUMMARY OF THE INSPIRE PROJECT
Integrated strategies and policy instruments for retrofitting buildings to reduce primary energy use and GHG emissions (INSPIRE)

Current energy policy and climate mitigation goals require distinct reductions of the primary energy demand and greenhouse gas emissions in the building sector. Thereby the existing building stock poses a special challenge since it proves very difficult to activate the large existing reduction potentials because of a variety of institutional, economic, informational and social reasons. So far clear-cut and widespread technically and economically optimized renovation strategies for the existing building types are not established for the relevant actors or public authorities drafting policy instruments and subsidy programmes.

There is a need for guidelines and standardized approaches for different building types aiming at reducing the complexity which arises from the vast space of potential energy-efficiency, retrofit and renewable energy production options. Such guidelines facilitate the dissemination of new technologies, lower their costs as well as technological and economic risks. Furthermore, there is a certain lack of knowledge regarding the social and the political dimension of building retrofit projects; the role of learning, networks and actors as well as institutional settings. Extensive analysis is needed on how different instruments, such as legal and economic approaches as well as networking can support innovation, the formation of new knowledge and learning processes, which will lead to the development and diffusion of retrofit measures and technologies that are cost-effective, sustainable and assure durability and structural safety.

Project Partnership

- *TEP Energy GmbH Zurich, Switzerland* – Project coordinator
  Martin Jakob, Hristina Chobanova, Claudio Nägeli
- *Econcept AG, Zurich, Switzerland*
  Walter Ott, Roman Bolliger, Stefan von Grünigen
- *Aalborg University, Denmark*
  Arne Remmen, Davide Maneschi, Mette Mosgaard, Christoffer Kirk Strandgaard
- *IIIEE, University of Lund, Sweden*
  Bernadett Kiss
- *University of Timisoara, Romania*
  Viorel Ungureanu, Adrian Ciutina, Alexandru Botici, Dan Dubina, Daniel Grecea, Iulia Ţuca, Florea Dinu, Valeriu Stoian, Carla Toduţ, Sorin-Codruţ Floruţ
- *VTT Research Centre, Finland*
  Ludovic A. Fülöp, Asko Talja

1 SCOPE AND OBJECTIVES

The increasing number of building retrofits that can meet the requirements of advanced building standards is an indicator for the availability and feasibility of energy-efficient technologies. The economic effectiveness and viability of such buildings, however depends on many factors, e.g. scope, time horizon, interest rate as well as energy price expectations and preferences. It has not yet been systematically analysed how to define, promote and support technically and economically optimized retrofit strategies to make sure the ambitious targets of primary energy reduction and CO_2 mitigations for different types of buildings in the existing stock can be achieved at lowest cost.

The INSPIRE project provides an overview and systematic assessment of retrofit strategies and policy portfolios, through comparative case study analysis. This knowledge is critical in designing, developing, implementing and evaluating policy instruments supporting effective retrofit strategies for the future.

The goal of the project was to systematically address the above stated questions for different building types and in different institutional or country contexts. The research resulted in a) guidelines and specific inputs for retrofit strategies for different building types and energy-related building standards as well as b) intervention points for policy approaches as well as institutional settings and design guidelines for policy measures to foster energy-efficient retrofitting. Results may be used in building retrofit strategy tools both on technical and on policy level.

2 RESEARCH ACTIVITIES

The main research activities of the project were divided into work packages.

WP 1: Techno-economic assessment of energy-efficient building retrofit strategies (current technologies)

The objectives of the WP1, based on the project description, are:

- Currently available technologies and retrofit practices will be evaluated with respect to technical performance, primary energy needs, range of application, costs and CO_2 emission reduction potential, for both broadly available and best practice technologies;
- The existing building stock will be classified (country-wise) into the most common BTs with respect to appropriate energy-efficiency retrofit measures: One- and two-family houses, multi-family houses, office buildings, school buildings, etc.;
- For each of these BTs technology mixes to fulfil ambitious energy standards are determined. Focus will be on cost efficient reduction of primary energy consumption and greenhouse gases. Especially, interesting is the exploration of favourable mixes of measures to reduce energy losses of buildings and measures to tap renewable energies within the building perimeter.

The WP was carried out by Econcept AG (responsible) and TEP Energy GmbH, with inputs from all partners.

WP 2: Case studies of sustainable renovation in Eastern and Northern Europe

Scope of WP2 is the adaptation of renovation experience of prefabricated concrete residential buildings in Finland to Eastern European (EE) countries, with special focus on the technological, economic, institutional and policy setting.

Concrete residential buildings represent the largest retrofitting challenge in EE; and one of the best opportunities to substantially improve energy efficiency of residential buildings.

The solutions from WP1, will be reviewed from the points of view of: (i) technological applicability in EE, (ii) compatibility with other, non-energy focused retrofit needs of concrete residential buildings and (iii) economic feasibility in EE markets. Therefore, the solutions will be analysed in a broader perspective, by integrating all the complex aspects of a building retrofit intervention.

The WP 2 was carried out by VTT and UPT.

WP 3: Embodied energy and embodied GHG of energy-efficient building retrofit strategies

In WP 3, the impact of embodied energy and embodied GHG on the performance of building retrofit strategies is explored and integrated into the evaluation framework of WP 1. More precisely it is investigated to which extent primary energy efficiency and GHG mitigation performance and thus, cost-effectiveness is undermined if embodied energy and embodied GHG is included in the considerations.

WP 3 is carried out by TEP Energy GmbH (responsible) and Econcept AG, with inputs from all partners. The contribution of each country typically would include a description of the state-of-the-art of embodied energy and embodied CO2 in the building sector:

- definition and methods used in each country;
- description of data availability and list literature (including provision of copies);
- compilation of some key figures (e.g. kWh and $kgCO_2$ per m^2) of construction elements and building technologies (e.g. wall, window, heating system) and energy-efficiency measures (e.g. wall insulation).

Basic research in WP3 was performed by TEP Energy (responsible) and Econcept for Switzerland.

WP 4: Policy instruments for innovation of energy efficient retrofit measures in existing building

The WP 4 will focus on analysing the role of learning and networking in energy efficient (EE) renovations.

- the challenges of (current) policy strategies with regards to the implementation of EE retrofit technologies will be identified. EE strategies and policy instruments for more EE and cost effective retrofitting in Europe will be reviewed.
- building projects, incl. broadly applied and best practice retrofit measures will be assessed, focusing on the role of knowledge development, learning, networking, actors and institutions. (3) Based on the assessments, key success factors will be identified for the development and implementation of different EE retrofit measures.
- it will be crucial for future design of different policy instruments addressing more efficient energy use in existing buildings. It will also help to identify points of intervention in the technology development and implementation phase (in terms of both new and currently applied solutions) for policy design. Innovative policy instruments will be discussed with the focus on network support.

The WP 4 was carried out by IIIEE (responsible) and Aalborg University.

WP 5: Synthesis

In WP 5, a synthesis is performed to generate guidelines of energy- and CO2-efficient retrofit strategies and tailored policy instruments to foster their diffusion, by country.

This material collects the results of the INSPIRE project with specific focus of prefabricated building typology prevailing in East European countries, including Romanian. The work summarised is most closely (but not exclusively) related with the contents of WP2, so the structure of this work package is described in more detail below.

3 WORK PLAN FOR WP2

3.1 *Scope and content*

The overarching scope of is to facilitate the adaptation of renovation experience of prefabricated concrete residential buildings in Finland to Eastern European countries, with special focus on technological (e.g. architecture, building physics & structure, safety), economic (e.g. business models), institutional and policy settings.

Concrete residential buildings present the largest retrofitting challenge in Eastern European countries; and one of the best opportunities to substantially improve energy efficiency of residential buildings on the large scale in the EU. WP4 will focus on the efficient use of existing best practice technologies highlighted in WP1.

The optimised solutions from WP1 will be reviewed from the points of view of: (i) technological applicability in EE, (ii) compatibility with other, non-energy focused retrofit needs of concrete residential buildings (e.g. architecture, envelope, accessibility etc.) and (iii) economic feasibility in EE markets. Therefore, the solutions will be analysed in a broader perspectives, by integrating all the complex aspects of a building retrofit intervention. There is a broad array of accessible and cost-effective technologies and know-how to reduce energy losses during the operation of buildings; but quite often energy efficiency requirements are not the only focus of retrofitting.

3.2 *Tasks, Milestones and Deliverables*

Task 2-1. Building typologies (Responsible PUT)
PUT will identify the most used concrete building typologies, with focus on their weaknesses (e.g. thermal comfort, ventilation, internal space, accessibility, etc.). PUT will realize the detailed analysis of the five most used building configurations.

Task 2-2 Design in Romania (Responsible PUT)
PUT will study past design requirements in Romania to identify the shortcomings that were designed in large number of buildings; number of buildings erected using these deficient codes. PUT will relate the performance of the five configurations identified in Task 2-1 to the codes used (Were codes applied correctly? What systematic problems their application created?). VTT will assess results from PUT and relate them to similar problems identified in Finland.

Task 2-3. Renovation experience in Finland (Responsible VTT)
VTT will summarise the Finnish experience in maintaining and retrofitting the prefabricated concrete building stock (e.g. phases of erection, technologies used, energy requirement improvements during the years, other improvements and solutions - improve accessibility, over-roofing, ventilation, architecture, etc.). The existing results of research project completed at VTT will be used also in this stage. VTT will deliver the result of this task as a report to PUT.

Task 2-4. Technology overview (Responsible PUT)
PUT (based on WP1 and Task 2-3) will summarize the most commonly used renovation techniques and will identify the most suitable for selected buildings to be analysed. Did the renovation carried out answer properly today’s needs in terms of raw materials consumption, emissions and energy efficiency? PUT VTT will study the possible use of future technologies in context of replacing the present ones and prepare the data for WP3.

Deliverable 2-1: Worksop for problem identification and search of suitable refurbishment proposals – Responsible PUT

Task 2-5. Retrofit market in Romania and Eastern European countries (Responsible PUT)
PUT will study the retrofit market in Romania. Focus on key players, financial instruments, and major bottlenecks in the financing process. Can they be corrected by legislative measures? Who has to act? VTT will extend the statistical review to other Eastern European countries. (This task relates the analysis to results of WP3).

Task 2-6. Business models (Responsible VTT)
VTT will propose business models to facilitate the retrofitting. VTT will present 4-5 options of financing models for an intervention (e.g. owner financed, added value cover the price of the retrofit, loans, state subsidies, local authority subsidies, energy bonus systems). PUT will analyse and refine the models. Why are they not working now? Can policy intervention change the balance (e.g. taxing, subsidy, state guaranty on loan, etc.)?

Deliverable 2-2: Report on the market situation and business opportunities in refurbishment – Responsible VTT

Task 2-7. Implementation of technology (Responsible VTT)
Analyse and adapt selected retrofit technologies to a number of two examples from the five defined in Task 2-1. Propose 3 retrofit alternatives for each configuration. One example worked out by VTT and improved/completed by PUT; the other worked by PUT and re-

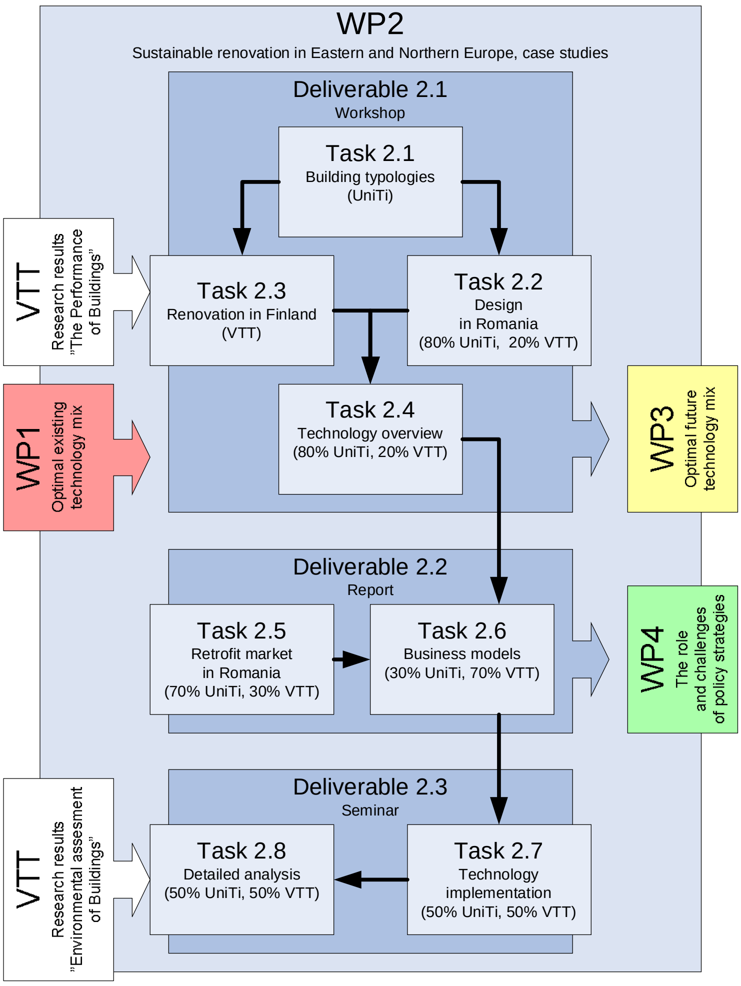
viewed by VTT. Focus on the full picture, not only one aspect of the problem. E.g. is this building market worthy? What is its value? What are the main deficiencies driving the price down? Are they related to the building itself (e.g. internal space inefficient, look, accessibility, low energy performance, etc.), or to the area (e.g. no school, no roads, bad connection to public transport, criminality, etc.), or are global (e.g. high unemployment in the whole country, etc.).

Task 2-8. Detailed analysis (Responsible PUT)
Select one retrofit proposal for each example case, and analyse in detail the impact (financial, added value, energy, CO2 etc.). Work out the technical details:
- reorganising internal space affect the safety of structure;
- adding balconies affect the structure;
- over-cladding;
- over-roofing affects the structure & the envelope;
- elevators affect the structure & add accessibility;
- some thermal improvements affect ventilation, ventilation improvements affect heating & cooling needs;
- can larger impact be achieved by a neighbourhood scale intervention?

Deliverable 2-3: Seminar presenting the results for selected actors in the refurbishment business – Responsible PUT

3.3 *Structure of WP2*

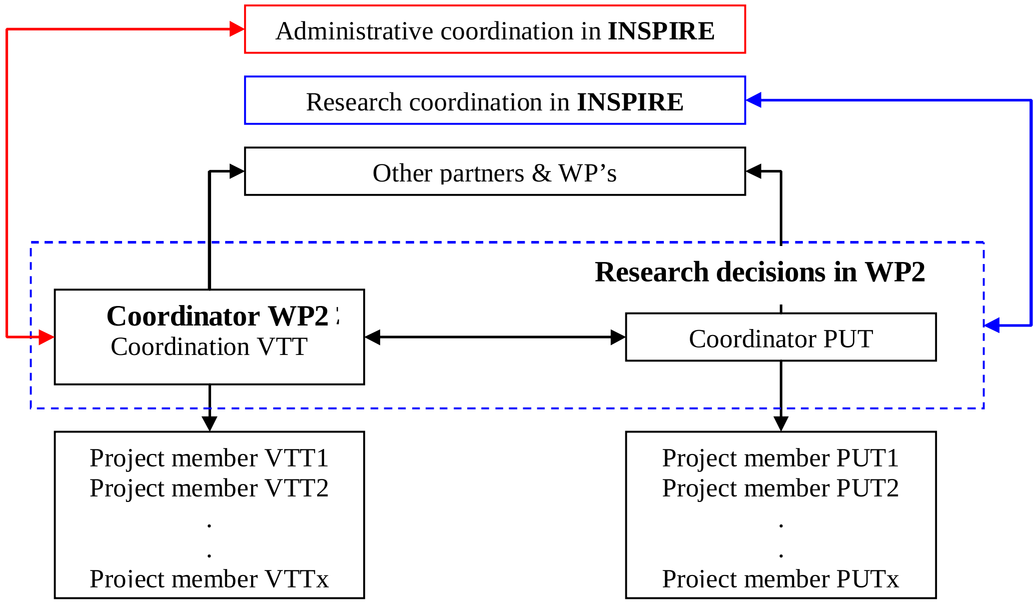
The chart below presents the structure of WP2 and its relationship with WP's of INSPIRE.



3.4 *Implementation and management*

The close cooperation of VTT and PUT in WP2 calls for an implementation and management plan clarifying the responsibilities of each partner, and structures within the WP for efficient decision making.

On the other hand, due to its complexity the WP requires a clear coordination, within the two organizations, of the teams carrying out the Tasks. In order to respond to these two requirements the below management structure is used within WP2.



The Coordinator of WP2 (VTT) is responsible for administrative management of WP2, and official communication to and from the project manager of INSPIRE. VTT is also responsible to make sure that deliverables of WP2 are provided on schedule.

In research questions, the Coordinator from VTT and the Coordinator from PUT have equal standing in communicating with other partners and the coordinator of INSPIRE.

The Coordinator for VTT is responsible for detailing the work requirements for Team members in VTT, for overseeing progress in VTT tasks, and to produce the documents containing results of those tasks (see Task descriptions).

The Coordinator for PUT is responsible for detailing the work requirements for Team members in PUT, for overseeing progress in PUT tasks, to produce the documents containing results of those tasks (see Task descriptions).

Within WP2, the detailed content of work in each task will be defined by the Coordinator from VTT and PUT together. Research decisions, based on the progress of work, will be taken by agreement. If no agreement can be reached, the Research Coordinator of INSPIRE will take the decision.

The Coordinator for VTT is Senior researcher scientist *Ludovic Fulop*, and the coordinator for PUT is Professor *Viorel Ungureanu*.

3.5 *Beneficiaries, exploitation of results and impact*

Industrial partners:

- Finnish industry with export potential;
- Eastern European construction companies active in renovation;
- Authorities, both government and local in Romania;
- EU authorities and policy makers.

The results are best used in Deliverable 2-3: where they may be integrated in training material used for energy auditing experts. This assures large scale and long term diffusion of the result of the project.

Opportunities in sustainably retrofitting the large panel reinforced concrete building stock in East Europe

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ABSTRACT: In this introductory paper the intention is to give a glimpse on the building renovation framework in some East European countries. Firstly we highlight the volume of the renovation needs that are expected in the coming years; especially in relation to the panel building stock. Obviously the total need will not be matched by executed renovation works due to the lack of funding and administrative retarding factors. But some business opportunities do exist in the renovation sector, and are foreseen to grow in coming years. Secondly we reflect on the wishes and desired of the occupants of the properties. What kind of renovations they wish to see implemented? How much the existing top-down actions and financial instruments are responding to their needs? As preliminary conclusion it is suggested that a closer cooperation between City Authority and Owner Associations, in order to implement broader scope renovation measures would respond better to the desires of the occupants. Also, energy renovations alone have limited appeal to end user, and co-benefits should be always emphasized.

1 INTRODUCTION

1.1 *Background statistics*

Prefabricated buildings are an important share of the building stock in East Europe. Renovation or replacement of these buildings is a huge undertaking considering that, about 508 thousand apartments are in panel buildings in Hungary and 1/5-1/7 of the population lives in them [Kecskés, Dénes 2000]; or, between 1959 and 1995 1,2 million panel apartments were built in Czechoslovakia hosting today 1/3rd of the population [Krajčovičová *et al.*, 2010]. The numbers are also larger in Commonwealth of Independent States countries where systematic renovation programs are starting e.g. in Saint-Petersburg[1].

Magnitudes are similar in Romania where 6.237.692 inhabitants, 56% in urban population, lived in 89 thousand collective buildings[INNSE 2003]. This is a total of 2.418.460 households of this type, and from the 89 thousand collective buildings about 57 thousand were made of large prefabricated concrete panels.

These building are fast approaching their design service life of 50 years, and extending the service life, both in technical terms and from the point of view of market worthiness, is a huge challenge. Additionally, improving the energy efficiency is a necessity given the energy efficiency targets of the Europe 2020 goals[2].

1.2 *Grounds for the project*

Besides East Europe (EE), a large number of prefabricated panel buildings exist in some Nordic countries, for example in Finland. While in the EE countries the technology was more or less

[1] http://spbren.ru/eng/Projects/5/34956.html
[2] http://ec.europa.eu/europe2020/targets/eu-targets/

compromised by the low quality buildings erected before 1989, Finland is an example proving that most problems of the typology are not inherent. They are simply the result of low quality targets. In fact concrete panel buildings are the choice for new builds in urban districts of Finland even today (see Fig.1).

Figure 1. Ongoing construction using prefabricated concrete panels in Espoo, Finland (2010).

There are differences between the trends of building with panels in Finland and East Europe. For instance, in Finland the building typologies were always more diversified. In most EE countries and certainly in Romania, due to the strong central planning of the socialist regimes a few typologies were built all over the countries with few modifications. This tendency obviously means that errors or inherent weaknesses were multiplied in very large number of buildings.

In EE countries a large number of buildings were built in a short period, again due to the forced drive of central planning. This gave no time for the designers to learn from past mistakes and gradually improve the building configurations. Much more of that gradual improving with time can be observed in Finland.

And finally, the buildings in Finland were planned with higher quality expectations from the start, even if the low quality of prefabricated buildings from 1960-1970's is notorious. Also, a decently functioning administrative framework was there to support the maintenance and refurbishment of the buildings. Contrary, the change of political system in 1990 in East Europe, and the following hesitations in the early 1990's, left an administrative gap with the consequence of the buildings and neighborhoods being neglected for several years.

In this context, the targets of our project were to initiate a knowledge exchange between Finland and some EE countries in order to understand if Finnish know-how could be employed to support underway and upcoming renovation tasks of the panel building stock. Obviously, if the answer would be yes, than Finnish administrative and company know-how could be utilized in the process. So we set up a project to understand both the economic and technological settings. The main questions were:

- What is the market environment for renovation in EE countries? What administrative and legislative background is governing these activities?
- What main drawback the buildings have from architectural, building physics and structural safety perspectives?
- How much of the renovation experience from Finland could be adapted in EE countries, and what adjustments are needed?

- Could we formulate proposals for potentially successful administrative models in these market environments, based on the knowledge acquired in the project and the knowledge of the Finnish experiences?

In this introductory paper, we highlight two important aspects of the renovation environment in Romania, and to certain extent Poland and the Czech Republic. The first is that of market potential in terms of realized and upcoming renovations. The second is some ideas on self-defined renovation needs of the occupants.

2 DRIVERS FOR RENOVATION AND MARKET POTENTIAL

2.1 *Energy targets*

As response to climate change the European Council reconfirmed the EU objective of reducing greenhouse gas emissions by 80–95% by 2050 compared to 1990 levels. Hence, the energy consumption of new and existing buildings has to be reduced as buildings account for 40% of Europe's energy consumption. But annually only about 1.2% of the buildings are renovated and about 0.1% demolished. Even if the 1.2% would be renovated to the highest standards of energy efficiency, renovation alone would deliver almost no reductions in energy use from the built environment[3].

In order to support energy renovation, most governments in Europe are running some sort of renovation subsidy program. In this general context we reviewed the potential for renovation in the period up to 2030 in the Czech Republic, Poland and Romania.

2.2 *Overview of the markets*

Population and dwelling stock are the biggest in Poland, then Romania, Czech Republic and Finland. The level of GDP per capita has been lower in Eastern Europe than in Finland, but the difference in the level of the housing stocks per capita is not so wide. However, the quality of older dwellings is rather poor in Eastern Europe.

Construction markets in European countries have varied much during last years and future forecasts are also changing. Statistics about new construction are more commonly available than about the renovation sector. The important inputs for understanding the market trends are general statistics (e.g. number of inhabitants, cities, economic structure) and building stock statistics, dwelling stock per capita etc.) Dwelling stocks by decades were compared in terms of quantity, size and types.

When it comes to renovation business, renovation needs are often higher than number of renovation implemented. This kind of discrepancy is illustrated by the fact that annual value of housing renovation in Poland and Czech Republic is a little less than 10% of that in Finland. In Romania the budget for housing renovation is only 4% of the Finnish value, while needs are much higher (Riihimäki *et al.*, 2012). The highest value of housing renovation market is in Poland, nearly 3 billion Euros (see Table 1).

Table 1. Value of residential renovation in the Czech Republic, Poland, Romania and Finland[4]

	2006 € mill.	2011 € mill.	average growth (%/a)	2011 €/capita	€/dwelling
Czech Republic	990	1160	3.2 %	110	272
Poland	2650	2950	2.2%	78	216
Romania	680	890	5.5%	40	106
Finland	4650	5650	4%	1047	1995

As the building stock ages, more extensive renovations of structures and building services are required. Renovations will increase in the future as result of the ageing of the building stock, due to efforts to improve the quality of dwellings and because of the need to repair various

[3] http://www.renovate-europe.eu/how-can-we-reduce-energy-demand-in-europe

[4] Riihimäki M., *et al.*, 2012 (Sources, Euroconstruct 2011 and Buildecon: Romania construction market report)

damages. Extensive renovations are generally a long and burdensome process for occupants and housing corporations. Several renovations may be needed in a block of flats at the same time, which constitute a lasting financial burden.

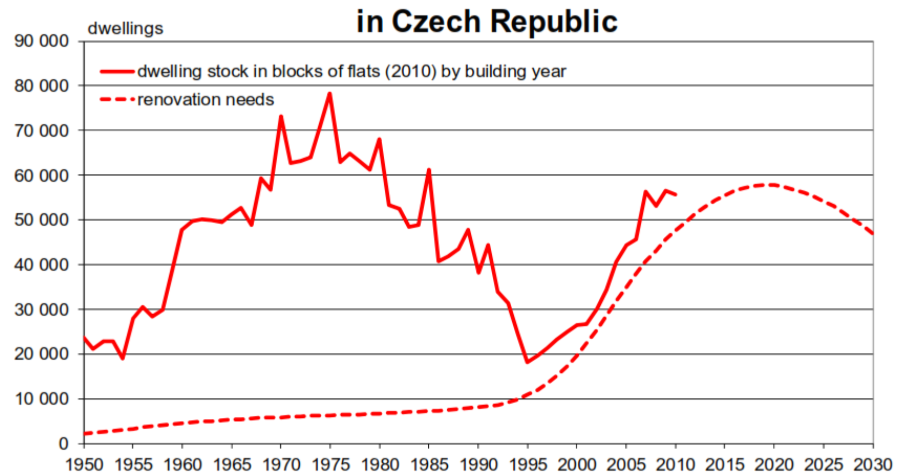
According to Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)[5] "major renovation" is defined as renovation of a building where:

(a) the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated;

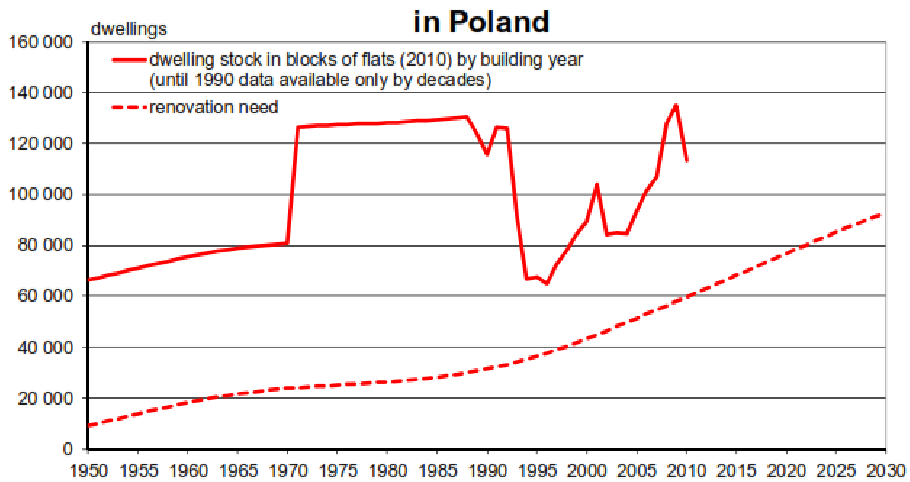
(b) or more than 25% of the surface of the building envelope undergoes renovation.

2.3 *Renovation needs forecast*

Riihimäki *et al.* (2012) modeled the timing of extensive facade renovations of panel buildings blocks using the so-called renovation-need model. Since no sufficient statistical data was available on the different façade types and renovation measures undertaken in the past, the renovation-need function based on total values has been used in calculation. Furthermore, the known programs to accelerate renovation (e.g. the PANEL program in the Czech Republic) have been taken into account. In the calculations about 50% of the facades would have been renovated at 50–60 years. Renovation (need) occurs primarily at 35–75 years of age, and forecasts are presented in Figure 2.



a)



b)

[5] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF

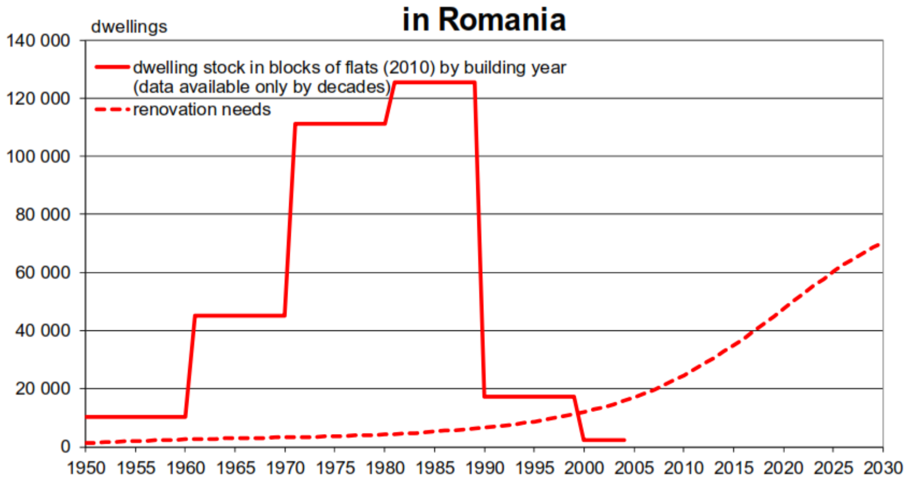
c) 

Figure 2. Renovation need of façades in block of flats in dwellings by year (Source:, Riihimäki M., et al, VTT 2012).

Both in Romania and in Poland large part of the renovation need is upcoming (Figure 2). For Romania, many blocks were built in the 1970's and 80's, thus the multi-story residential building stock is quite young. The moderate renovation need, forecasted by the model for the present time may be attributed to (1) the overestimation of the quality of the initial facades (2) the underestimation of the effect of lack of maintenance from 1990. Even with these moderate estimates, about 30,000 flats are in need of renovation and the need will grow strongly in the coming years. A more pessimistic estimate is that about 80% of the dwellings would come to the end of their life time within 20 years unless serious measures are taken [UN, 2001].

Furthermore, the façade renovation needs are also brought forward in time by the implementation of the energy reduction targets.

Table 2. Average growth rate of renovation needs in countries. (Source: Riihimäki M., et al., VTT 2012)

	2006-2010 % / a	2011-2015 % / a	2016-2020 % / a	2021-2025 % / a	2026-2030 % / a
Czech Republic	6	3	1	-1	-3
Poland	3	3	2	2	2
Romania	8	7	6	5	3

3 THE NEEDS OF THE OCCUPANT

As it has been highlighted, energy reduction targets are important drivers of renovation of the building stock. Also, most energy focused renovation programs in Europe are top down. The Europe 2020 goals are divided into national targets[6], which become drivers of national legislation. We wanted to understand how top-down initiatives are echoing with the needs of the occupants of prefabricated blocks in Romania. Hence a survey was initiated to better understand the needs of the occupants.

3.1 *Implementation and methodology*

The survey was implemented in the multi-criteria decision making (MCDM) setting. A slightly modified version of VTT-ProP[7] hierarchy was the basis of the MCDM model used. The key focus areas were "Conformity", "Performance" and "Cost". Each key focus area was divided further in decision criteria of lower levels.

Conformity was subdivided in the following three criteria: *vicinity*, a property of the immediate neighborhood of the buildings; *location*, a property depending on the location of the build-

[6] http://ec.europa.eu/europe2020/pdf/targets_en.pdf

[7] Also implemented in EcoProp: http://cic.vtt.fi/ecoprop/ecoprop_web_site/Mainpage.html

ing within the fabric of the city and access to infrastructure and other services and *spatial system*, a quality of the space distribution in the apartments, and how much it conforms with the wishes of the occupant.

Performance was divided in five criteria: *internal comfort*, an indoor space quality affecting the wellbeing of the occupants, relating to quality of the indoor air, access to natural light, presence of noise or vibrations; *state of deterioration*, a property of the building which reflects the attitude of the other owners and their expectations concerning quality of the living space; *adaptability*, a property of the apartment's internal space to be adjustable to changing expectations; *safety*, a property of the building to counter external hazards and *accessibility*, a quality of the internal space itself, but also of the access routes to the apartment.

Finally, costs were assembled from two criteria: *price*, the immediate cost needed to be paid for the apartment and *maintenance cost*, the long term cost of owning the property.

The 1000Minds[8] decision-support software was used for prioritizing alternatives. The tool is using "potentially all pairwise rankings of all possible alternatives" or PAPRIKA for calculating weights on the criteria. Point values represent the relative importance of the criteria or attributes to decision-makers. Since most of the criteria listed above can only be interpreted in context of each responder's life situation, we used three generic levels for each criterion:

- level describing a scenario above the basic expectation of the occupant;
- level just fulfilling the expectation of the occupant;
- level below expectation of the occupant (a compromise on the criteria).

3.2 *Results*

Data collection is continuing online (http://virtual.vtt.fi/virtual/respire/survey.html). From the current responses (20+) a few general conclusions are clear.

The most consistent response set is obtained concerning the importance of *internal comfort*, responders agreeing on the importance of this criterion; while most varying responses we obtained for *accessibility* and *adaptability*. On *safety* and *spatial system* the responder's basic expectations are set, and are not willing to go below expectation choices. They are most flexible in their opinion about *maintenance cost*, *price* and *location*, accepting to upgrade these criteria for better alternatives.

On average the responses emphasize on qualities to be improved by the city authority, *safety*, *neighborhood* and *location*., adding up to 31% of the priorities of the responders (Figure 3). A second set of interesting qualities can be improved by the home owner association (HOA) with moderate effort: *indoor quality*, *state of deterioration*, part of *safety* and reducing the *maintenance cost*. These represent together about 35% of the priorities.

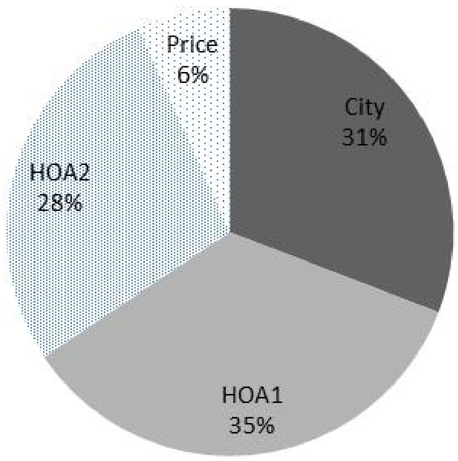


Figure 3. The responsible administrative level for carrying out improvements desired by occupants.

[8] http://www.1000minds.com/

It is worth noting that only *indoor quality* and *maintenance cost* may be improved by renovation undertaken by a single apartment owner, emphasizing that HOA's do need to act together to respond to expectations of their members. The renovation measures by individual owners should only by viewed for what they are, solutions of desperation.

A third set of qualities are also within the reach of the HOA (28%), but with substantially more effort and expense. These are deep-renovations targeting aspects of social sustainability of the building stock *spatial system*, *adaptability* and *accessibility. Spatial system* is a strong driver of choice, also linked with *adaptability* of the internal spaces. On the other hand, *accessibility* should be a wider societal concern, given the aging population in Romania.

Five hypothetical apartments were used to understand the choices of the responders in real-life scenarios. The apartments were: (1) new built in good location, (2) medium location but in good state, (3) new built in bad location, (4) average location with renovation needs, and (5) very good location and very good state. Conformity, performance and cost qualities have been adjusted accordingly to the five choices. With very good agreement (Kendall's coefficient 0.897) responders agree that:

- their first choice is a new development in good location, despite of higher price (78%);
- their second choice is also new development, even in a bad location and despite the higher price (57%);
- their third choice is an average location apartment in good shape (65%).

An existing apartment in an average location which needs renovation was not desired despite the lower price, and an excellent location old apartment was not desired because of the inherent compromises on performance parameters and higher price (Table 3). It can be concluded, that occupant's expectations on conformity and performance is not any more fulfilled by existing apartments, and they are willing to pay for upgrade to new-build. This trend means that sustainability of the existing stock can be considered to be already in question.

Table 3. Choices of responders from the 5 offered apartments

	Conformity	Performance	Cost	1st	2nd	3rd
New development. Good location.	Above	Above	Above	78%	23%	0%
New development. Bad location.	Average	Above	Above	9%	57%	22%
Good state. Average location.	Average	Average	Average	13%	22%	65%
Needs renovation. Average location.	Average	Below	Below	0%	0%	9%
Good state. Excellent location.	Above	Average	Above	0%	0%	4%

4 CONCLUSIONS

Some trends can be anticipated from the review presented. Many of them are revisited in more detail in the dedicated papers later in the book, so we only state a few preliminary ideas to give a framework of thought for the reader.

Firstly, it looks that renovation needs are building up now, or are expected to build up in the immediate future, in most East European countries. The question is not of market needs, but of possibilities of financing. Compared to even Finnish renovation markets, the available resources in East European countries are limited.

Secondly, the top-down programs, implemented based strictly on the drive for more energy efficiency, are (partly) missing the target. They are too narrowly formulated, and expectably result almost exclusively in basic quality façade interventions. But this is not tackling most of the renovation needs of the building for achieving longer term sustainability. It is also not attracting enough interests of the occupant to encourage active interest in co-financing the renovation programs. Social sustainability goals like *accessibility*, *adaptability* are also missed, since they would come to the discussion only if deep-renovation measures are considered. The top down-programs would need broader scope, even if we focus on the renovation of a single building unit.

Thirdly, the strengthening of the role of home owner associations, and work together with city authorities and local businesses [Aaltonen, 2012], on mutually supporting targets is the real key to starting transforming these neighborhoods in sustainable communities [Nielsen, 2012].

Top-down programs of the governments should target to facilitate such common work, including the study of the why stakeholders are unable to achieve coordinated action at present. There is also a potential for proactive role of local construction renovation companies and company associations. They have the technical knowhow on renovation and local market conditions. But, they also have considerable lobby power with the local authority, an important argument in favor of renovation programs by the cities being the creation of local workplaces [Nielsen, 2012].

ACKNOWLEDGEMENT

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Urban sustainable strategies

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ABSTRACT: In the city of Timisoara, the collective housing phenomenon is widely spread, with approximately half of the city's population accommodated in apartment buildings. The collective housing neighborhoods have developed in Timisoara during four different periods of time, each of them characterized by specific features. During the last few years, efforts have been made to encourage the thermal refurbishment of these buildings, through both national and local measures. But in order to be effective, this process must be approached in a holistic manner; the actions should be oriented towards a joint purpose, namely reaching the balance on all of the following levels: the social level, the economic level, as well as the ecologic level. This paper concentrates on possible urban strategies regarding the implementation of the thermal refurbishment process, in accordance to urban standards such as the housing units' density, which directly influences the quality of life within the communities.

1 INTRODUCTION

Given the large stock of apartment buildings presently found within the urban tissue of the city of Timisoara, as well as within other important cities throughout Romania, the issues regarding the organization and administration of neighborhoods consisting of such buildings have become more and more important to specialists in the field.

Built between four different periods of time (Radoslav *et al.*, 2010), these apparently similar neighborhoods are in fact very different, especially from the point of view of the quality of life that they provide for their inhabitants. Although many factors contribute to the overall definition of this element, perhaps the most important ones refer to the physical organization of the neighborhood, the housing units' density and the public facilities existing on site, the indoor comfort of the apartments, as well as the general aspect of the neighborhood and of the buildings themselves.

During the past few years, efforts have been made to increase the energy efficiency of the apartment buildings, through a number of measures and initiatives regarding the thermal refurbishment of these buildings (Brata *et al.*, 2012). These operations are almost always associated with the transformation of the attic into one or more loft-type apartments, which automatically leads to an increase in the housing units' density, with approximately 20%. This phenomenon is particularly important from the urban planners' point of view, since the density is an essential factor in the distribution of public facilities throughout the city, thus majorly influencing the overall quality of life within the communities.

Given the multitude of typologies that can be found within the apartment buildings neighborhoods within the city of Timisoara, as well as throughout the country, we should create strategies in accordance to each neighborhood's needs, instead of applying a single model for all the situations. The study thus concentrates on finding specific strategies for each type of collective housing neighborhood, in accordance to its own realities and needs, in order to solve the social-economical inequities, often present within the communities.

2 THEORETICAL CONSIDERATIONS

The National Program for Thermal Refurbishment was initiated in Romania a few years ago, by the Ministry of Development, Public Works and Buildings, in order to increase the energetic performance of residential buildings (Brata *et al.*, 2012). This program represents a very useful initiative that targets the reduction of energy consumption needed in order to ensure the indoor comfort, as well as the reduction of gas emissions. The program is based on a set of European Directives and recommendations, as well as on a handful of Romanian laws and norms. However, given the pace in which the energy efficient refurbishment program develops in Romania, we can estimate that it will take at least 100 more years in order to achieve the thermal renovation of all the apartment buildings in the country.

We strongly argue that, in order to be effective, this program must be approached in a holistic manner, which should eventually lead to a balanced development, from the point of view of the following issues: the social issue, the economic issue, as well as the ecologic issue. This idea can also be found at C. Butters (Butters, 2004), who states that sustainable development cannot be achieved without gradually improving all of the following aspects, at the same time: the social one, which aims towards social diversity, accessibility, identity, security, variety, involvement and sociability; the economical one, which can be achieved by cutting revenue expenditure, improving functions, diversifying activities and adjacent financial structures, services and communications, by management and flexibility; the ecologic one, through a more harmonious use of land, through biodiversity and bio-climate, by producing non-pollutant energy, re-naturalising the water cycle, recycling, adequate accessibility and by improved overall health.

But the most delicate of them all are the social problems, which can sometimes become very complicated. The subject of social exclusion is currently one of the most important concerns at the European level; together with extreme poverty, the absence of current facilities (such as public transportation, schools, kindergartens, sports grounds, green areas, commercial areas, parking places, etc.) can transform a neighborhood into an isolated area within the limits of the city (Fig. 1). Solving the problems regarding social exclusions, structural changes, the ageing of population, climate changes and mobility is the main theme of 2007 Leipzig Charter, a European document which hopes to lead to economic prosperity, social balance and a healthy environment. In this document, the prosperity mentioned above depends on an increased attention paid to ”*the underprivileged neighbourhoods, in the context of a city as a whole”* (Leipzig Charter, 2007). According to this Charter, we should thus take into consideration these problematic areas of the city when establishing the global strategies for its development, directing the investments towards them.

Figure 1. Timisoara – some of the most under-developed areas of the city.

From the urban planners’ point of view, the process of thermal refurbishment, usually associated in Timisoara with the transformation of the attic into one or more loft-type apartments, is important due to its consequences, namely the way in which it interferes with some urban standards, such as the housing units' density. Indeed, only a reasonable density, namely 25-30 units/ha for individual housing units (Radoslav *et al.*, 2009) and approximately 60 units/ha for collective housing units, can sustain the public facilities mentioned above (such as public transportation, schools, kindergartens, sports grounds, green areas, commercial areas, parking places, etc.). However, in Timisoara we can also find areas in which the housing units' densities are higher than the acceptable limit (over 100-150 housing units/ha); it is here where we should operate with more attention, since the high densities could contribute to severe social problems.

Further on, the study concentrates on the analysis of the situation currently existing within the city of Timisoara, regarding the collective housing neighborhoods and their particular features, such as the public facilities provided, in relation to the housing units' densities and the on-going process of thermal refurbishment.

3 COLLECTIVE HOUSING NEIGHBORHOODS IN TIMISOARA – CASE STUDY

The city of Timisoara has a total area of 13,003.87 ha, out of which 6870.21 ha compose the built-up area, and a population of 334,089 inhabitants (including 16,438 commuters, of which the majority are students), according to the 2002 census. In the residential area, which extends on 2643.74 ha – approximately 53.15% of the built-up area, the average housing units' density is of 367.70 housing units/1000 inhabitants, with approximately 126.37 inhabitants/ha. From the total of 122,195 housing units currently existing within the limits of the city, approximately 52,000 housing units are placed in apartment buildings.

The collective housing neighbourhoods were built in Timisoara during four different periods of time (Fig. 2), each characterized by specific features, regarding the disposal of the apartment buildings within the neighborhood, the housing units' density and the facilities provided for each area (in relation to the existing density), the surface and the organization of the apartments, as well as the general aspect of the buildings themselves.

The first period, developed between 1962-1975, produced neighborhoods with a low housing units' density, within which the apartment buildings were placed at a distance of approximately 60 m between each other, thus offering a convenient intimacy degree to their inhabitants. Although the apartments' surface was usually reduced to a minimum, the neighborhood itself offered all the needed facilities, such as schools, kindergartens, sports grounds, commercial areas, etc. In Timisoara, the most representative neighborhoods built during this period of time are the Tipografilor and Calea Lugojului Neighborhood, with a total of 4.500 apartments and 15.700 inhabitants, as well as the Circumvalațiunii Neighborhood, with 11.400 apartments and 29.900 inhabitants (Opris, 1987).

The second period, developed between 1975-1982, is by far the worst period of them all, characterized by the forced densification of the urban tissue. The neighborhoods erected during these years are characterized by very high housing units' densities, with apartment buildings placed at a distance as reduced as 15 m between each other. The apartments themselves maintain a low surface, while the public facilities disappear almost entirely from the neighborhoods. The only exception is the commerce, which flourishes at the ground floors of the apartment buildings situated alongside the main arteries of the city (during this period, the concept of 'commercial street' was reintroduced). Unfortunately, most of Timisoara's collective housing neighborhoods were built within these years, due to the pressures placed upon the city, in the context of the forced industrialization process, which led to an accelerated increase of the population. Thus, during this period of time, the following neighborhoods were erected: the Calea Șagului and Dâmbovița Neighborhoods (partially built between 1962-1975), with 12.582 apartments and 44.000 inhabitants, the Stadion, Spitalul Județean and Timișoara Sud Neighborhoods, with 5.917 apartments and 20.700 inhabitants, the Sportivilor and Negoiul Neighborhoods, with 3.132 apartments and 10.900 inhabitants, the Calea Girocului Neighborhood, with 4.540 apartments and 15.900 inhabitants, as well as the Plavat Neighborhood, with 4.473 apartments and 14.700 inhabitants (Opris, 1987).

The third period, developed between 1982-1989, witnessed an improvement of the situation – the housing units' densities were lowered once again, while the apartment buildings were placed at favorable distances between each other, around partially open interior courtyards. The apartments' surface increased significantly during these years, while the neighborhoods themselves were provided with public facilities. However, since many of these developments were still under construction at the time of the December 1989 Revolution, some of these facilities were never finalized and the terrain dedicated to them remained up until recent years un-built. But under the pressure of contemporary realities, these lots are gradually occupied with new apartment buildings, which contribute to the increase of the existing housing units' density, and thus to the deterioration of the overall life quality. Some of the most representative neighborhoods built during the 1982-1989 period within the city of Timisoara, are the Calea Torontalului, Aradului, Lipovei and Matei Basarab Neighborhoods (partially built between 1975-1982), with 11.525 apartments and 40.300 inhabitants, as well as the Ion Ionescu de la Brad Neighborhood, with 2.404 apartments and 8.500 inhabitants (Opris, 1987).

Finally, after more than ten years during which the development process stagnated, the year 2000 marked the beginning of a new stage regarding the collective housing developments. However, the overall quality of the new insertions is, unfortunately and in most cases, very low.

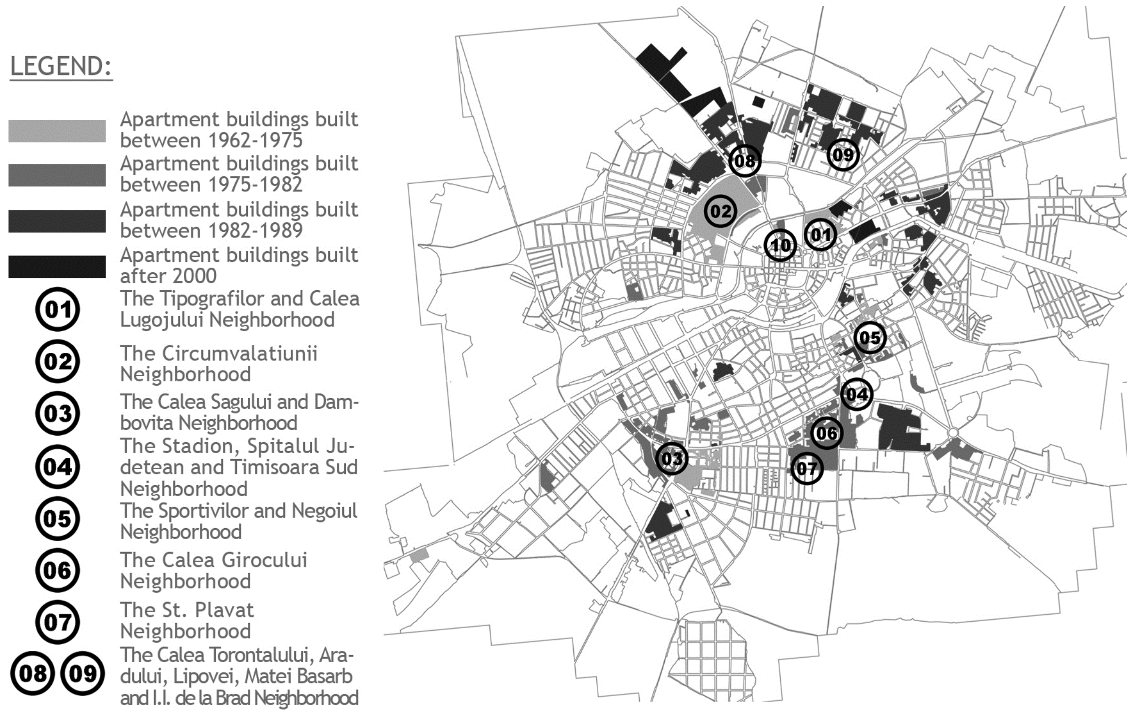

Figure 2. Timisoara – the distribution of collective housing neighborhoods within the city, in accordance to the four different periods during which they developed.

Locally, the first measure towards the improvement of the energetic performance of residential buildings, implemented in Timisoara in 2004, consisted on encouraging people to replace the terraced roofs of their buildings with attics, in exchange to lower taxes. Another measure, also implemented in 2004, was to reduce taxes for those who replaced the old windows of their building, which were completely inefficient from the point of view of thermal insulation. People were extremely responsive to these proposals and, as a result, they started the refurbishment of their buildings almost immediately. One of the neighborhoods in which the effect of these measures is clearly visible is the Soarelui Neighborhood (see Fig. 3), where almost all the apartment buildings currently benefit from attics instead of terraced roofs. This leads to an increased indoor comfort within the apartments from this area of the city, both during the winter months (when the heat loss is significantly diminished), as well as during summer.

Figure 3. The Soarelui Neighborhood, Timisoara – where we can see clearly the effect of the first measure mentioned previously – almost all the apartment buildings in the area have attics instead of terraced roofs, which leads to an increased indoor comfort.

Presently, the European funds destined to the thermal refurbishment of apartment buildings are being directed towards the buildings situated alongside the main traffic arteries of the city. Although this approach will certainly improve the overall aspect of the city, our proposal is to identify the most under-developed neighborhoods in Timisoara and direct the investments towards these areas, in accordance to the principles of the Leipzig Charter; otherwise, these areas will shortly become neighborhoods with huge social exclusion problems.

Figure 4. Timisoara – apartment buildings recently refurbished within the Dambovita Neighborhood and the Soarelui Neighborhood.

Further on, our study concentrates on the analysis of some of the most representative apartment buildings neighborhoods in our city, regarding the relation between the housing units' density and the existing facilities.

3.1 *Circumvalatiunii 1 Neighborhood*

The first urban entity analyzed by this paper is the Circumvalatiunii 1 Neighborhood (see Fig. 5), which is one of the earliest interventions of this type within the urban tissue of Timisoara. Situated in the north-western part of the city, this neighborhood was built between 1962-1975, thus being characterized by a low housing units' density, of approximately 50 units/ha. Within the neighborhood, the apartment buildings are placed at reasonable distances between each other, while the areas between them are arranged as green courtyards, with trees and sitting areas. The physical organization of the neighborhood contributes to an increase of the overall life quality within the community, both due to the high intimacy degree offered by the disposal of the apartment buildings, as well as because of the quality of the public space.

Figure 5. The Circumvalatiunii 1 Neighborhood, Timisoara

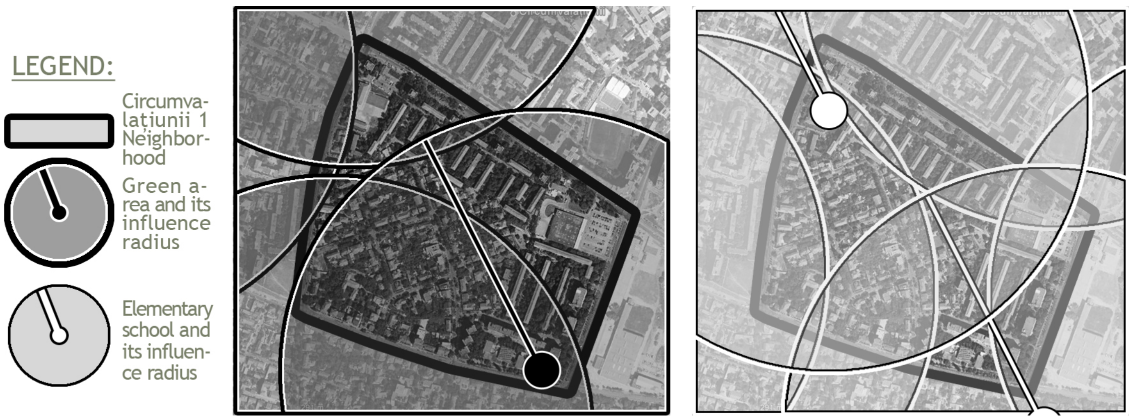

Figure 6. The Circumvalatiunii 1 Neighborhood, Timisoara – green areas and elementary schools currently existing within the area.

Throughout the neighborhood, there are currently 2145 apartments, which are unfortunately provided with only 351 parking lots, one of the lowest ratios in the city. However, from the point of view of green areas (see Fig. 6), the neighborhood is quite covered, having access to green squares situated both on its territory, as well as in the vicinity. Also, an elementary school (Fig. 6) situated within the limits of the neighborhood improves the overall quality of the area, since it is easily accessible for all the children in the community and, thus, an active center within the urban tissue.

Due to the low housing units' density currently existing on site, this neighborhood in particular can support an increase in the total number of apartments; however, if this were the case, efforts should be made in order to increase the number of parking lots, a facility currently problematic within the neighborhood.

3.2 *Calea Buziasului Neighborhood*

The second neighborhood on which our study concentrates is the Calea Buziasului Neighborhood (see Fig. 7), that is situated in the south-eastern part of the city. It was built in the beginning of the 1975-1982 period and it has a housing units' density of approximately 155 units/ha. This density is twice as high as the acceptable limit, which leads to huge social problems within the neighborhood. In this area, the apartment buildings are situated at very low distances between each other, which contribute to a decrease of the intimacy degree and, thus, of the overall life quality.

Figure 7. The Calea Buziasului Neighborhood, Timisoara.

Figure 8. The Calea Buziasului Neighborhood, Timisoara – green areas and elementary schools currently existing within the area.

Within the neighborhood, there are currently 2744 apartments, which are provided with a total of 848 parking lots. Unfortunately, although the housing units' density is quite high for this neighborhood, no green area (see Fig. 8) can be found within its limits. Also, in this neighborhood, there are no elementary schools (see Fig. 8); however, in its vicinity, towards East, we find a local school that covers quite comfortably this area's requirements.

Due to the high housing units' density, as well as because of the acute lack of public facilities within this neighborhood, we strongly argue that an increase of the total number of the apartments should not be encouraged in this area. Should this be the case, the overall quality of life would decrease even more, which would automatically lead to the collapse of the neighborhood from the social point of view. Moreover, we believe that efforts should be made in order to increase the quality and the number of public facilities, in order to improve the actual living conditions within the neighborhood.

3.3 *Calea Girocului Neighborhood*

Further on, our study concentrates on the analysis of the Calea Girocului Neighborhood (see Fig. 9), which is situated in the southern part of the city. This area was built during the 1975-1982 period and already encounters huge social problems, due to the fact that it has one of the highest housing units' densities in Timisoara, namely approximately 250 units/ha. Within the neighborhood, the apartment buildings are situated very close to each other, while some of them are arranged around partially open interior courtyards, which, unlike the same structures produced during the 1982-1989 period, have reduced surfaces; the intimacy degree provided by the apartments in this area is thus very low, which contributes to a decrease of the overall life quality within the area.

Figure 9. The Calea Girocului Neighborhood, Timisoara.

In this neighborhood, 848 parking lots correspond to the total of 2160 apartments, currently existing on site. However, this neighborhood contains within its limits a green square (see Fig. 10), which enhances the overall quality of life for its inhabitants. Also, on the two sides of the small park, there are two schools (see Fig. 10), which are accessible to all the children in the neighborhood.

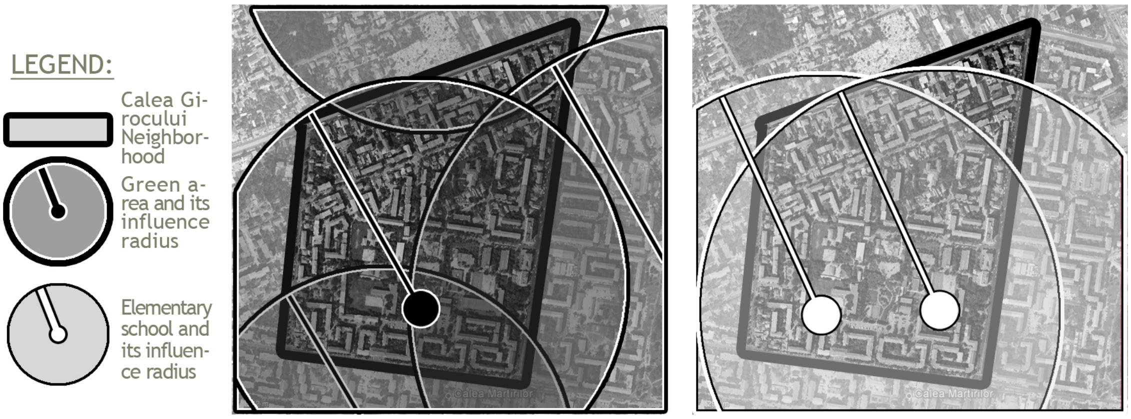

Figure 10. The Calea Girocului Neighborhood, Timisoara – green areas and elementary schools currently existing within the area.

Considering the incredible high housing units' densities currently existing in this area, the increase of the total number of the apartments should definitely be forbidden here. Otherwise, the neighborhood will become over-crowded and the social difficulties currently encountered within the community will accentuate beyond acceptable limits. Also, efforts should be made in order to increase the total number of parking lots, since this is the only public facility which does not satisfy the requirements of this community.

3.4 *Calea Torontalului Neighborhood*

Figure 11. The Calea Torontalului Neighborhood, Timisoara.

Calea Torontalului Neighborhood (see Fig. 11), on which our study concentrates next, is situated in the northern part of Timisoara. It was built during the 1975-1982 period and has a housing units' density of approx. 60 units/ha. The apartment buildings within this area are placed around partially opened courtyards, at reasonable distances between each other. However, along the main boulevards, this arrangement does not apply; here, the apartment buildings form a continuous front towards the street, while their ground floors accommodate commerce.

Within this area, the 3058 apartments currently existing on site are provided with a total of 1918 parking lots. Although the density of the housing units is quite high in this area, unfortunately no green areas (see Fig. 12) have been arranged here. The situation is similar when it comes to elementary schools (see Fig. 12) – no such facilities exist within the limits of the neighborhood; thus, the overall quality of life for the members of this community is essentially diminished.

Taking into consideration the lack of public facilities within this neighborhood, as well as the relatively high housing units' density encountered here, we strongly argue that the total number of the apartments currently existing in this area should not increase through future developments. Moreover, we believe that funds should be directed towards the improvement of the current situation, because the lack of public facilities, such as green areas or schools, can lead to huge social problems within the community

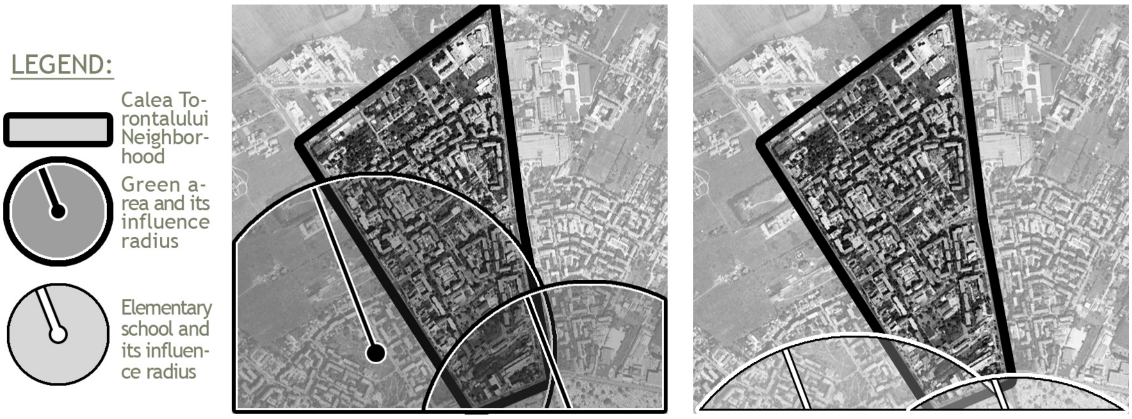

Figure 12. The Calea Torontalului Neighborhood, Timisoara – green areas and elementary schools currently existing within the area.

3.5 *Bucovina Neighborhood*

Figure 13. The Bucovina Neighborhood, Timisoara.

Further on, our study concentrates on Bucovina Neighborhood (see Fig. 13), which is situated in the vicinity of the Calea Torontalului Neighborhood, towards East. It was built towards the end of the 1975-1982 period, when the situation already started to improve; thus, it has a housing units' density of approximately 70 units/ha. Within the neighborhood, the apartment buildings are situated at reasonable distances between each other, thus offering an improved intimacy degree for the members of the community.

Regarding the situation of the parking lots, there are 818 such units in this neighborhood that correspond to a total of 1730 apartments, which is one of the best ratios within the city. This neighborhood is privileged when it comes to green areas (see Fig. 14) – the small green square which is arranged on its territory plays quite an important part within the community, improving the overall quality of life. Unfortunately, although the housing units' density of this neighborhood is high enough to support a school, within the limits of this territorial unit there are no such facilities (see Fig. 14).

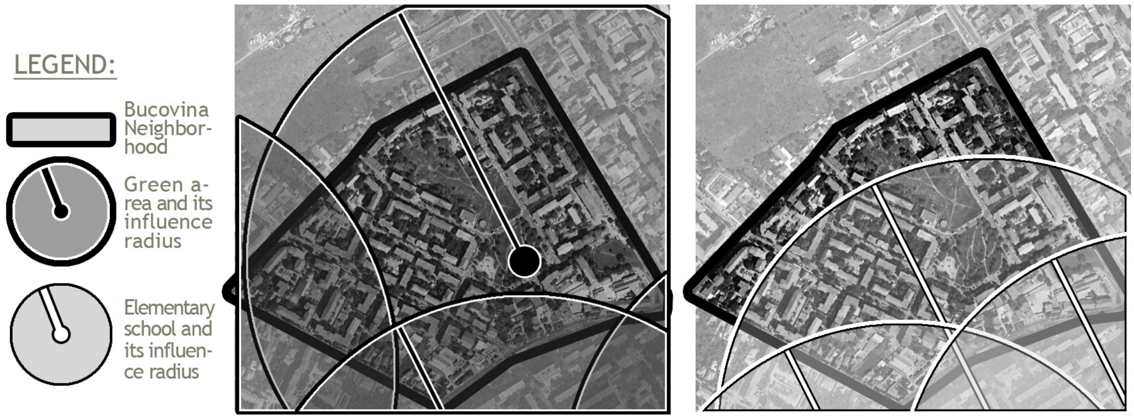

Figure 14. The Bucovina Neighborhood, Timisoara – green areas and elementary schools currently existing within the area.

Considering the low housing units' density currently existing on site, we can state that this neighborhood in particular can support an increase of the total number of the apartments; however, if this were the case, efforts should be made in order to accommodate a school within the limits of this area, as well as to increase the total number of the parking lots, which are currently insufficient, in order to provide an increased quality of life for the members of this community.

3.6 *Dorobantilor Neighborhood*

The following neighborhood on which our study concentrates is the Dorobantilor Neighborhood (see Fig. 15), which is situated alongside the Bega Canal, on its northern shore. It has a density of approximately 70 housing units/ha, while the apartment buildings within the area are placed either around courtyards or alongside the main streets.

Regarding the situation of the parking lots, within this neighborhood there are currently 1010 such units, which correspond to a total of 2100 apartments. Although the apartment buildings area does not contain within its limits any square, in its vicinity, alongside the Bega Canal, there are several green areas (see Fig. 16). Also, in the vicinity of the apartment buildings area there are three schools (see Fig. 16); however, in order to reach these schools, children must cross some important traffic arteries, which complicates the situation, because the heavy traffic is a real threat for young children.

Considering the low housing units' density currently existing on site, an increase of the total number of the apartments is possible; however, should this be the case, efforts need to be made in order to improve the overall quality of public facilities within the community, especially regarding the accessibility of the elementary school.

Figure 15. The Dorobantilor Neighborhood, Timisoara.

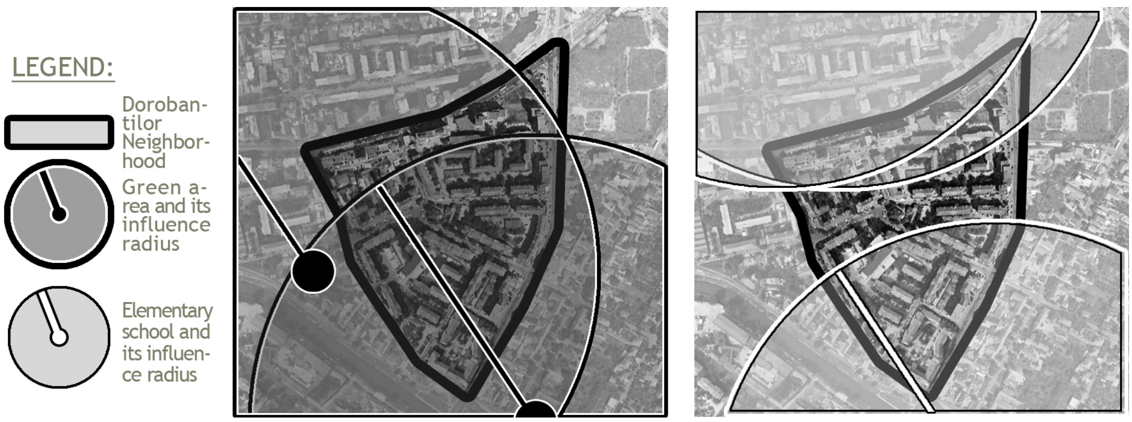

Figure 16. The Dorobantilor Neighborhood, Timisoara – green areas and elementary schools currently existing within the area.

3.7 *Soarelui Neighborhood*

The last neighborhood on which our study concentrates is the Soarelui Neighborhood (see Fig. 17), which is situated in the southern part of the city, near the Calea Buziașului Neighborhood. It was built between 1982-1989 and thus has a density of 60-70 housing units/ha. The apartment buildings within this area are placed around courtyards, which have a relatively generous surface, thus ensuring a high intimacy degree for the apartments themselves.

From the point of view of green areas, the Soarelui Neighborhood is privileged, since it contains, within its limits, two green squares (see Fig. 18), which improve significantly the life quality of its inhabitants. The neighborhood is also provided with an elementary school (see Fig. 18), accessible to all the children in the area.

Taking into consideration the low housing units' density currently existing within this neighborhood, as well as all the public facilities which improve the overall life quality for the members of this community, we believe that this area can support an increase of the total number of the apartments. However, this intervention does require attention in terms of establishing a fair relation between the total number of the apartments and the public facilities existing on site.

Figure 17. The Soarelui Neighborhood, Timisoara.

Figure 18. The Soarelui Neighborhood, Timisoara – green areas and elementary schools currently existing within the area.

4 CONCLUSION

Considering the results of the studies presented above, regarding the situation currently existing within the collective housing neighborhoods in Timisoara, we strongly argue that, in order to achieve the sustainable development of these areas, we should create strategies for each type of apartment buildings neighborhood within the city, instead of applying a single model for all the situations. Thus, we should identify the most under-developed neighborhoods in the city and first operate there. Then, we should decide which neighborhoods can support an increase in their housing units' densities; there and only there should we allow the transformation of the attics into building floors with apartments; otherwise, we risk suffocating the entire neighborhood.

For the neighborhoods with housing units' densities higher than the acceptable limits, that also lack public facilities, we should make efforts to decrease the density, through two possible operations. The first measure proposed refers to the transformation of the apartments situated at the ground floors of the buildings into commercial spaces/stores (Radoslav *et al.*, 2005). The second operations counts on the intervention of the City Council, that should, in time, buy some of the 5.000-10.000 empty apartments currently existing in Timisoara; then, efforts should be made in order to group these apartments into strategically-placed blocks of flats within problematic neighborhoods; in the end, these buildings should be demolished, thus obtaining a lower density in the neighborhood, as well as the much needed terrain for the implementation of facilities that are currently missing from the area.

In the end, we should make sure that the energy efficient refurbishment of apartment buildings throughout the country is conducted at the level of private initiative, through small and medium-sized enterprises, instead of huge corporations; otherwise, the current policies will strengthen the large companies in this domain, while suffocating the smaller ones. Also, it is important for the owners' associations, that contribute with 30% of the investment value to the thermal refurbishment of their buildings, to be involved in the selection of the entrepreneurs; otherwise, the principle of subsidiarity (Toledo Declaration 2010), which states that, in order to achieve good governance, decisions that affect a certain level should be made at that level alone, is not respected.

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Sustainable retrofitting solutions for precast concrete residential buildings. Architectural and structural aspects

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ABSTRACT: In the present context, a large part of the Romanian urban population, like that of Eastern Europe, lives in collective residential buildings with concrete structure made of large prefabricated concrete panels. Most of these buildings are over 30 years old, and the materials used for thermal insulation are already outdated. Starting from the representative typologies of existing buildings, the context when they were built, their evolution in time, and their current and actual problems, the paper presents some directions, modalities, intervention methods and their implementation for rehabilitation. The paper presents architectural solutions for redesigning the interior spaces of large panel prefabricated concrete buildings by coupling apartments on horizontal or vertical direction and also the structural interventions to be considered. 3D numerical analyses are conducted on these buildings, both on initial and retrofitted structures. The study is focused on using steel solutions for strengthening the affected elements, due to their inherent advantages such as clean intervention, reversibility, resistance and adaptability.

1 THE BUILDING STOCK

1.1 *Romanian Building stock*

According to the Census of Population and Housing of 2011, Romania had about 19 million inhabitants (INSSE, 2003). They were living in 8.5 million dwellings with 22.7 million rooms. 52.8% of the population lives in urban areas, most of them in collective residential buildings. The total number of apartment buildings is around 84000 units, containing 2.5 million apartments. According to the same census, over 71% of the existing urban housings were multi-dwelling type, covering an about 66% from the total inhabitable area. From the total of 57431 large panel prefabricated concrete buildings, the largest part was built during the period 1965-1989, 41540 buildings having 5 storeys.

The construction of this large number of precast collective dwellings was achieved during the heavy industrialization period between 1958 and 1978, when a large wave of population migrated from rural area towards the cities, doubling in this way the urban population and the number of cities grew from 187 to 237. In order to accommodate the large number of urban habitants new homes had to be erected in a short period of time and the solution using highly industrialised building technologies with simple assembling on site was adopted (Niculescu, 1961).

However, this phenomenon was a common feature of Eastern European cities in the 1970s and 1980s. In order to achieve large cost advantages in the construction of these apartment blocks, the national design institutes delivered standardized projects that were to be built in the cities. In Romania the prefabricated housing development used a series of standardized projects. The most popular ones were the low rise 5 storey (project type 770, project type 774, project type 994, project type 1013-1168; project type 1340; project type 1586; project type 2926; project type 1399) and the 9 storey project type 772.

Even by the late 1980s, sanitary conditions in most Eastern Bloc countries were generally far from adequate. For all countries with monitored data, 60% of dwellings had a density of greater than one person per room between 1966 and 1975 (see Fig. 1). The average in western countries was about 0.5 persons per room.

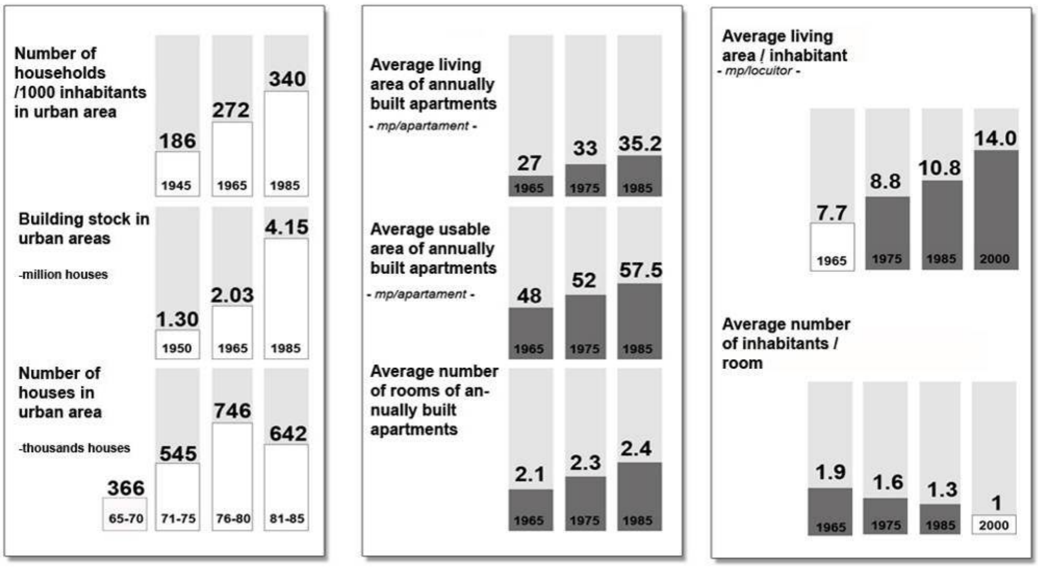


Figure 1. Statistical data regarding housing numbers and used areas.

The prefabricated concrete residential buildings present major differences between typologies according to few basic criteria:

- urban criteria: density (number of units/ha); related exterior facilities (schools, shopping centres, green spaces); number of storeys; accessibility (type of roads, parking areas, distance from these to the housing) (BIT 24/1967).
- architectural criteria: surface (built square metres, inhabitable area, and usable area); built space, the facades, space configuration, access definition (BIT 8/1968; 7/1969;6/1970; 4/1971);
- energy consumption and CO_2 emission: the differences between the finishing of prefabricated panels and the difference in envelope stratification (panels) and the slab;
- finishing criteria (thermal, waterproof and noise insulation) (Project Type 744; 770-78; 1340);
- engineering (differences in seismic conformation according to the time when the housing units were executed) (BIT 4/1969, BIT 11/1970).

In the past years in many cases the owners of the apartments demolished the structural partition walls of the rooms to increase the living space (see Fig. 2).

Figure 2. Dysfunctionalities in urban neighbourhoods (T744R blocks of flats).

Due to the fact that these buildings are over 30 years old, the finishing and thermal insulation materials are out-dated. The first necessity for interventions was recognized at national level in the period 2000-2005. At that time a set of revised documentation, regulations, laws and governmental decisions have emerged but none refers to the possibility of creating openings in the structural walls in order to reconfigure the interior space, balconies enclosure or elevator shafts.

In present conditions, the apartments of such buildings are privately owned, the buildings being in condominium type ownership. The buildings are in most of cases administrated by a Home Owner Association (HOA).

1.2 *Existing building stock in Timisoara*

As housing typology, the city of Timisoara has its urban space divided into ten inhabitable neighbourhoods (areas), with a total of 21.837 housings units of various kinds. The total number of individual buildings is of 15.039 units of single residence buildings and 3.159 units of two or more residences, with variable height (from 1 to 3 storeys). The collective dwellings (with 5 to 11 storeys) accounted for a total of 3.639 units. From these 88% were made of precast concrete panels. The inhabitable fund includes 122.195 apartments, with a total area of 4.372.696 square meters and 277.944 inhabitable rooms. From all the apartments, 71.3% belong to collective dwellings, 28.7% belong to individual buildings, in which a number of 334.089 people live in 115.421 households.

The 1960s to 1990s generated a major densification of the housing areas through collective dwellings constructions.

This evolution and densification of the city was accomplished through the construction of neighbourhoods both in undeveloped areas at that time, as well as through insertions in the built fund (see Fig. 3).

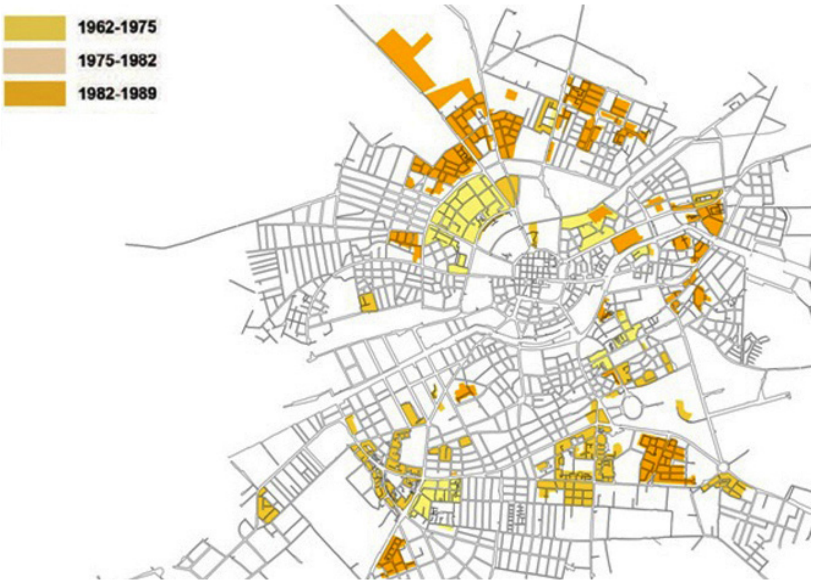


Figure 3. Stages of densification for residential buildings in Timisoara.

In Timisoara, the housings made of large precast concrete panels were executed in three major stages using different model project typologies depending on the applicable state decrees at the time, and in accordance with the evolution of the design and urban systematization stages (Radoslav *et al*, 2011). The studies conducted on the existing building stock for the city of Timisoara (Botici *et al*, 2012), confirmed the fact that in the period 1962-1990 three different types of projects were mainly used. In the first period of this urban development, between 1962 and 1975, the most used standard project was “T744R-IPCT”. In the second period, 1975-1982, frequently used project type was “770-IPCT”, while between 1982 and 1989 the project type “1340-IPCT” had the largest application.

Irrespectively of the structural and energy consumption of the units, the major dysfunctions of these neighbourhoods refer to their lack of reinforcing an attractive urban image, the problems of interior spaces, the lack of public green areas and public space. During the past 10 years the facades of these units were improperly contoured to a mix of shapes, materials, and colours. The urban space was diminished by inhabitants that turned large green areas into parking lots. Also, the interior reduced surfaces of these flats drove the inhabitants to create enlargements in the structural partition walls in order to redesign the interior space and also to extend their living area by integrating the balconies in the living areas.

2 INTERIOR INTERVENTIONS ON T744R BLOCK OF FLATS

2.1 *Description of the standardized collective building T744R*

In the first period of the three-stage urban development of Timisoara, between 1962 and 1975, the standard project "T744R-IPCT" (see Fig. 4) has been intensively used. It had a densification of 70 unit/10.000m^2 resulting in a distance between the units of approximately 60 meters; and flats had relative small living areas (Radoslav *et al*, 2011). The neighbourhoods were built near the city centre as shown in Fig. 4.

Figure 4. a)''IPCT" project type T744R b) Neighbourhoods in Timisoara City built between 1962-1975.

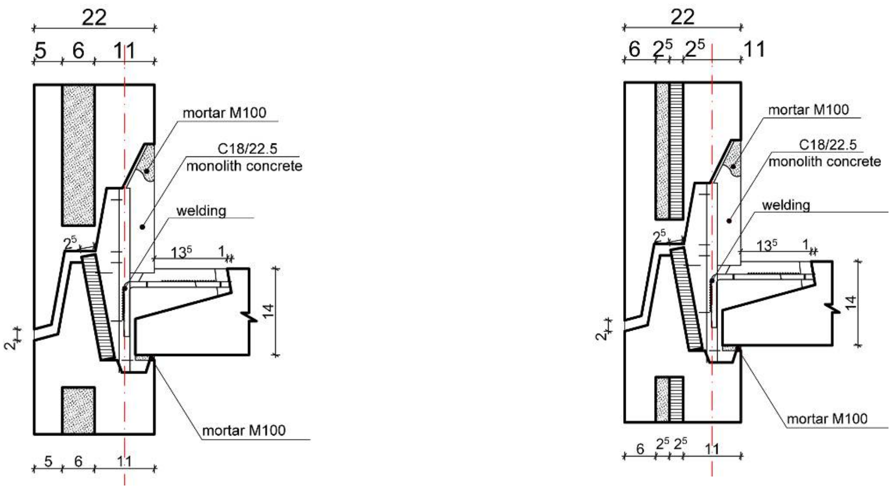
The buildings are 5 storeys with a total height of 14 meters (interior storey high of 2.60m). The units accommodate 4 apartments on each level. A block of flats building is composed of one or more units and they usually form continuous street fronts.

The structural system is made of precast concrete panels assembled on site. The panels were precast on specialized construction plants and transported to building site. The T744R unit has an interior longitudinal concrete wall, composed of standardized precast concrete panels and 6 interior transversal walls.

The internal panels used in case of internal walls are single layered elements of 14 cm thickness, made of B250 (equivalent class C16/20) concrete. The entrance and staircase is located in the middle span of the structure. The exterior walls were also realized from precast panels, composed of three layers with different functions: the load bearing layer, the thermal insulating layer and protection layer.

The thermal insulation layer is placed on the external face of the load bearing layer and has about 6cm. The protection layer is made of reinforced concrete, 5cm thick. "T744 IPCT" project type was realized using mainly two types of exterior panels (see Figure 5).

Both panel types have the load bearing layer 11cm thick, made of B250 (C16/20 equivalent) concrete class. The difference between panel types is the thermal insulation, which was changed in the second period from a 6cm thick mineral wool layer, to a thermal insulation composed of 2.5cm aerated concrete and 2.5cm polystyrene.



- exterior wall: 22cm thickness (var. I)
1) structural layer: 11cm thickness (C16/20)
2) thermal insulation: 6cm thickness (mineral wool)
3) protection layer: 5cm thickness (C16/20)

- exterior wall: 22cm thickness (var. II)
1) structural layer: 11cm thickness (C16/20)
2) thermal insulation: 2.5cm (BCA) + 2.5cm (polystyrene) thickness
3) protection layer: 6cm thickness (C16/20)

Figure 5. Exterior wall panels for T744R-IPCT project – details for connections and insulation.

2.2 *Retrofitting interventions and optimization of the interior partitioning*

Reconfiguration of the interior partition in order to increase the comfort of living can be achieved by merging two flats into one. The purpose of the study is the analysis of different types of apartment repartitioning, in order to obtain cost-effective, structural and functional solutions that could be integrated into a reliable 3D building matrix. The main idea for apartment coupling is to create openings in walls or floors in such a way that living comfort and furnishing possibilities are increased and also the area of balconies is well used. Also for this particular case the new apartment configuration ensures a large liveable area in a semi-open space interior configuration, a configuration nowadays frequently used in practice. The reconfiguring by cutting large openings in the structural diaphragms must be done in a coherent way, in order not to affect the ability of the structure to withstand vertical and horizontal loads (Botici *et al*, 2012).

The interventions on existing balconies should be carefully studied at the level of the entire building and made accordingly in order not to decrease the visual appeal of the building. This matrix should allow flexibility for the apartment owners and should not impose obligation. Also it should analyse different scenarios and set special rules for the unfavourable cases (see Figs. 6-8).

Figure 6. Horizontal reconfiguration and optimization of usable area inside of apartments.

Figure 7. Horizontal reconfiguration by coupling two apartments.

For these cases structural solutions and regulations must be provided, in order to accommodate a diversity of possibilities regarding the “open space” (see Fig. 8).

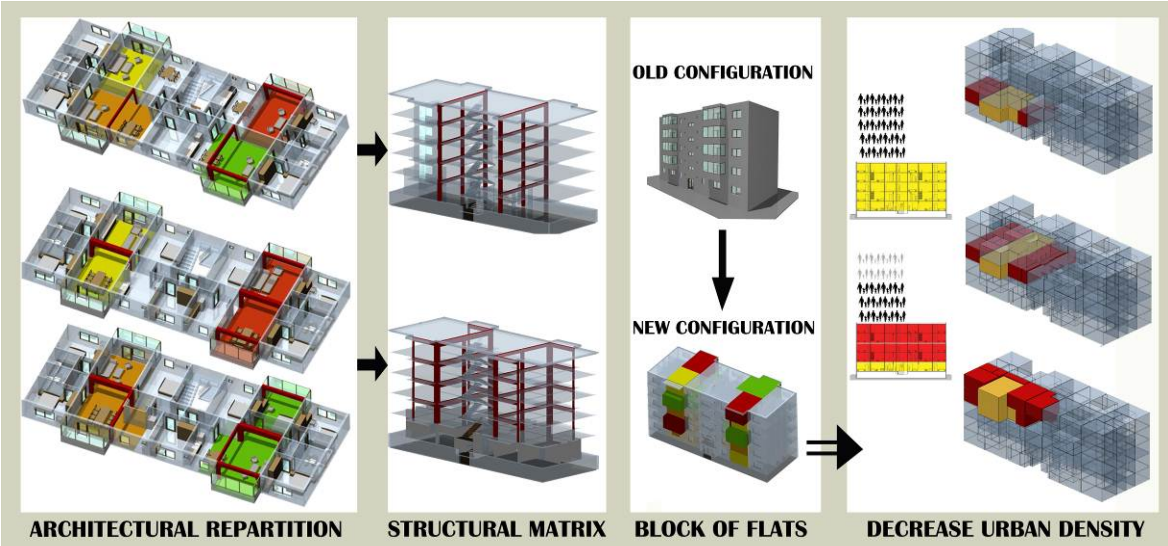


Figure 8. Statistical data regarding the building stock and used areas.

This type of intervention can rebalance certain urban areas in terms of density, green zones for residents and can also decongest traffic routes. From a social perspective this type of intervention involves a release on the public area allocated to parking spaces. At the same time it implies an urban density decrease (see Fig. 9).

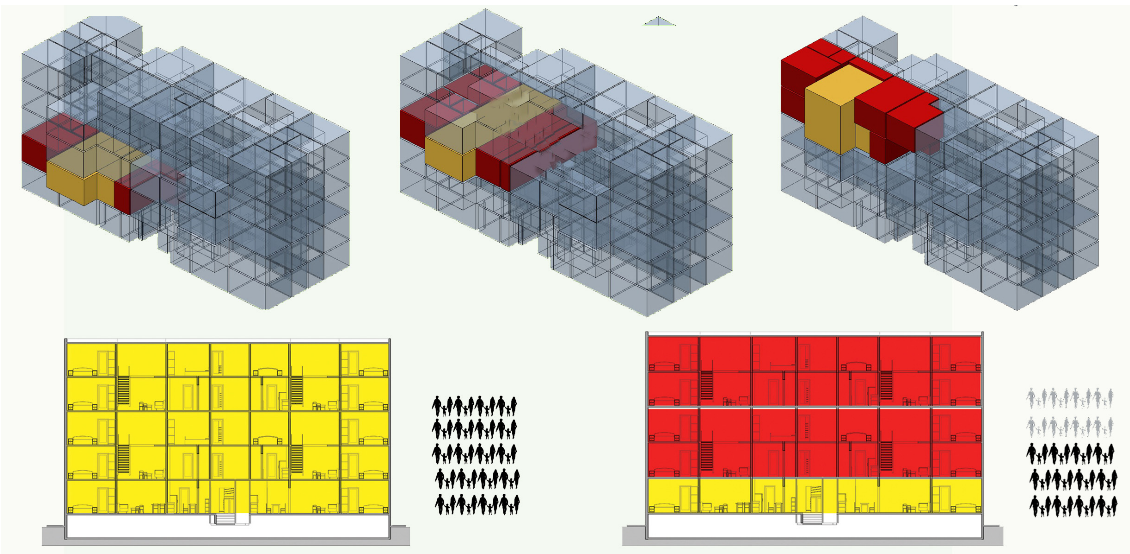


Figure 9. 3D matrix with different densification scenarios method.

3 STRUCTURAL ANALYSIS

The design of the retrofitted structure is carried out in two stages: (i) verification of the current state of the structure and (ii) verification of the structure after intervention (retrofitted structural system). It is also important to underline here that from the period 1965-1975 until now, the load as well as structural codes changed several times, including the seismic action/code. Consequently, these must be accommodated in the re-design of buildings.

3.1 *Behaviour of the un-retrofitted structure under current loads*

The performance of the original structure was evaluated with the ETABS computer code, by using 3D analyses based on shell finite elements. The thickness of the shell elements modelling horizontal and vertical diaphragms was equal to the thickness of the load bearing layer. The seismic load was accounted through a spectral analysis using the ground acceleration value a_g=0.16g and a control period T_c=0.7s. The first modes of vibration, translational, longitudinal, torsional and the corresponding periods are shown in Figure 10.

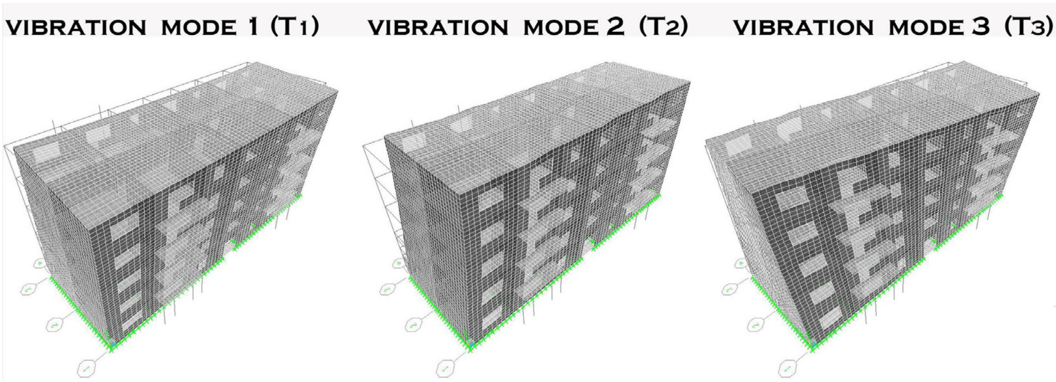


Figure 10. Eigen vibration modes and the corresponding periods of original structure ($T_{1,y}$=0.100s, $T_{2,x}$=0.080s, $T_{3,\theta}$=0.078s).

Three wall diaphragms were checked i.e.: axis *A*, axis *C* and axis 2 (see Fig. 6). The largest internal force values resulting from the seismic load combination are given in Figure 11. The diaphragm checks were done using bending moment – axial force interaction diagrams and the pair (N, M) values are shown in Figure 12.

Panel axis A

Nr.etaj	N [kN]	M [kNm]
Etaj 4	-219.98	100.32
Etaj 3	-464.78	328.84
Etaj 2	-742.73	660.15
Etaj 1	-1048	1065.29
Base	-1393.6	1508.05

Panel Axis C

Nr.etaj	N [kN]	M [kNm]
Etaj 4	-121.59	-84.68
Etaj 3	-242.53	-89.38
Etaj 2	-358.62	-116.59
Etaj 1	-465.48	-115.28
Base	-548.67	-243.92

Panel Axis 2

Nr.etaj	N [kN]	M [kNm]
Etaj 4	-726	-501
Etaj 3	-1445	-1408
Etaj 2	-2165	-2473
Etaj 1	-2893	-3640
Base	-3686	-4719

Figure 11. Internal forces for panels in axis A, axis C (transversal) and respectively axis 2 (longitudinal).

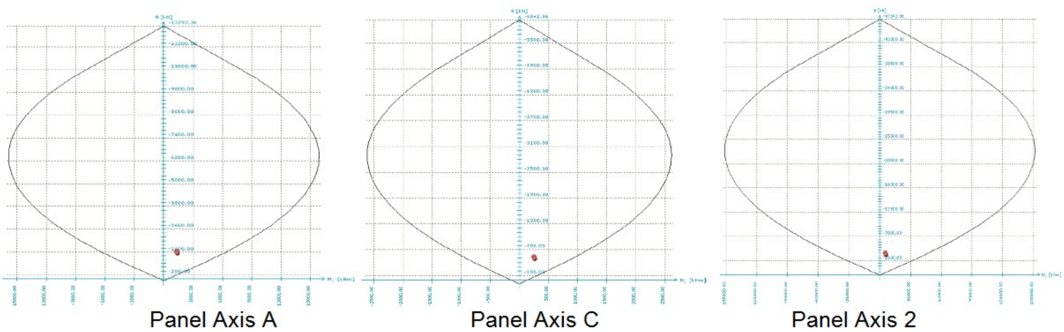


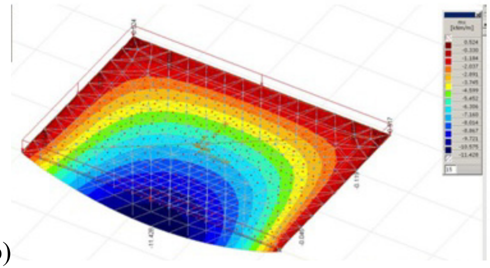
Figure 12. Verification of concrete panels using bending moment-axial force interaction diagrams. Points within the diagram represent the state of internal forces resulting from the calculations.

Other checks for the panels included the checking of the internal core of concrete in compression and shear, verification of horizontal reinforcement in joints; resistance to crushing and shear of the joints at the ground level.

Special attention was given to the verification of reinforced concrete slab in the living room (panel P42-21) due to the fact that one intervention is proposed in this area in case of apartment coupling on horizontal. This panel is supported only on three edges. Figure 13 presents the design value of bending moment and the resistance to bending moment in the floor slab and also the M_x component in the floor slab.

Design value of bending moment [kNm]			Resistance to bending moment [kNm]	
M_x	11.43	<	$M_{x,Rd}$	11.48
	-0.52			
M_y	3.90		$M_{y,Rd}$	6.23
	-0.53			

(a)



(b)

Figure 13. (a) M_x and M_y design bending moments and corresponding bending moment resistance; (b) M_x component in the floor slab.

The allowable deflection of the slab is limited to $l/250$= 4130/250 = 16.52mm. The deflection resulting from the SLS is 3.188mm, being satisfactory.

3.2 *Apartment repartitioning by creating enlargements in transversal diaphragms*

The structural behaviour was evaluated through 3D analyses using ETABS computer code. The analyses were performed on the initial structure (denoted as case „A") and on the structure with large openings in the vertical walls in axes *C* and *F* (see Fig. 6), strengthened with steel profiles (denoted as case „B") as shown in Figures 14-17.

Due to the high rigidity of the slabs which act as a horizontal diaphragms, the results show no significant increase of lateral displacements for the retrofitted structure (case B - diaphragms with large openings) in comparison to initial case A (see Fig. 14). In both cases the first mode of vibration is transversal; the second one is longitudinal, while the third mode is torsional.

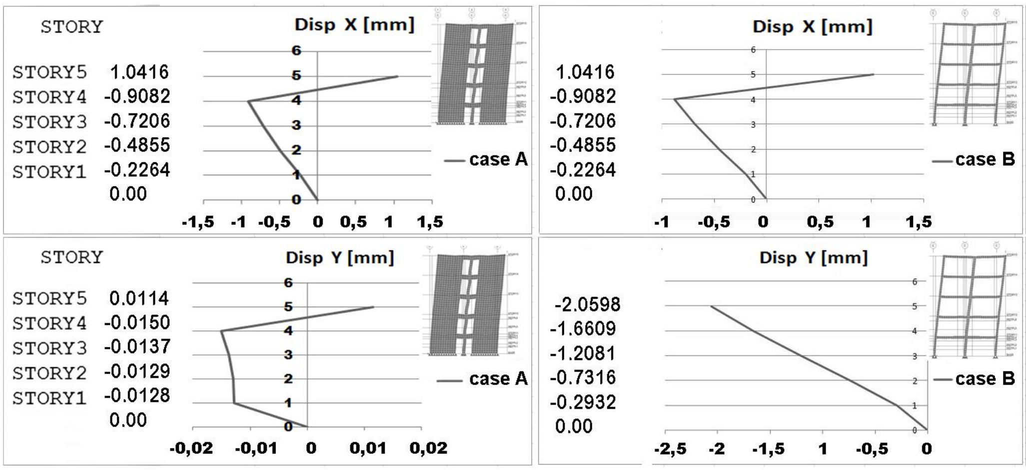
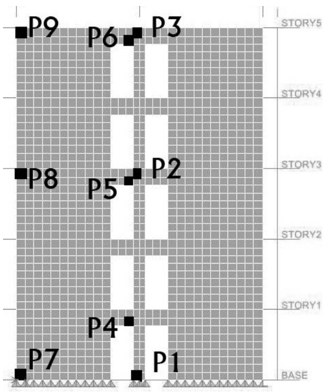


Figure 14. Lateral displacements [mm] for analysed cases "A" and "B".

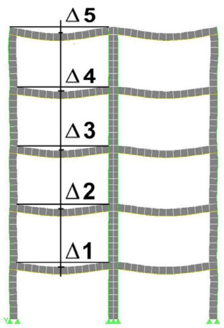
By the direct comparison of the normal stresses S_{11} and S_{22} from the seismic combination, for case "A" and case "B", a slight increase of the values in second case can be observed. In the same time the stress redistribution due to the interventions brings changes in the stress field. In general, substantial changes are observed in the door lintels. The shear stresses S_{12} show that for case "B" the values are 5 times higher than for case "A" due to the stress redistribution. The most sensitive areas are at the lower levels, generally in the panel connection regions. For the studied seismic level the stresses are smaller than the design resistance limits. This situation is exemplified in Figure 15.



	S11 [N/mm2]		S22 [N/mm2]		S12 [N/mm2]	
	case A	case B	case A	case B	case A	case B
P 1	-0,853	-0,878	-2,712	-2,721	-0,141	-0,743
P 2	-0,637	-0,631	-1,862	-1,834	-0,072	-0,491
P 3	-0,461	0,543	0,407	0,401	-0,105	-0,212
P 4	-0,524	-3,642	-0,829	-0,829	0,291	1,571
P 5	-0,756	-4,051	-0,534	-0,506	0,288	1,853
P 6	-0,755	-2,283	-0,463	-0,456	0,035	1,223
P 7	-0,325	-0,721	-1,643	-3,728	-0,134	-1,071
P 8	-0,157	-0,252	-0,718	-0,927	-0,022	-0,267
P 9	0,088	0,131	0,112	0,131	-0,066	-0,075

Figure 15. Values of normal and shear stresses.

From the serviceability limit state conditions, in axis *C* where the enlargements were performed, a maximum vertical deflection of 0.65 mm was obtained. The deflections for all storeys, for different loads and the combination, which contain the seismic action, are presented in Figure 16.



[mm]	DEAD	PERM	SEISM	LIVE	COMB 3
Δ5	0,301	0,211	0,112	0,034	0,653
Δ4	0,252	0,142	0,101	0,092	0,551
Δ3	0,231	0,134	0,092	0,086	0,502
Δ2	0,204	0,119	0,072	0,079	0,423
Δ1	0,156	0,097	0,044	0,068	0,313

Figure 16. Deflections in axis *C* [mm].

In the new configuration, the vertical loads from fundamental load combination will be resisted by the steel reinforced concrete frame structure. Figure 17 presents the bending moment diagram on the new composite structure in case of fundamental combination (see Fig. 17A) and respectively the combination containing the seismic action (see Fig. B).

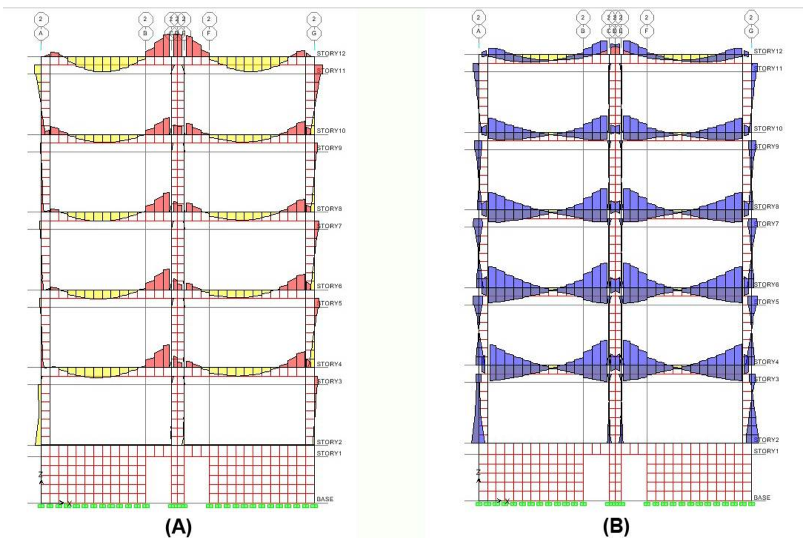
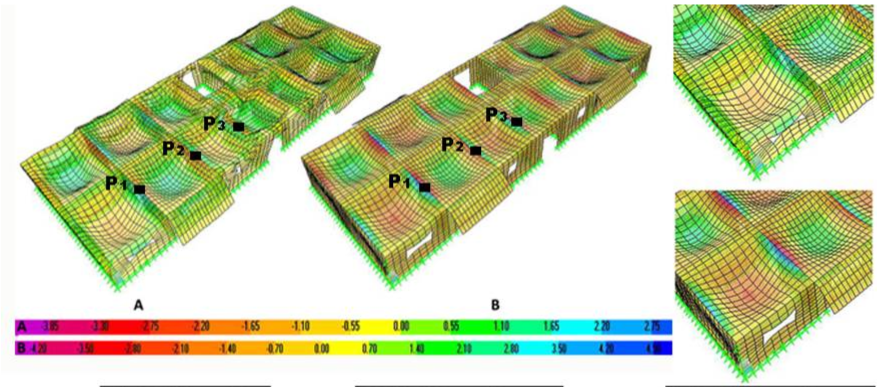


Figure 17. Bending moment diagram on the steel reinforced concrete frame [mm].

In comparison with case “A”, in case “B” the normal and shear stresses increase in the slab areas as shown in Figure 18.



	S11 [N/mm2]			S22 [N/mm2]			S12 [N/mm2]	
S11	case A	case B	S22	case A	case B	S12	case A	case B
P 1	2,995	3,241		0,672	3,075		0,401	0,758
P 2	2,519	2,537		0,829	2,567		0,405	0,585
P 3	2,401	2,704		0,987	2,173		0,417	0,866

Figure 18. Values for normal and shear stresses [N/mm^2] for a current slab.

The numerical analyses have shown also that the required strengthening of the diaphragms depends on the seismic intensity area. These interventions may generally be local and can be done considering the existing reinforcements in tension.

3.3 *Horizontal repartitioning by pairing two apartments*

One possibility to enlarge the living areas of the flats is by pairing two apartments horizontally. The checks of the structure after retrofitting was performed according to CR2-1-1.1:2011 by considering two additional openings of 1350 mm in the central longitudinal walls in axis *2*, as shown in Figure 19.

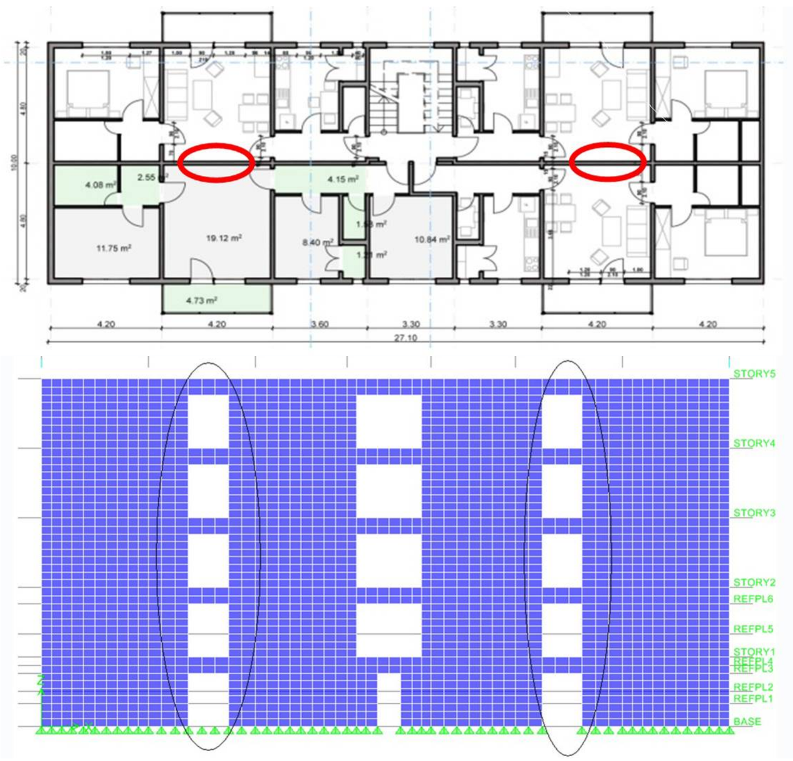


Figure 19. T744R – Creation of openings in the longitudinal diaphragm in axis 2.

The 3D modal analysis on the retrofitted structure shows that the first mode of vibration, on transversal direction is almost the same, with T_1=0.111s. The second mode of vibration remains on longitudinal direction, but with a higher period of T_2=0.097s, affected by the openings that were performed in the diaphragms. For the third mode of vibration the period is T_3=0.081 s. The analysis shows that internal forces in the unaffected diaphragms are similar to the values recorded for the initial structure, but major differences are recorded in the diaphragm in axis 2. Generally, the same structural checks were conducted. The verifications revealed that the middle longitudinal concrete wall has to be reinforced locally, in order to resist the loads.

3.4 *Vertical repartitioning by pairing two apartments*

The pairing of two apartments at different storeys and turning them into a single apartment can be realized by creating openings in the slab area and adding an interior staircase. Vertical extension of living room areas can be considered one of the most spectacular methods for increasing the comfort of habitants (see Fig. 20). The structural analyses shows that the vertical concrete walls are practically unaffected by the new opening in the slab. However, opening created in the slab changes the internal force distribution in that particular slab. For the evaluation of the cut slab, the slab panel P42-21 was verified by considering a cut of 1200×1200mm.

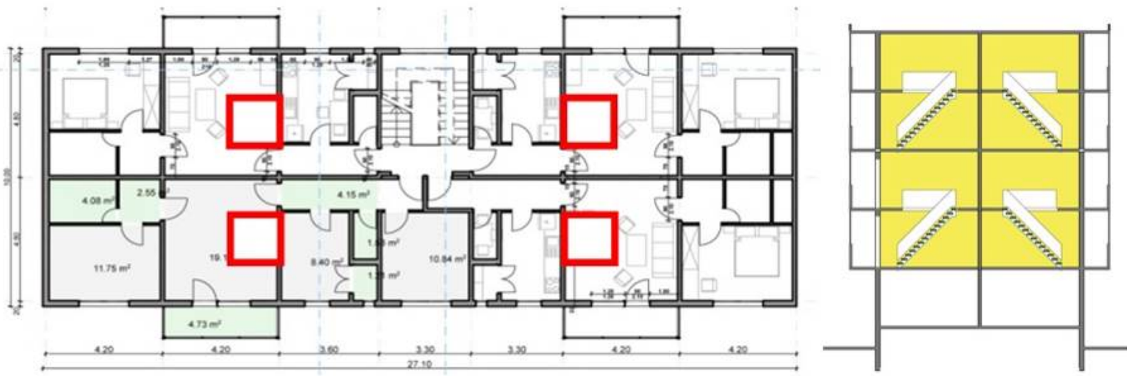
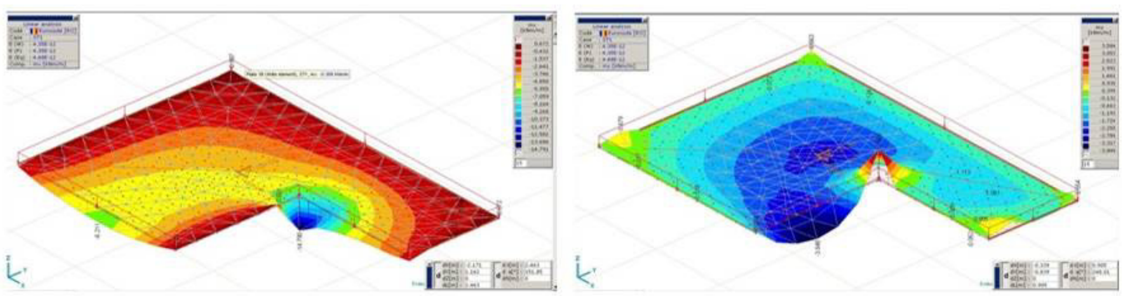


Figure 20. T744R – Detail with cut intervention on slab (plan and elevation).

In the new configuration, the panel is a floor slab supported on two edges and half of the third. Figure 21 shows the values of bending moments on the two main directions (M_x, M_y) of the plate in comparison with the resistance which should be considered in comparison with the results presented in Figure 13. In these conditions it becomes clear that the slab should be consolidated on *x* direction.



Design value of bending moment [kNm]			Resistance to bending moment [kNm]	
M_x	14.79 (-0.67)	>	$M_{x,Rd}$	11.48
M_y	3.90 (-3.85)	<	$M_{y,Rd}$	6.23

Figure 21. T744R – M_x and M_y bending moments on cut diaphragm.

4 SOLUTIONS FOR STRUCTURAL CONSOLIDATION

4.1 *Consolidation for vertical wall openings*

4.1.1. Consolidation using steel profiles

The strengthening solution of the vertical openings consists of a steel frame enclosing the cut, by welded angles and forming a hat section accommodating the concrete cut. The profiles are fastened to the concrete wall with anchors passing from one side to the other. The frame stanchions are simply supported at the base, above the floor slab.

The correct fixing of the hat section to the precast reinforced concrete structure requires chemically bonding of the anchor bolts. In order to check the new system, a new analysis has been performed, by considering the additional steel elements connected to the cuts. The number of the anchoring bolts (minimum 15 pieces) resulted from the condition of assuring a complete interaction between the steel and concrete elements through capacity design.

The structural analysis shows that strengthening of the openings is required on all floors. The strengthening can be done by attaching individual steel frames to the remaining concrete diaphragm, at every storey (see Figure 21) or using a continuous steel frame as shown in Figure 22. The additional weight of steel components is less than 200 kg, and the columns and beams can be assembled on site by welding or bolting.

In the first case (see Figure 21) the frames are considered pinned at the base, above each floor slab. Connection of the steel frame to the reinforced concrete structure is done using chemical anchors. The beam-to-column connection is realised by welding and the outer flanges of columns and the beam are fixed to the reinforced structure with chemical anchors (see detail 2 in Figure 21). The advantage of the solution is that intervention can be limited to a single apartment at a time.

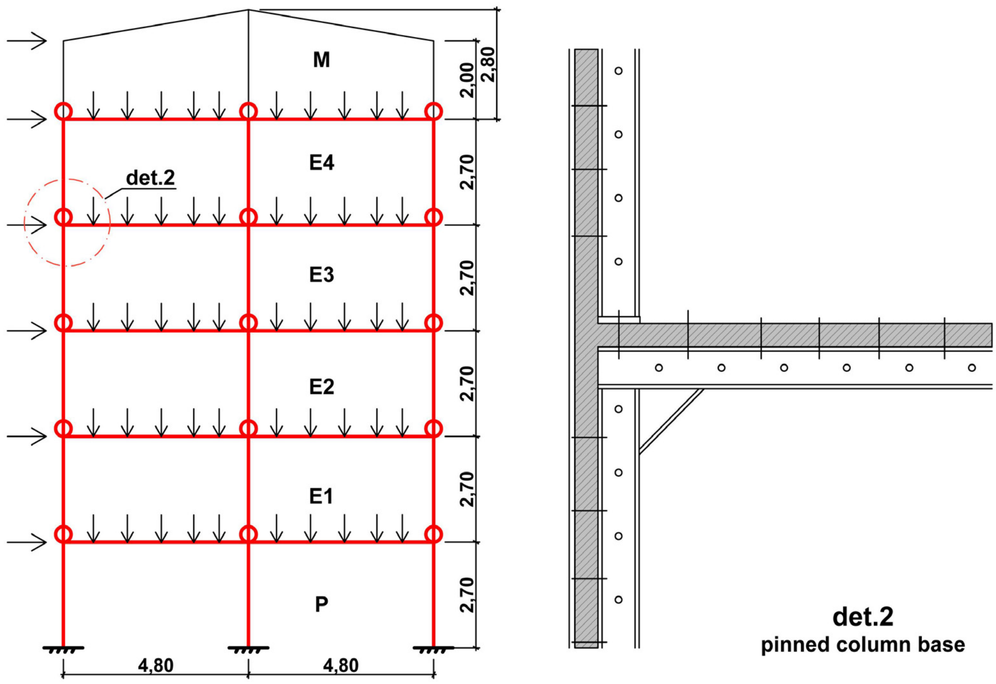


Figure 21. Transversal frame – pinned column base.

In the second case the structural system is proposed as a continuous frame with rigid joints (see Figure 22) where the steel columns are connected at about 1.0 m above each slab, and beams at 0.8 m from the beam-to-column joint (see detail 3 from Fig. 22). The main advantage is the continuous framing results in smaller steel element sections, but the continuity of the vertical elements requires whole building to be taken out of use during renovation.

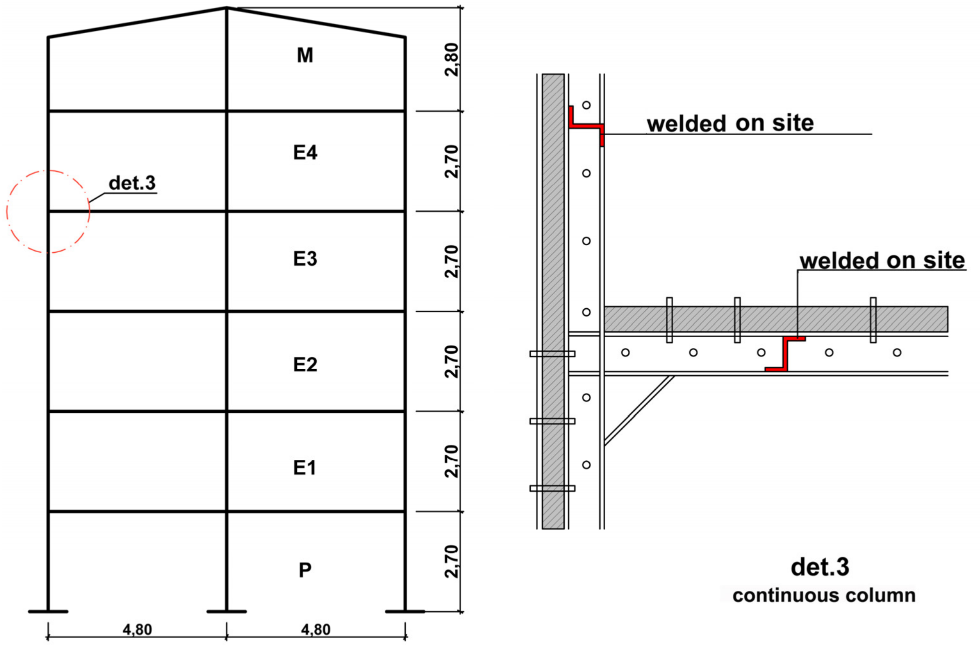


Figure 22. Transvers frame – continuous columns.

In this case the steel frames are connected to the reinforced concrete diaphragms by means of chemical anchors, designed in such a way that composite steel-concrete section results. The connections with chemical anchors are used to both the wall diaphragms and the slabs, as shown in Figures 23-24. Practically, the initial structure with precast reinforced concrete large panels is transformed into a composite structure made with vertical diaphragms and alternating composite frames.

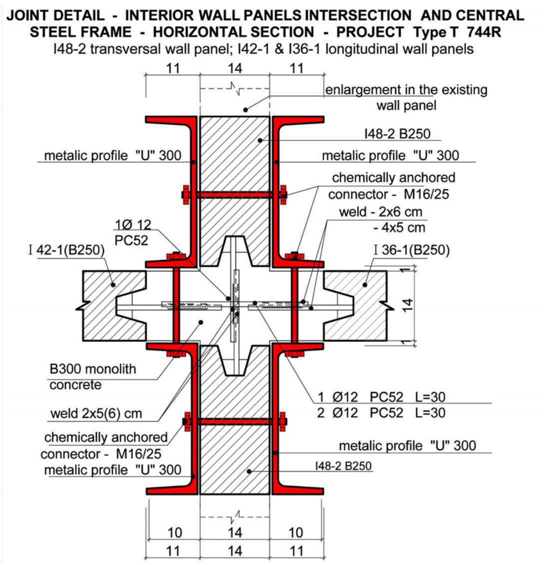


Figure 23. Internal walls consolidation
– joint detail – horizontal section.

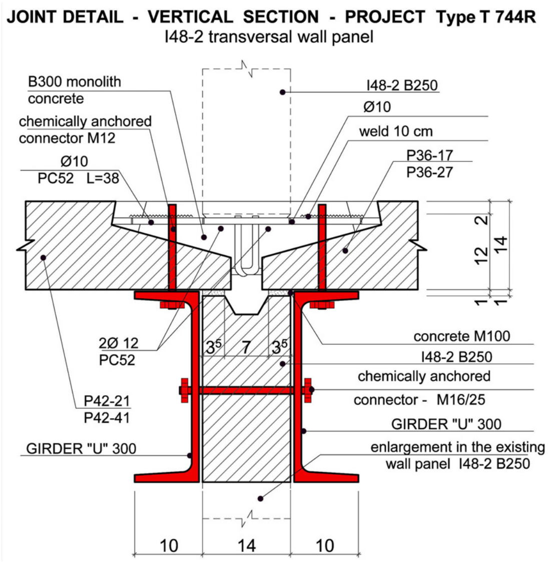


Figure 24. Slabs and wall connection
– joint detail – vertical section.

The described solutions present a series of advantages such as reversibility, easy erection, partial manufacturing in workshop, easy interventions in case of impairment, easy checking of execution quality.

For all the described situations the new composite steel – reinforced concrete frames are able to resist the gravitational loads and to transmit the loads to the foundations. The horizontal seismic forces are partially resisted by the frames, and partially redistributed through the horizontal slabs to the vertical diaphragms unaffected by the intervention.

4.1.2. Concrete jacketing

Concrete jacketing represents a classical solution in case of diaphragm openings and increases significantly the initial element section, which further result in increased stiffness. Concrete jacketing should work with the existing element through adherence and additional reinforcement. Substantial inconvenience consists in increasing the thickness of the original element which leads to reduced clearance and a relatively high added weight. For the proposed openings in the walls a concrete jacketing of 10cm thickness is needed on each side of the wall (see Fig. 25).

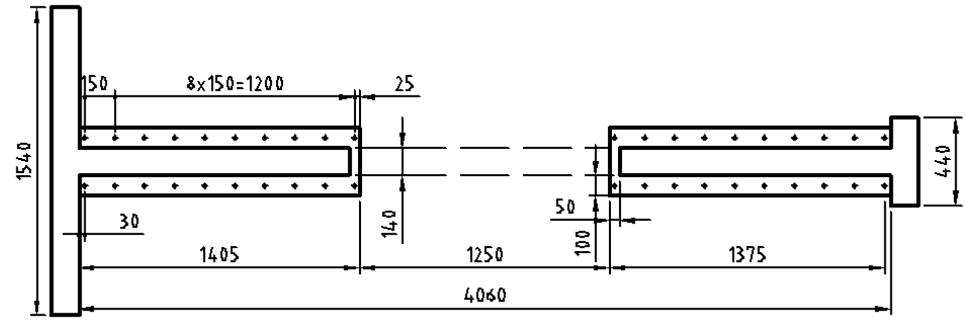


Figure 25. T744R –Concrete jacketing of walls.

4.2 *Consolidation of the concrete slab*

As resulted from the static analysis, additional reinforcement is needed in the concrete slab, near the cut-out opening. For this a practical solution is adopted, by mechanical connection of some mild steel plates bonded to the concrete surface both on top and on the bottom. The total length of the plates is equal to the cut length to which an anchorage length is added. The connection with the existing concrete slab is assured by vertical bolts. Considering also capacity design, a number of 11 screws are needed. For assuring a good interaction, the steel plates will be welded together in the junction area for continuity (see Figure 26).

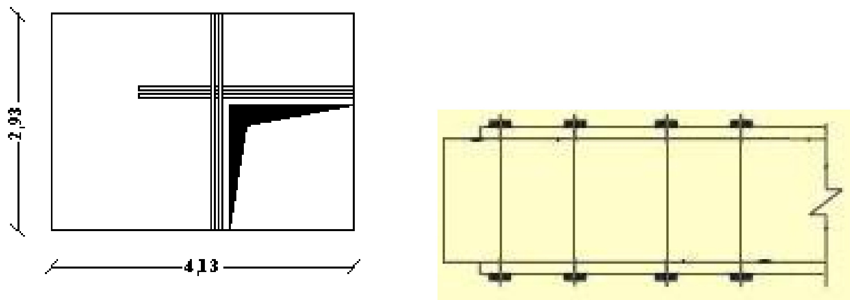


Figure 26. T744R – The layout of the steel plates.

5 POTENTIAL OF THE RETROFITTING INTERVENTION TO IMPROVE SOCIAL SUSTAINABILITY OF THE BUILDING

The type of retrofit interventions sketched in the paper aim to improving social sustainability of the concrete building typology. The European framework for assessing the potential improvements is given in the standard EN 15643-3:2012, while the methodology of assessment is described in more details in prEN 16309:2011. The European standardization process is at the start concerning social sustainability. Some categories of social performance aspect have an agreed basis for standardization, but some lack this basis at present. Also, as aspects and especially indicators of social performance are difficult to quantify; a checklist approach is promoted by the standards without specifying assessment schemes or valuation methods.

In this section, an attempt is made to estimate the improvement potential of social performance with the retrofit solutions presented, but also to highlight the full range of possible measures towards transforming the building stock. The aim is to support decision making in early stages of promoting retrofit measures and to help policy development.

The functional unit can be considered the full building T744R-IPCT as described in section 2.1, with a usable area of 1188.9m^2. The building is a residential one containing 20 apartments. The horizontal reconfiguration of internal space inside an apartment (see Figure 6) is considered as a reference case of retrofit. After reconfiguration the useful area increases slightly due to the incorporation of the balconies. The building remains of residential type, but the potential number of occupants decreases due to the transformation of the apartment spaces. The design service life of the building is 50 years (EN1990:2002), but the retrofit takes place after about 30-40 years of service. The remaining service life is 10 years. In context of implementing the quite complex retrofit, the extension of the service life could be considered.

The system boundaries should be set strictly to the perimeter of the building superstructure, its foundations system and exclude the site of the building. This choice must be done in the Romanian legal context as the building is privately owned. Use stage should be covered, with focus on module B1 – *Use scenario* (Figure 1 in EN 15804 and presented in Figure 27 of the paper). To further simplify the assessment only the impact on the users of the building can be considered (see Annex B, EN 15643-3:2012).

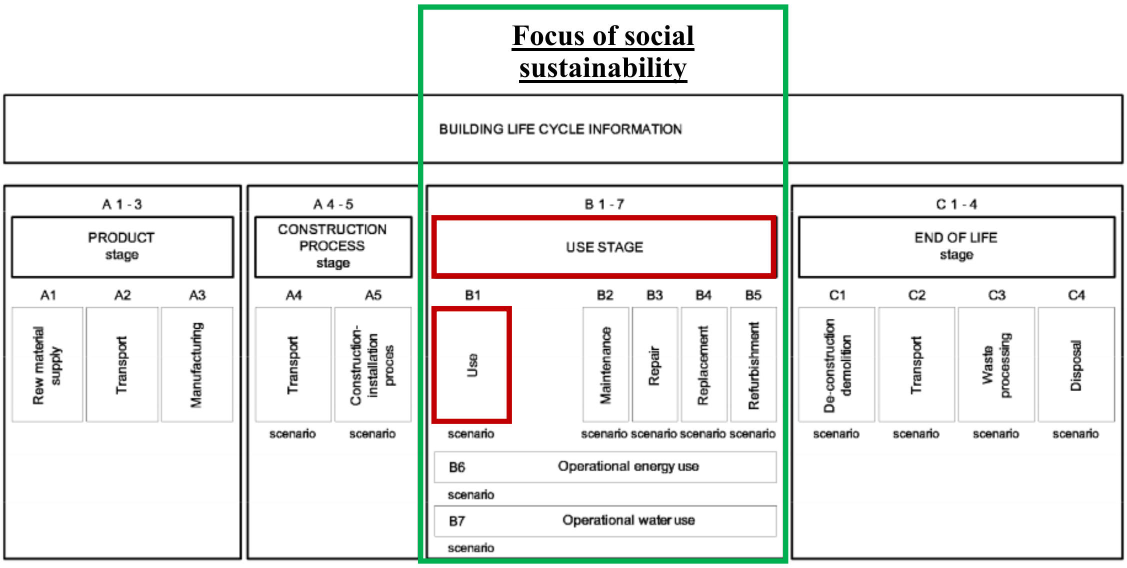


Figure 27. Social sustainability focuses on the use phase of the building life cycle (reproduction from EN15804).

Hence, defocusing from impacts on the neighbourhood and involvement of society is proposed. The neighbourhood impacts considered here not relevant in the use phase, as most take place in the execution phase of the retrofitting. Broader impacts on society, primarily the local community, may be very significant in the use stage, as the retrofit proposed can change the number and social profile of occupants, e.g. reducing the population density in neighbourhoods. However, the focus on these broader impacts is out of the scope of this study.

Given these limitations, the list of aspect related to social performance, and a few possible measures to improve performance are given in Table 1, based on the upcoming standard prEN 16309 (2011).

It can be noted from Table 1 that not all means of improving social sustainability are available at the building level. For instance the approach to the building is something that is in the responsibility of municipalities in the Romanian context.

Table 1. Aspects of social sustainability affected by the retrofit interventions.

Aspect related to social performance	Sub-aspect and section number in prEN 16309:2011	Relevant? (yes/no)	Applicable national or European requirement (as in 2013)	Possible measures to improve performance for the social aspect	Measure ensured by the initial design?	Applied in renovation concept Figure 6?	Could presented technique be used?
Accessibility for people with special needs	Approach to the building (7.2.2)	no	NP051/2001	Not relevant because it is outside of system boundary	no	no	no
Accessibility for people with special needs	Entrance and movement inside the building (7.2.2)	yes	NP051/2001	Access ramps for ground floor apartments. Ensure accessibility ensured for 20% of the floor area	no	no	yes
Accessibility for people with special needs	Entrance and movement inside the building (7.2.2)	yes	NP051/2001	External elevator systems. Accessibility to 100% of the floor area	no	no	yes
Accessibility for people with special needs	Entrance and movement inside the building (7.2.2)	yes	NP051/2001	Width of door openings upgraded for accessibility	no	partly	yes
Accessibility for people with special needs	Entrance and movement inside the building (7.2.2)	yes	NP051/2001	Minimum width of corridors and room spaces upgraded	no	partly	yes
Accessibility for people with special needs	Access to building services (7.2.3)	yes	NP051/2001	Minimum width of bathroom spaces upgraded to include manoeuvring space	no	no	yes
Adaptability	Adaptability (7.3)	yes		Minimization of internal load-bearing elements	no	yes	yes
Adaptability	Adaptability (7.3)	yes		Ease of demolition/demountability of internal elements	partly	yes	yes
Adaptability	Adaptability (7.3)	yes		Provisions for possible future equipment e.g. elevators	no	no	yes
Health and comfort	Visual comfort (7.4.5)	yes		Increased daylight contribution	yes	no	yes
Health and comfort	Visual comfort (7.4.5)	yes		Improve visual connection with exterior by modifying window heights, aspect ratios etc.	yes	no	yes
Health and comfort	Spatial characteristics(7.4.6)	yes		Modify number and floor area of rooms.	yes	yes	yes
Health and comfort	Spatial characteristics(7.4.6)	yes		Number and floor areas of toilets, bathrooms, volumes of storage rooms	yes	yes	yes
Health and comfort	Spatial characteristics(7.4.6)	yes		Outdoor area and balconies	yes	yes	yes
Maintenance	Maintenance (7.6.)	yes		Ease of access. Accessibility without dismantling/removal of building components.	no	no	yes
Safety and security	Resistance to climate change (7.7.2)	yes		Zoning of apartments to create buffer spaces (e.g. south facing facades in hot climate)	no	yes	yes
Safety and security	Accidental actions (7.7.3)	yes		Maintain structural stability for earthquake and explosion	yes	yes	yes
Safety and security	Accidental actions (7.7.3)	yes		Optimization of size of smoke and fire compartments	no	no	yes
Safety and security	Accidental actions (7.7.3)	yes		Improved design for the means of escape in case of fire (including people with disabilities. Improved access of fire fighters.	yes	no	yes

6 CONCLUSIONS

The interior repartitioning of concrete residential buildings can improve the comfort of inhabitants in such buildings. The apartment coupling horizontally or vertically will result in new internal configurations and can offer improved interior space, new types of flats, with implications at larger scale on the local community, such as the decrease of densification in urban areas. These types of interventions can also be used to revitalise parts of the city and contribute to cities urban regeneration.

Structurally, both types of interventions are possible but attention should be given to local detailing: (i) when cuts in the vertical diaphragms are performed, these should be reinforced by additional steel frames or concrete jacketing; (ii) if cuts are made on horizontal diaphragms, additional reinforcement near the cut-outs is needed.

Since technical possibilities exist, social sustainability targets should be considered by authorities on pair with ecological goals, with real estate development programs including such targets in their financing schemes. These social targets are both desired by owners (Botici *et al*, 2014) and are is some cases required by regulation. Achieving higher social sustainability standards is technologically possible, but not easy to implement on the existing large panel building stock, hence focus should be on the minimal improvements costs.

ACKNOWLEDGEMENTS

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Structural rehabilitation of precast reinforced concrete wall panels using CFRP composites

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ABSTRACT: The large number of precast reinforced concrete wall panel buildings that were built across the country attracted the interest on this type of structural system. Although these structures proved good seismic behavior in time, a considerable part of them are already 50 years old. Due to architectural reasons, change of use in buildings, functional space requirements and other factors the seismic performance of these structures was decreased by modifications of the load bearing elements. The current experimental program was set in order to analyze this type of structures, evaluate the seismic performance of the precast reinforced concrete wall panels (PRCWP), investigate the weakening induced by several types of cut-outs in the walls, apply different strengthening systems and analyze the retrofitting costs. The strengthening systems presented in this paper comprise: Externally Bonded Carbon Fiber Reinforced Polymer Reinforcement (EBR-CFRP), Near Surface Mounted Carbon Fiber Reinforced Polymer Reinforcement (NSM CFRP) and Textile Reinforced Mortar (TRM) using glass fiber (GF) grid. All the strengthening systems induced a more ductile behavior, comparison of wall results is highly influenced by the compressive strength of concrete which is not the same for all the wall panels, initial reinforcement available in the wall and the type of repair applied in each case.

1. MOTIVATION

The huge field of applications on precast reinforced concrete (RC) large wall panel buildings is the main reason of research and interest. Exploring this direction some aspects need to be established, such as the seismic performance of them, the weakening induced by several types of cut-outs, the type of strengthening system which can restore the initial load bearing capacity of the elements and the costs implied by strengthening. There is a large variety of strengthening systems available today which can be used individually or in combination with other strengthening systems, and the selection of it is most often based on the financial aspect. Limited literature is currently available on evaluation of strengthening costs, the one mentioned in the current paper was developed considering material and labor cost valid for Romania. Related to RC wall cyclic tests, online databases are more accessible sources, some of them being the shear wall database by Palermo [1] and the shear wall database by The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) [2].

2. EXPERIMENTAL PROGRAM DESCRIPTION

The current experimental program comprises a number of six precast reinforced concrete wall panels (see Figure 1): PRCWP (7-E1) having a narrow door opening, PRCWP (8-E3) having a large door opening, PRCWP (9-E1/E3) having a narrow door opening, enlarged to a large door opening, PRCWP (10-L1/L3) having a narrow window opening, enlarged to a large window opening, PRCWP (11-L1) having a narrow window opening, and PRCWP (12-E1) having a narrow door opening. There is a number of 11experimental tests which were carried out on these six precast RC wall panels, but only 7 tests will be presented in this paper. The first specimen (PRCWP 7-E1) was first tested unstrengthened (PRCWP 7-E1-T), repaired and post-damage strengthened (PRCWP 7-E1-T/R) and tested again. The second specimen (PRCWP 8-E3) was also tested unstrengthened (PRCWP 8-E3-T) and after it was repaired and post-damage strengthened (PRCWP 8-E3-T/R) and tested again. The third specimen (PRCWP 9-E1/E3) was only prior-to-damage strengthened (PRCWP 9-E1/E3-R/T) and tested. The fourth specimen (PRCWP 10-L1/L3) was first tested unstrengthened (PRCWP 10-L1/L3-T), then it was repaired, post-damage strengthened (PRCWP 10-L1/L3-T/R) and tested again.

The wall specimens were laterally loaded, reversed cyclic - displacement controlled. As the height of the wall is 2150 mm, 21.5 mm corresponds to 1% drift ratio. The displacement control has its unit a drift ratio of 0.1% (2.15 mm). Two cycles per drift were made [3]. The test was stopped when the specimen lost 20% of its load bearing capacity. The boundary conditions consist of restrained rotation and out of plane displacement prevention. The compressive strength (cubic measured) for the panels was 45.5 MPa for the PRCWP (7-E1) specimen, 17.5 MPa for the PRCWP (8-E3) specimen, 44.5 MPa for the PRCWP (9-E1/E3) specimen and 27.25 MPa for the PRCWP (10-L1/L3) specimen.

For the PRCWP (7-E1) specimen the reinforcement includes horizontal and vertical bars, a spatial cage on the entire height in the left pier, a spatial cage in the coupling beam, welded wire mesh in the right pier and a spatial cage at the top right corner of the door opening. Reinforcement of the PRCWP (8-E3) specimen contains horizontal and vertical bars, spatial cage on the entire height in both piers and a spatial cage in the coupling beam. In case of PRCWP (9-E1/E3) specimen the reinforcement comprises horizontal and vertical bars, a spatial cage on the entire height in the left pier, a spatial cage in the coupling beam and welded wire mesh in the right pier. For the PRCWP (10-L1/L3) specimen the reinforcement is composed of horizontal and vertical bars, welded wire mesh in the left and right pier, spatial cage in the coupling beam, wire mesh in the parapet and inclined bars at the top and bottom left corner of the window opening. Specimen (12-E1) has the same reinforcement as (7-E1) and specimen (11-L1) has the same reinforcement as (10-L1/L3) [4].

The instrumentation part in the experimental test consisted of three measuring quantities, namely displacements using displacement transducers, unit strains (using strain gauges) and forces (using piezo-resistive transducers). In addition to the measured quantities an important behavioral aspect of the reinforced concrete walls was recorded, namely the cracking pattern. The front face of the wall panel was surveyed for crack occurrence and propagation and all the information was marked on the wall. In order to localize the cracks an orthogonal reference grid was marked on the wall. These gridlines divided the wall face in 64 rectangles. A photo map will be assembled in order to obtain the final cracking pattern [5].

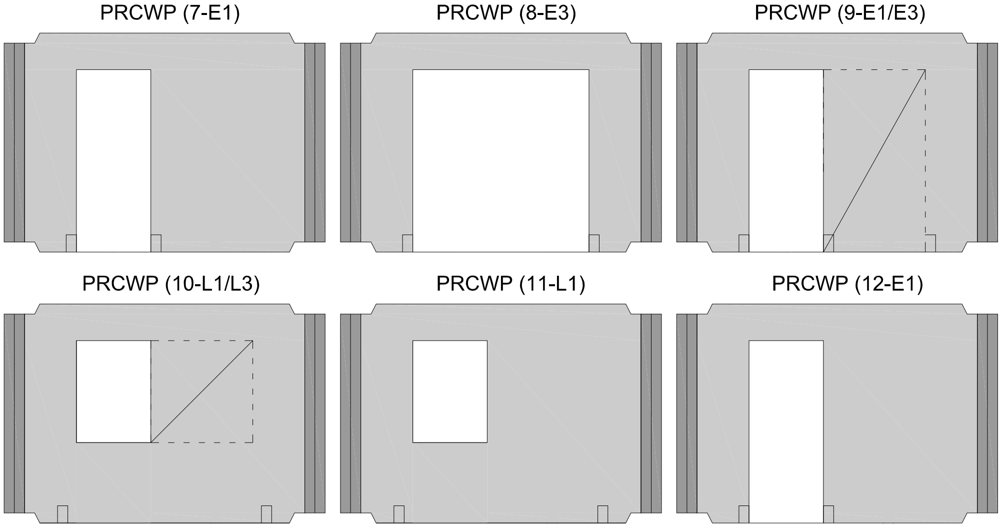


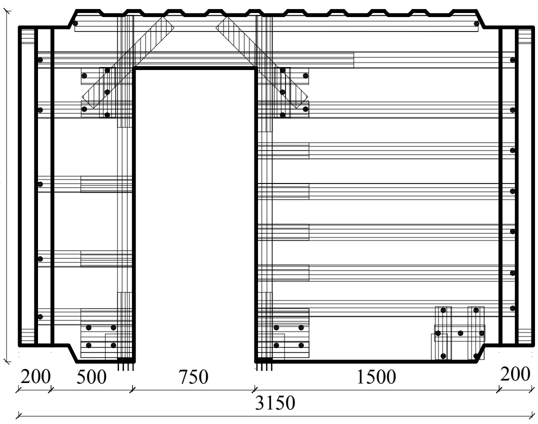
Figure 1. The precast reinforced concrete wall panels comprised in the experimental program.

3. STRENGTHENING STRATEGIES

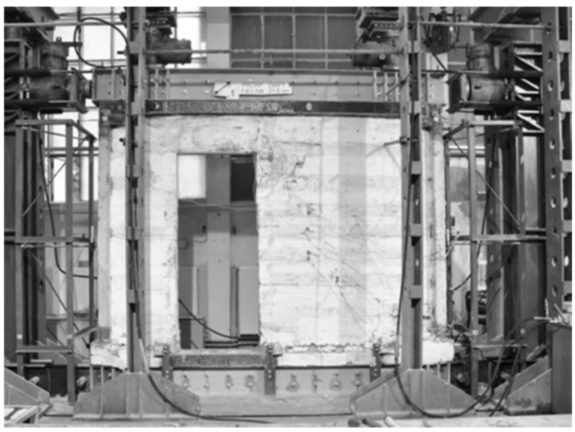
The strengthening strategies presented in this paper were chosen and applied in order to restore or increase the initial load bearing capacity of the walls. Four strengthening systems were chosen in the current experimental program, but only three of them are presented here, namely Externally Bonded Carbon Fiber Reinforced Polymer Reinforcement (EBR-CFRP), Near Surface Mounted Carbon Fiber Reinforced Polymer Reinforcement (NSM-CFRP) and Textile Reinforced Mortar (TRM) using Glass Fiber Grid. An important aspect in the performance of the strengthening system for the post-damage strengthened wall panels is the repair phase, which was done here by replacing the crushed concrete with high strength mortar. Cracks were not injected with epoxy resin, factor that influences the degree of repair of the panel but also significantly reduced the cost of repair and strengthening. The strengthening systems and the material consumption for each experimental test are presented in the section below.

3.1 Post-damage strengthened PRCWP (7-E1-T/R) having a narrow door opening

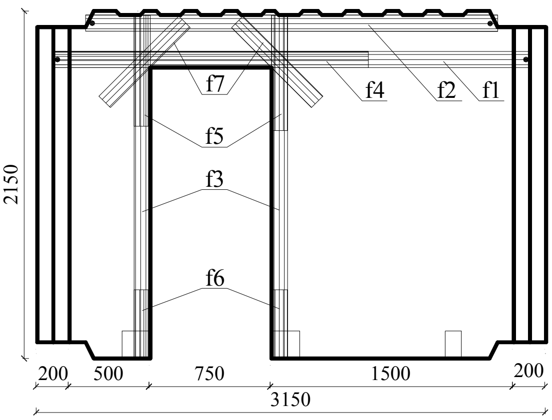
The strengthening layout of the specimen is represented in Figure 2 and was composed of flexural, shear and confinement strips. The strain gauge positions on the CFRP strips are also shown here. The flexural strips were disposed around the opening and along the upper edge of the spandrel beam. Additional second layer of short strips were placed inclined at the upper corners of the opening, horizontal till the upper length of the opening, and vertical at the upper and bottom side of the opening. The bottom vertical strips around the opening were anchored to the foundation with CFRP tows. The shear strips were disposed horizontally on the piers, anchored at their ends by overlapping strips on the opening side and by short CFRP tows at the wing-side end. CFRP confinement was provided at the inside toe of both piers and the outer toe of pier 2, at the pier to beam connection regions and at the ends of the wing walls. The material consumption of the strengthening using EBR-CFRP comprised 7.50 m^2 CF-fabric and 10 kg epoxy resin [6].



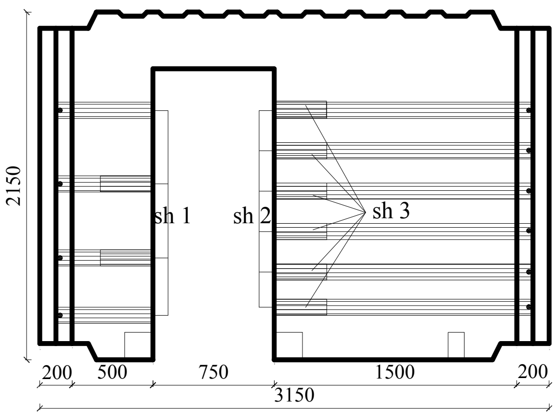
a) PRCWP 7-E1-T/R specimen



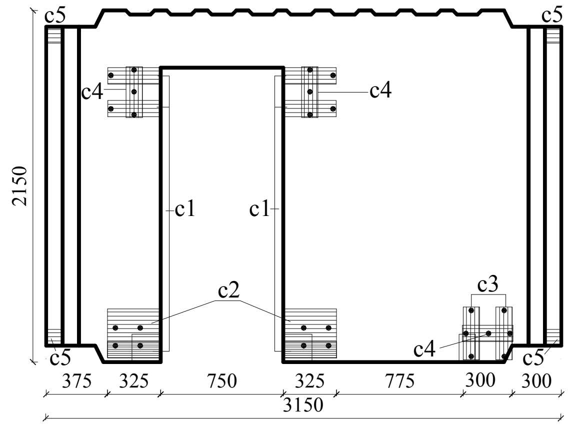
b) Experimental 7-E1-T/R wall

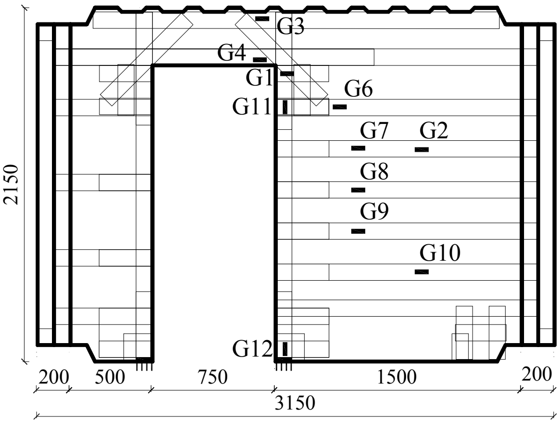


c) Flexural (f) strengthening



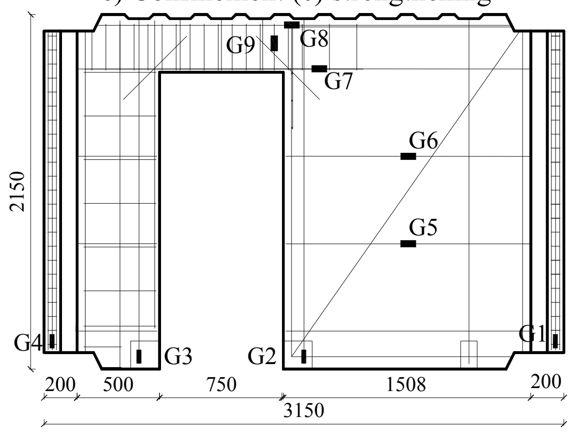
d) Shear (sh) strengthening





e) Confinement (c) strengthening

f) Strain gauges (G) on CFRP strips



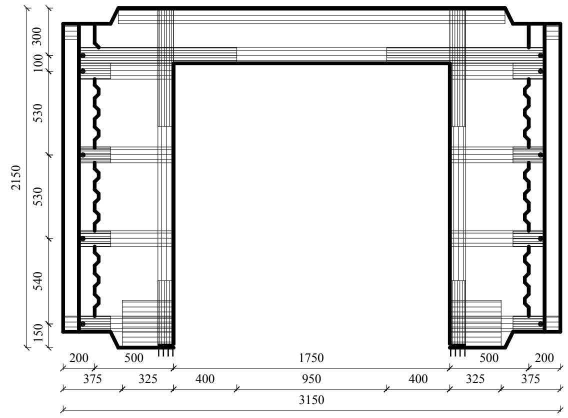
g) Strain gauges (G) on steel reinforcement

h) CFRP strips application

Figure 2. The strengthening layout of the precast reinforced concrete wall panel with narrow door opening [6].

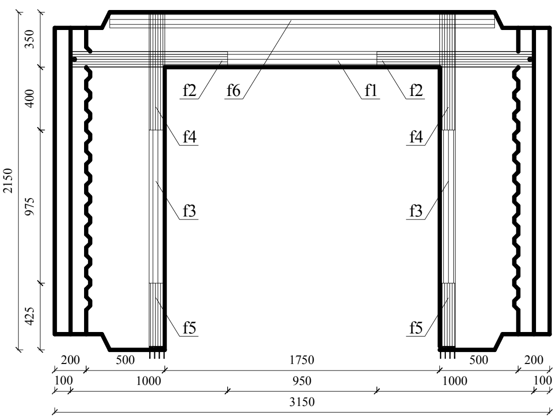
3.2 Post-damage strengthened PRCWP (8-E3-T/R) having a large door opening

The strengthening layout of the specimen is represented in Figure 3 and was composed of flexural, shear and confinement strips. The strain gauge positions on steel reinforcement and on CFRP strips are also shown here. The flexural strips were disposed around the opening and along the upper edge of the spandrel beam. The shear strips were disposed horizontally on the piers. The confinement strips were applied at the bottom corners of the opening and at the ends of the wing walls. The material consumption of the strengthening comprised 5.40 m^2 CF-fabric and 8 kg epoxy resin [3].

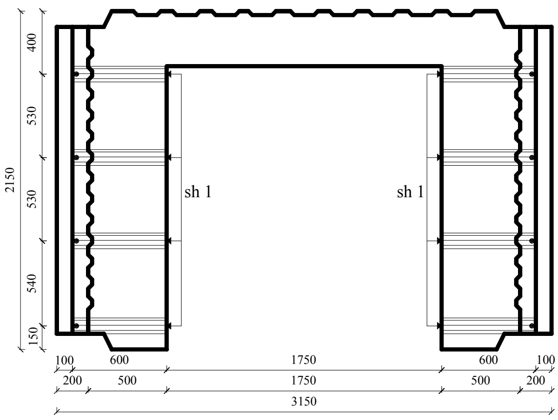


a) PRCWP 8-E3-T/R specimen

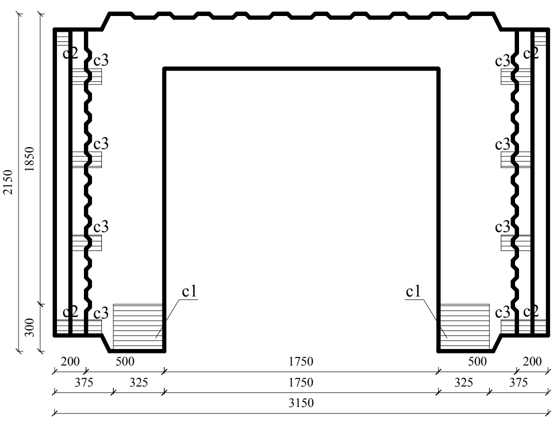
b) Experimental 8-E3-T/R wall



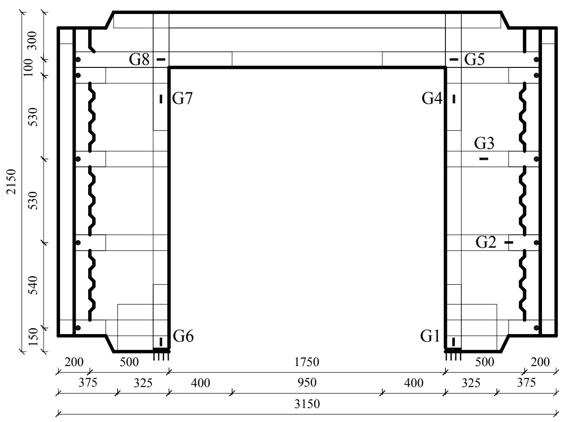
c) Flexural (f) strengthening



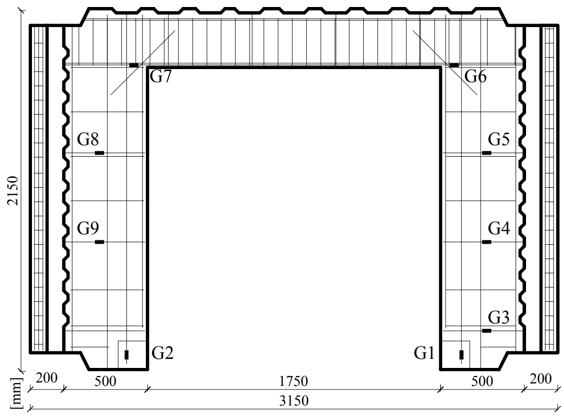
d) Shear (sh) strengthening



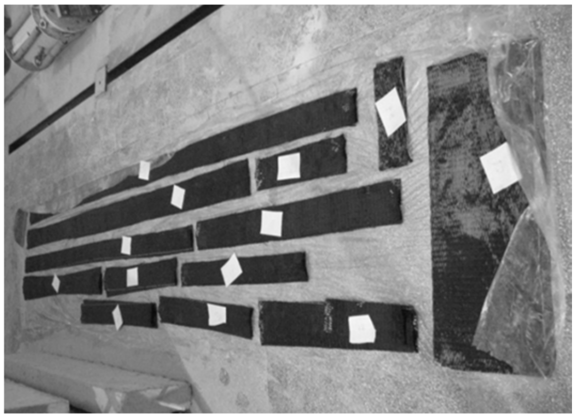
e) Confinement (c) strengthening



f) Strain gauges (G) on CFRP strips



g) Strain gauges (G) on steel reinforcement



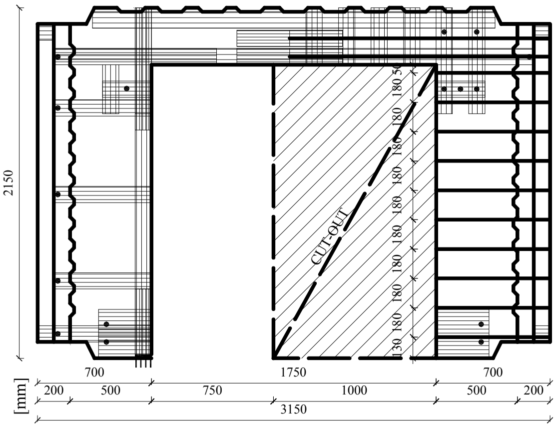
h) CFRP strips cut

Figure 3. The strengthening layout of the precast reinforced concrete wall panel with large door opening [3].

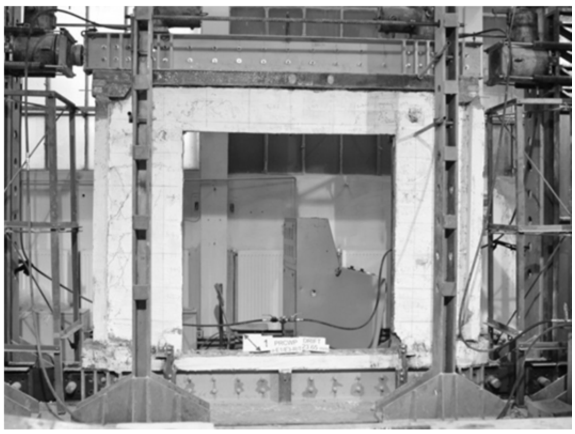
3.3 Prior-to-damage strengthened PRCWP (9-E1/E3-R/T) having an initial narrow door opening, and enlarged to a large door opening

The strengthening strategy for the prior-to-damage strengthened PRCWP (9-E1/E3-R/T) is composed of CFRP-EBR and NSM-CFRP and is presented in Figure 4. The applied strengthening intended to increase the flexural, shear and confinement capacity of the specimen. In the case of NSM-CFRP, 12x1.2 mm Carbon Fiber (CF) plates were used, disposed horizontally on the entire height of the right pier, the last two from the top were extended until the middle of the coupling beam. All the CF plates were anchored in the wing. For the CFRP-

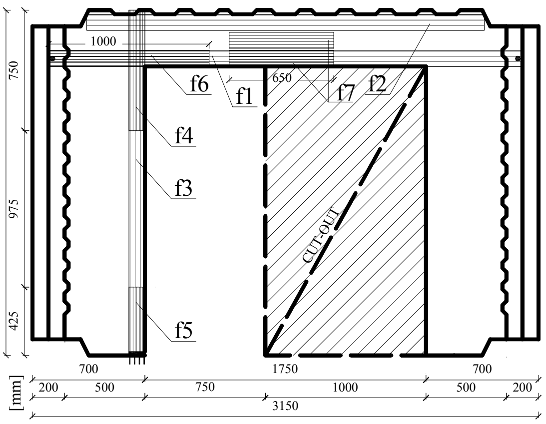
EBR system flexural, shear and confinement strips were used. The flexural strips were disposed around the opening on the left side and along the upper edge of the coupling beam. Additional second layer of short strips were placed horizontal till the upper length of the opening, and vertical at the upper and bottom side of the opening. The bottom vertical flexural strips were anchored to the foundation with CFRP tows. The shear strips were disposed horizontally on the left pier, anchored at their ends by short CFRP tows at the wing-side end, and CFRP hoops were used on the spandrel beam. CFRP confinement was provided at the inside toe of both piers, at the pier to beam connection regions and at the ends of the wing walls. The strain gauge position on the steel reinforcement, CF plates and CFRP strips is also shown here [7].



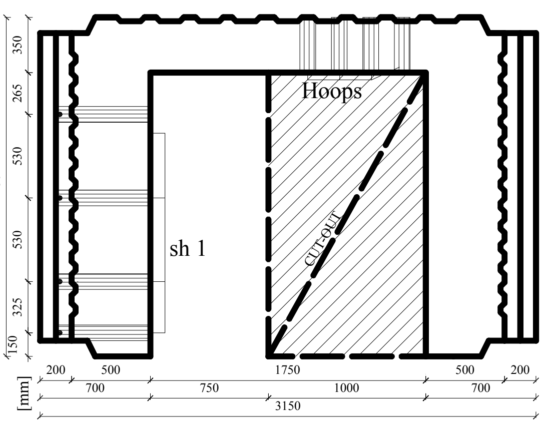
a) PRCWP 9-E1/E3-R/T specimen



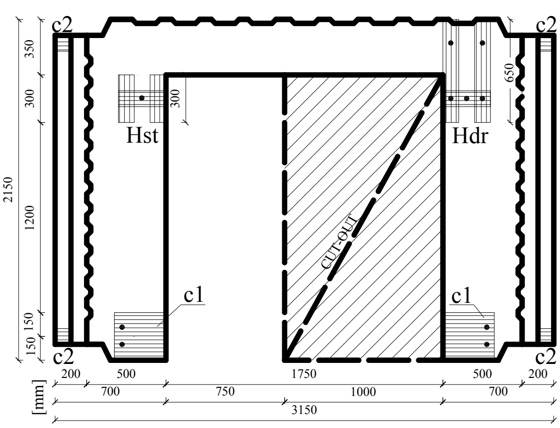
b) Experimental 9-E1/E3-R/T wall



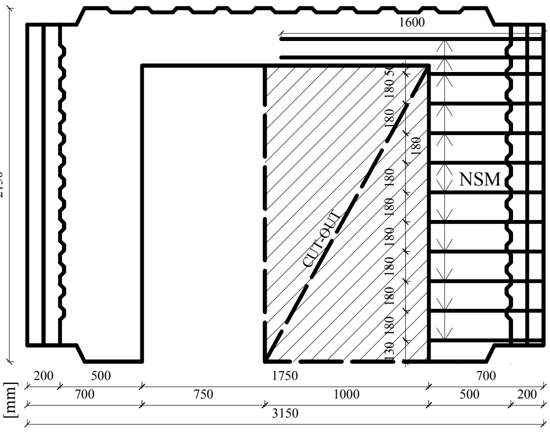
c) Flexural (f) strengthening



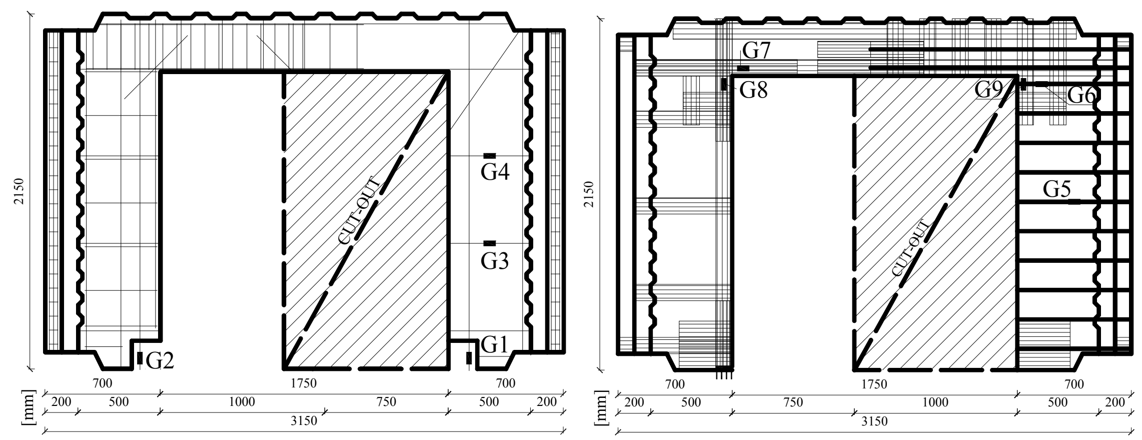
d) Shear (sh) strengthening



e) Confinement (c) strengthening



f) NSM CFRP strengthening



g) Strain gauges (G) on steel reinforcement h) Strain gauges on CFRP strips and plates

Figure 4. The strengthening layout of the wall with initial narrow door, enlarged to a large door opening [7].

3.4 Post-damage strengthened PRCWP (10-L1/L3-T/R) having an initial narrow window opening, and enlarged to a large window opening

After repairs were made, surface preparation phase started consisting in polishing the necessary surface, drilling ϕ8 mm holes for the threaded rods, rounding the corners of the opening about 20 mm, blowing the surface using compressed air and vacuum-cleaning the surface of the wall. The strengthening strategy was based on TRM technique. The TRM technique provides a viable alternative to “classic” FRP interventions without compromising strength and ductility increase [8]. An anchor system was used in order to assure the transmission of stresses and deformation from the structure substrate to the reinforcement layer [9]. The threaded rods (12 cm length) were fixed using resin through the panel. According to the retrofitting plan (Figure 5), the grid was cut using scissors considering their dimensions. After all the fibers were cut, the bonding primer was applied on the surface of the wall, followed by the first layer of mortar. The glass fiber grid was then applied (Figure 7a), followed by the second layer of mortar (Figure 7b). Strain gauges were mounted on steel reinforcement (Figure 6a) and on glass fiber grid (Figure 6b) [10]. The material consumption in this case implied 18 m^2 of glass fiber grid, 98 threaded rods for the anchorage, 35 kg bonding primer for the TRM system and 175 kg component mortar of the TRM system.

Figure 8 shows the strengthening materials used [11] in the experimental tests presented in this paper. Figure 8a) represents the carbon fiber plates used for the Near Surface Mounted Carbon Fiber Reinforced Polymer Reinforcement (NSM-CFRP). Figure 8b) shows the carbon fiber fabric used for the Externally Bonded Carbon Fiber Reinforced Polymer Reinforcement. Figure 8c) represents the glass fiber grid used for the Textile Reinforced Mortar system. Figure 8d) shows the component mortar used in the Textile Reinforced Mortar system.

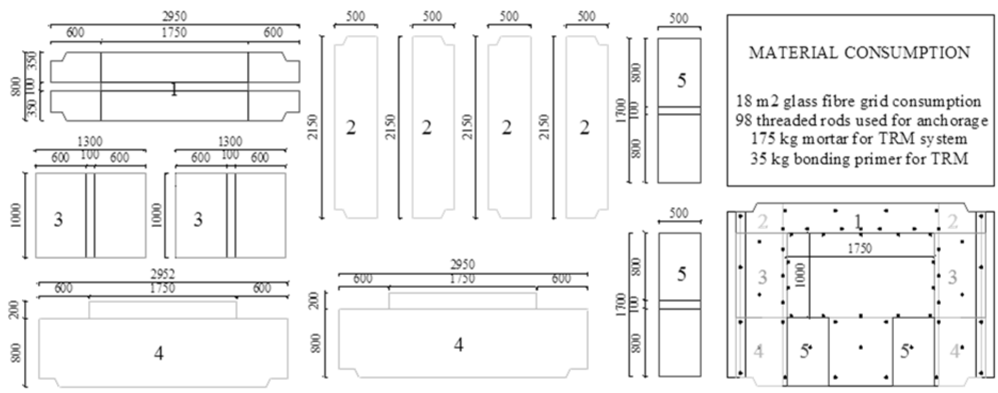


Figure 5. The strengthening layout of the wall with narrow window enlarged to a large window opening

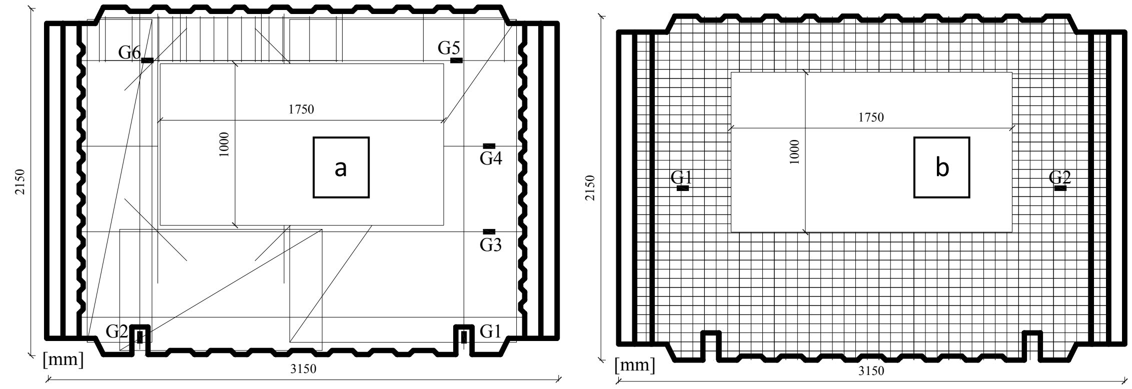


Figure 6. Strain gauges (G) position on a) steel reinforcement and b) glass fiber grid [10]

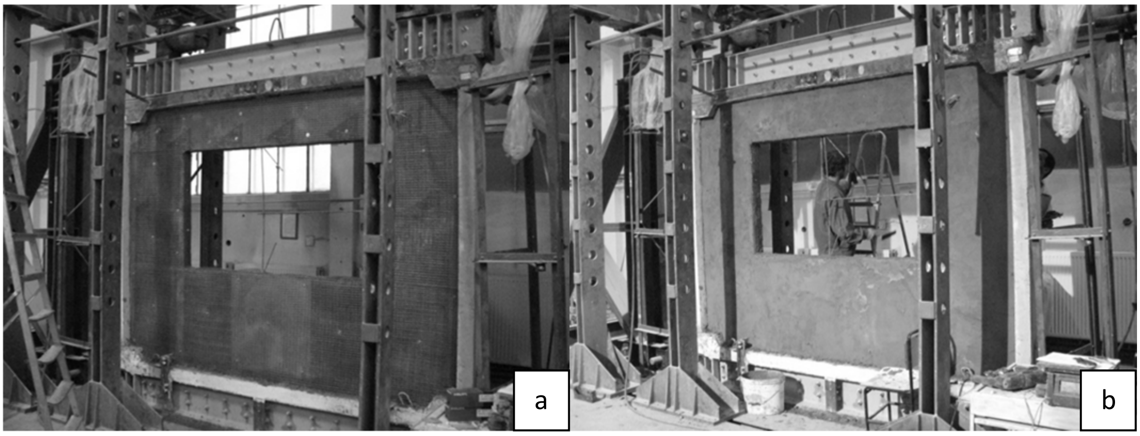


Figure 7. Application of a) glass fiber grid and b) second layer of mortar for the PRCWP (10-L1/L3-T/R) [10]

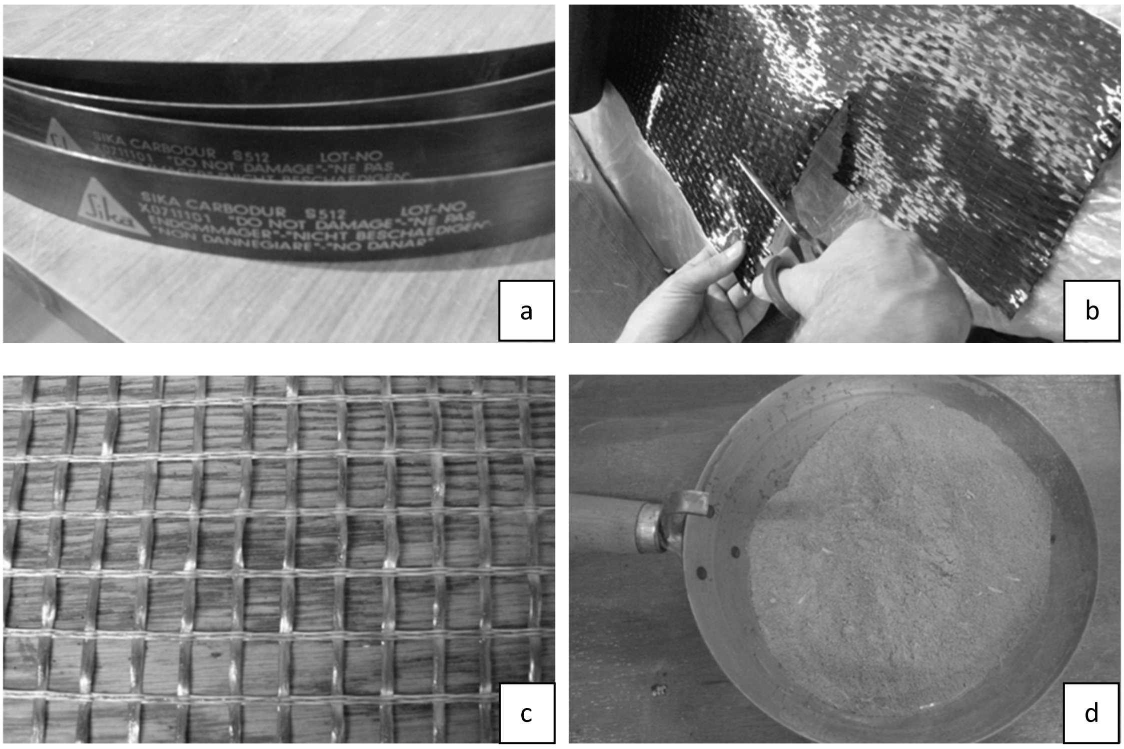


Figure 8. The materials used are: a) CF plates, b) CF fabric, c) glass fiber grid and
d) component mortar in TRM

4. FAILURE DETAILS

During the experimental tests, all the specimens recorded a number of cracks and certain types of failure depending on the opening dimension, compressive strength of concrete, reinforcement, strengthening strategy and the unstrengthened condition for some specimens.

4.1 Unstrengthened PRCWP (7-E1-T) having a narrow door opening

In the below figures are shown the failure details recorded in the experimental test of the (7-E1-T) wall panel. Concrete crushing, thick diagonal crack and reinforcement rupture are some of the failures presented here.

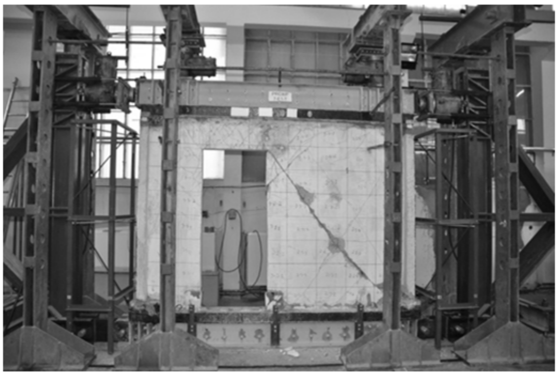


Figure 9. Failure of the specimen at 17.20 mm [6]

Figure 10. Concrete crushing of door corner

Figure 11. Panel bottom right corner crushing

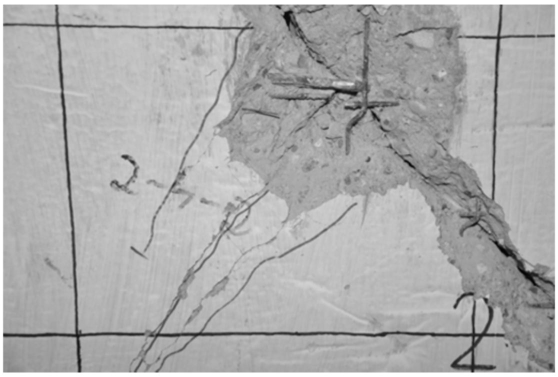


Figure 12. Horizontal mesh component rupture

4.2 Post-damage strengthened PRCWP (7-E1-T/R) having a narrow door opening

Figure 13. Shear strips debonding

Figure 14. Confinement strips rupture

Figure 15. Shear strips debonding

Figure 16. Diagonal crack reopening

4.3 Unstrengthened PRCWP (8-E3-T) having a large door opening

In the experimental test of the (8-E3-T) specimen concrete crushing was recorded at the top corners of the opening. The cast in place mortar at the bottom corners of the opening also crushed. The thick diagonal crack is in the right pier and concrete crushing lead to failure of the specimen.

Figure 17. Upper left door corner crushing

Figure 18. Upper right door corner crushing

Figure 19. First diagonal crack in the right pier

Figure 20. Cast in place mortar crush

4.4 Post-damage strengthened PRCWP (8-E3-T/R) having a large door opening

As shown in the below figures shear strips debonding, flexural strip swelling, confinement strips rupture and concrete crushing lead to failure of the post-damage strengthened specimen.

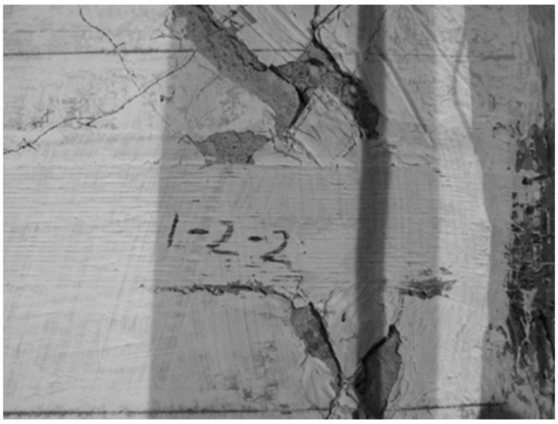


Figure 21. Shear strip debonding

Figure 22. Shear strip debonding

Figure 23. Flexural strip swelling and concrete crush

Figure 24. Cast in place mortar crush

4.5 Prior-to-damage strengthened PRCWP (9-E1/E3-R/T) having an initial narrow door opening, enlarged to a large door opening

Figure 25. Flexural strip swelling, confinement strip rupture and concrete crush [3]

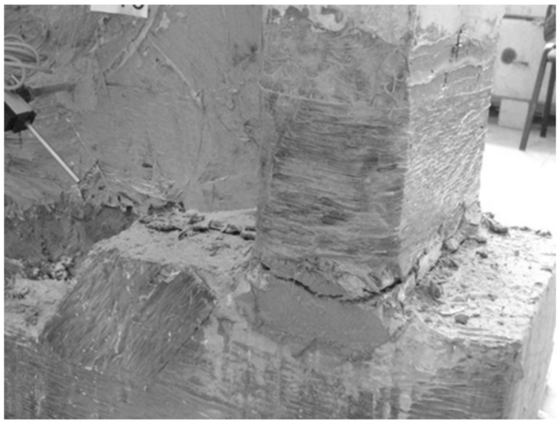


Figure 26.Mortar crush

4.6 Unstrengthened PRCWP (10-L1/L3-T) having an initial narrow window opening, enlarged to a large window opening

In the unstregthened condition the wall panel experienced concrete crushing at the top and bottom left corner of the window opening and severe diagonal cracks in the left pier.

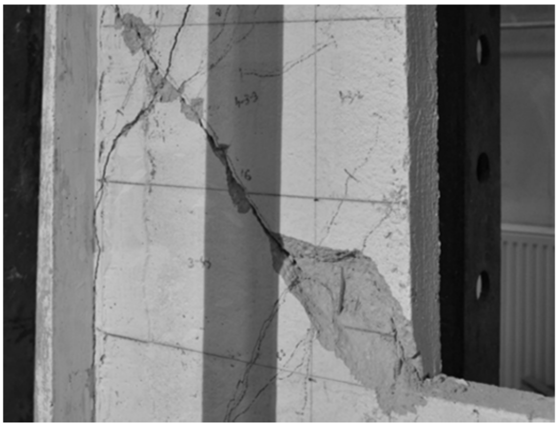


Figure 27. Flexural strip swelling, confinement strip rupture and concrete crush

Figure 28. Mortar crush

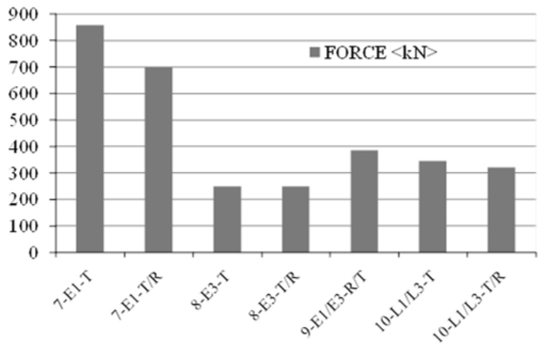
4.7 Post-damage strengthened PRCWP (10-L1/L3-T/R) having an initial narrow window opening, enlarged to a large window opening

Figure 29. Debonded TRM areas between threaded rods [10]

Figure 30. Rear view of the left pier [10]

5. RESULTS

The force and displacement histograms are presented here, and also the strain-displacement diagrams for each test. Comments on the results are presented in the conclusion section of this paper.



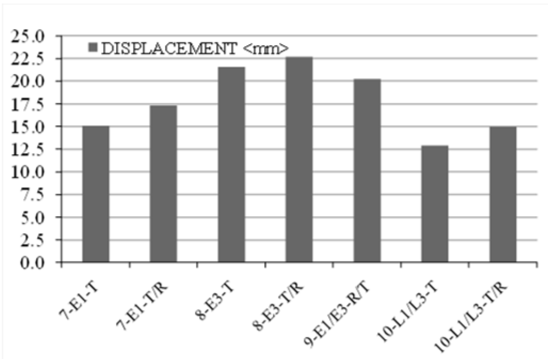
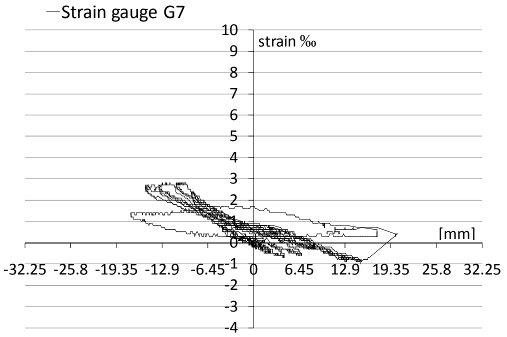
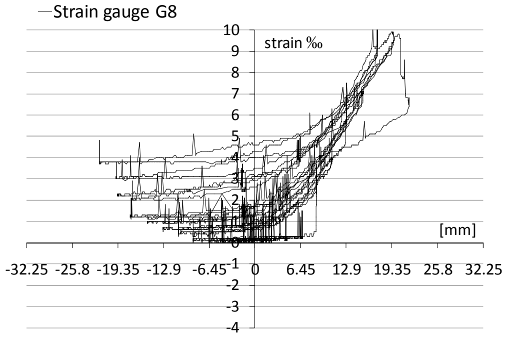


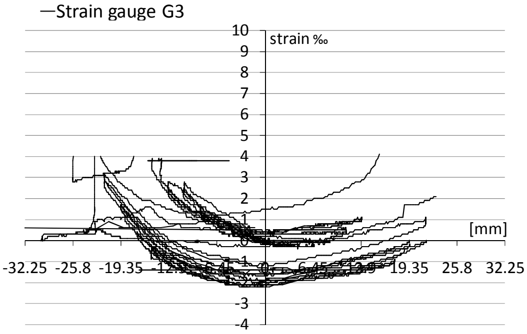
Figure 31. Maximum horizontal force

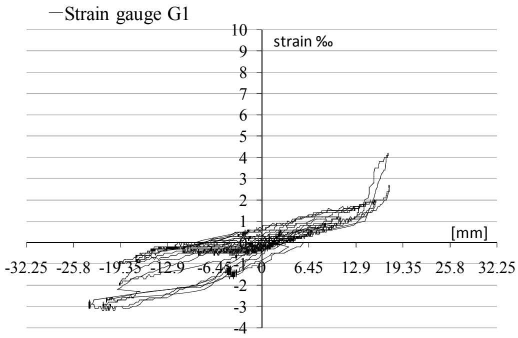
Figure 32. Displacement corresponding to maximum horizontal force



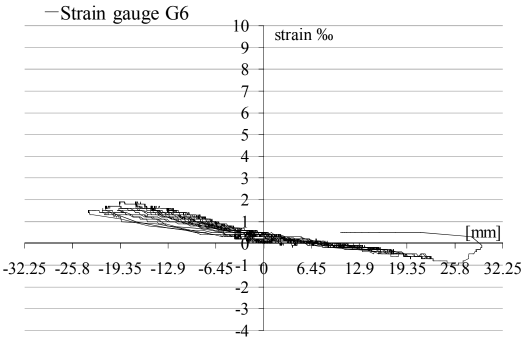


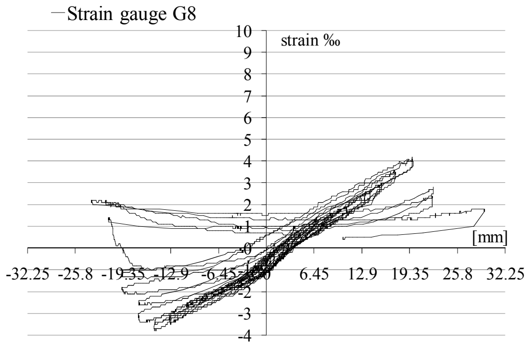
a) Strain gauge G7 on steel reinforcement (7-E1-T)   b) Strain gauge G8 on CFRP strip (7-E1-T/R)



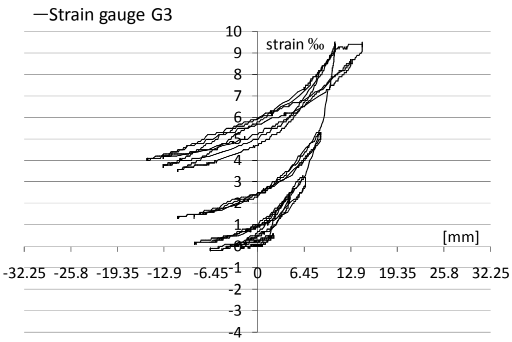


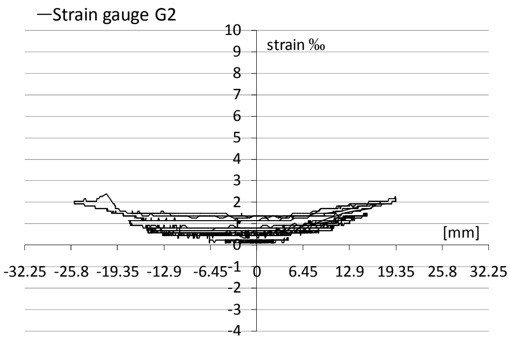
c) Strain gauge G3 on CFRP strip (8-E3-T/R) [3]   d) G1 on steel reinforcement (9-E1/E3-R/T) [7]





e) Strain gauge G6 on CF plate (9-E1/E3-R/T) [7]   f) Strain gauge G8 on CFRP strip (9-E1/E3-R/T) [7]





g) G3 on steel reinforcement (10-L1/L3-T) [10]   h) Strain gauge G2 on GF grid (10-L1/L3-T/R) [10]

Figure 33. Strain-displacement diagrams for strain gauges recorded in seven experimental tests on PRCWP

6. CONCLUSIONS

Concluding upon the results, the test of the (9-E1/E3-R/T) specimen shows the effect of the cut-out in the wall compared to specimen (7-E1-T) and (7-E1-T/R) by a significant loss in load bearing capacity, and also the effect of initial retrofit towards (8-E3-T/R) by a significant gain in the value of the load bearing capacity, yet in the second statement we should not neglect the difference in the compressive strength of concrete, and the quantity of initial steel reinforcement available in the wall panel. According to Figure 33 a, d and g the steel reinforcement reached yielding during the experimental test of PRCWP (7-E1-T), (9-E1/E3-R/T) and (10-L1/L3-T). Strain gauges applied on CFRP strips (Figure 33 b, c and f) recorded values up to 10‰ in tension, fact that shows the strips were stressed but no rupture was attained. Figure 33 (e and h) show the strain-displacement measurement on a CF plate and GF grid, both being slightly loaded. All the strengthening systems induced a more ductile behavior and in almost all cases the initial load bearing capacity of the element was restored. We have to take into account here the fact that in some cases the unstregthened elements lost more than 20% of their load bearing capacity in the initial experimental test. Analyzing the costs we obtained a strengthening cost per square meter of 90.25 EUR/m^2 for the TRM system, which proved to be more expensive in the current experimental program than the strategy using EBR-CFRP (≈ 62EUR/m^2) and cheaper than the one using (NSM-CFRP) strengthening system (≈ 100 EUR/m^2) [10].

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Strategy for providing the required structural safety level of reinforced concrete large panel walls with cut-out openings

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ABSTRACT: This paper addresses the seismic behaviour of the reinforced concrete (RC) walls. The objectives of the research are to investigate the seismic performance of the precast reinforced concrete walls, assess the weakening effects caused by doorway cut-outs and reveal the effects of the seismic retrofit by externally bonded carbon fibre reinforced polymers (CFRP-EBR). The experimental program consisted in seven quasi-static cyclic tests on near-full scale precast reinforced concrete wall specimens. Particular care was given to the design of the test set-up and loading procedure in order to model the outrigger effect which stimulates shear behaviour instead of the flexural one. The experimental variables referred to the opening and the strengthening condition. The influence of the cut-out opening size on the shear strength, stiffness and energy dissipation rate was considerable. The retrofitting technique by means of CFRP-EBR yielded improved behaviour characteristics, primarily in terms of energy dissipation; however, certain limitations were identified on the use of this strengthening system in reversed cyclic applications. In addition, the test results showed that by considering the outrigger effect the cyclic response and the failure mode of the shear walls is governed by diagonal compression. These imply a different look on the seismic design and analysis of the reinforced concrete wall structures.

1 INTRODUCTORY NOTES

This paper is a brief and partial overview of a wider experimental program on the application of Fiber Reinforced Polymers (FRP) for strengthening of precast concrete large panels affected by cut-out openings. This program was initiated and coordinated by the authors, from the Department of Civil Buildings of the "Politehnica" University of Timisoara, Romania and it received financial support from the Romanian National University Research Council (CNCSIS) through a number of research grants acknowledged at the end of the paper. The research program resulted in a number of PhD theses under the supervision of Professor Stoian Valeriu, from the same institute. Most of the information presented hereinafter was published in the PhD thesis "Seismic retrofit of precast RC walls by externally bonded CFRP composites" of the first author of this paper (Demeter, 2011).

2 BUILDING INVENTORY

Likewise other Eastern European countries, Romanian urban areas underwent significant transformation during the second half of the 20th century, regarding the housing conditions. A considerable 28% of the total room area of residential buildings, as of 2002 according to National Institute of Statistics (NIS, 2002) was represented by flat blocks of reinforced concrete construction realised in the period of 1950-2000, totalling more than 57000 buildings. Over 40000 of these blocks are low-rise 5-storey Precast Reinforced Concrete Large Panel (PRCLP) buildings, see Figure 1, more than 3500 are 9-storey (P+8) and more than 4500 are 11-storey (P+10) mid-rises. The Romanian terminology used was *large-panel residential building* or *large-panel block*.

The construction of the large panel started in the early 1960's and gained wide application starting from 1970, see Figure 2.3. A landmark event was the Vrancea earthquake of March 4, 1977. This event marked the decline of 11-storey (P+10) but did not affect the ascent of 5-storey (P+4) and induced the emerging of 9-storey (P+8) configurations. Post-1977 large-panel reinforcement was modified. The 1970 to 1990 period can be referred to as the decades of P+4 low-rises, with more than 36000 buildings constructed. The 1989-1990 marked the end of large-panel construction in Romania.

The architectural floor plan of a 5-storey block consists generally in four flat units and a staircase, without elevator shaft. The ground floor is at about 1 meter above street level and the utility (uninhabitable) basement level is about 2 meters below ground level. Flat roofs are the prevailing roof types.

The structural system of the 5-storey PRCLP buildings is composed of the cast-in-place RC foundation system and the entirely precast superstructure. The foundation system consists of foundation strips and 200 mm thick RC walls. The superstructure was made of room-size (2÷5 m) precast slab and wall panels, assembled on-site through vertical and horizontal joints along their edges. Joints were using lap welding of steel reinforcement and casting in-place concrete emulating the conventionally formed cast-in-place RC structures. Modular construction was employed using M300 mm as unit.

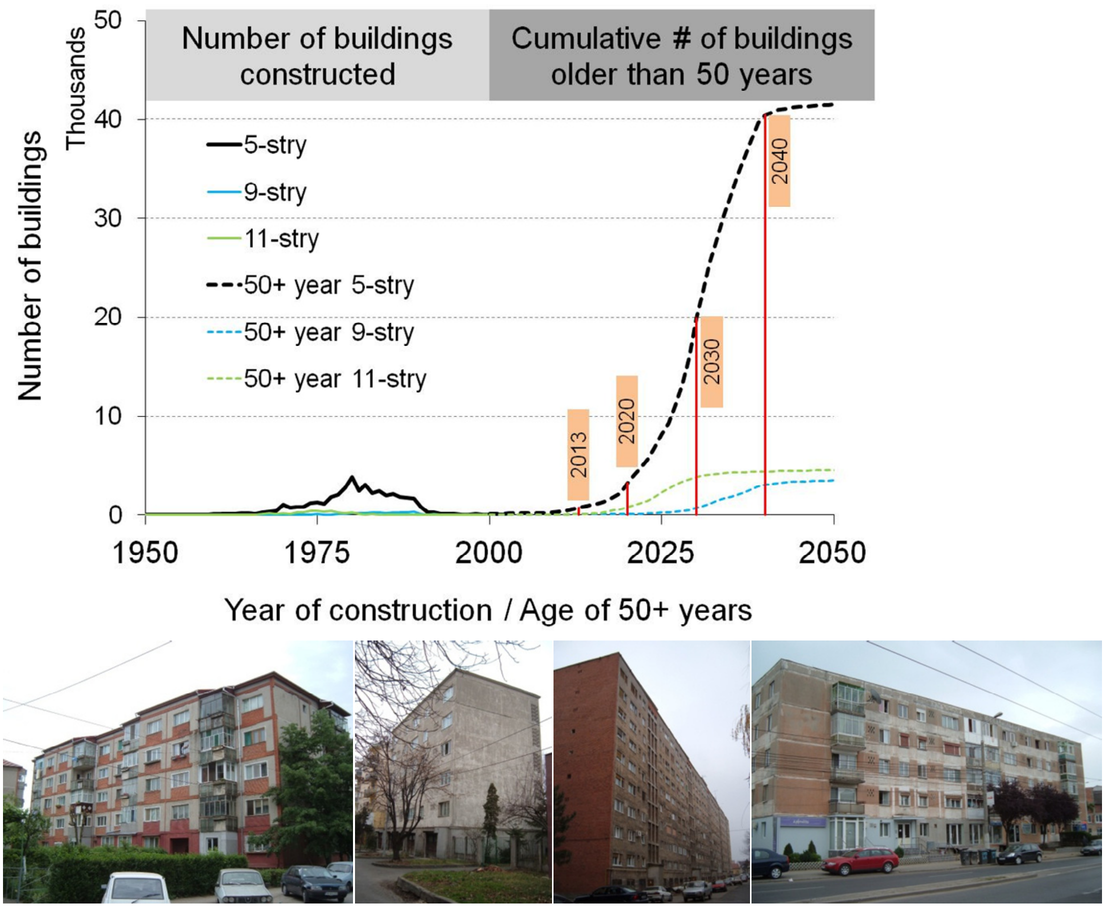

Figure 1. Reinforced concrete blocks of flats in Romania.

3 CONCEPTUAL OUTLINE AND STRUCTURAL REMODELLING

Structural alterations by doorway cut-outs (see Figure 2), impair the seismic performance of a reinforced concrete wall member. According to the common sense of structural engineering the weakening effect should be proportional to the size of the cut-out opening, although this assumption needs further data regarding the shape and position of the opening. Moreover, the weakening should be quantified in terms of strength, stiffness, ductility and energy dissipation. Even the assumption of weakening may be subject of investigation with respect to the structure's overall response given that slitted walls were adopted (Muto *et al.*, 1974) as seismic rehabilitation method.

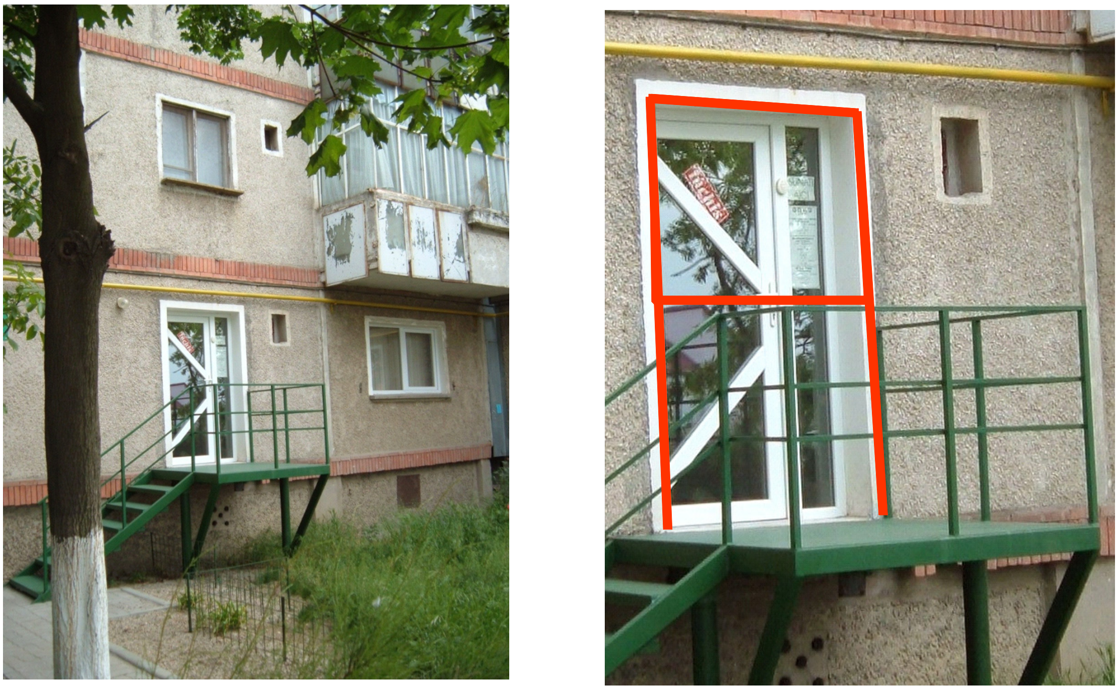

Figure 2. Typical example of structural remodelling by doorway cut-outs.

In order to enhance the seismic performance of the cut-out weakened walls retrofitting should be carried out. The strengthening technique of FRP-EBR (Externally Bonded Fibre Reinforced Polymers) was introduced in the past twenty years and gained widespread application for its advantages with respect to conventional/traditional methods. The technique is primarily used for RC beams and column members and masonry elements. As with many other novel techniques, the structural engineering research and design regarding the FRP-EBR strengthening is one step behind technology and application, consequently a series of unaddressed issues are expected. As externally bonded reinforcement (EBR) this technique can be used similarly (emulating) to conventional steel reinforcement, but bearing in mind the differences between steel and FRP in terms of material and geometric properties. In the case of an RC shear wall the reinforcement, either steel or FRP, should be flexural, shear or confinement and should have corresponding directions at specific locations: vertical concentrated at the extremities, horizontal or diagonal in the web, and transversal, respectively. Furthermore the strengthening should address such behaviour aspects as strength, stiffness, ductility and energy dissipation.

The conceptual outline of the research, see Figure 3, is to investigate the seismic performance of the precast reinforced concrete walls, assess the weakening effects caused by doorway cut-outs and reveal the effects of the seismic retrofit by externally bonded carbon FRPs. It is important that the foregoing analysis can be achieved at three structural levels of complexity, namely for a structural element, a building system or for the entire building structure.

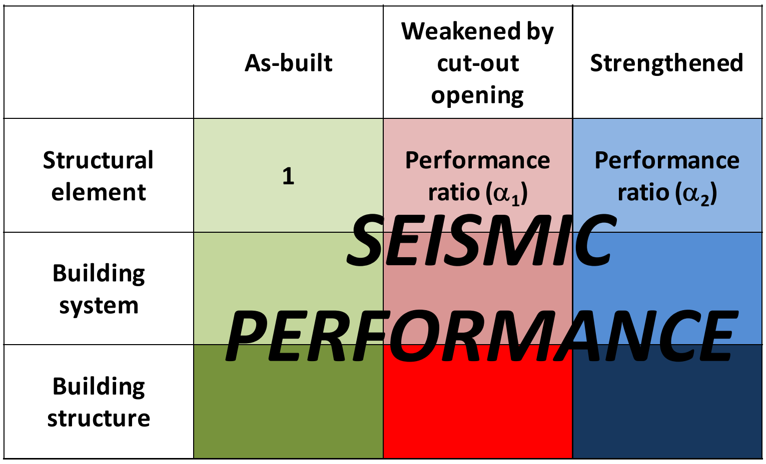

Figure 3. Conceptual outline of the experimental program.

4 EXPERIMENTAL PROGRAM

4.1 *Objectives*

The objectives of the experimental research, see Figure 4, were to record the seismic performance of the precast large wall panels considering the outrigger effect of adjacent structural members, to assess the weakening of doorway cut-outs and to investigate the performance of the CFRP-EBR strengthening method. The tests were carried out in the Reinforced Concrete Structures Laboratory of the Department of Civil and Industrial Buildings, Faculty of Civil Engineering, "Politehnica" University of Timisoara, Romania during March, 2008 through December, 2009.

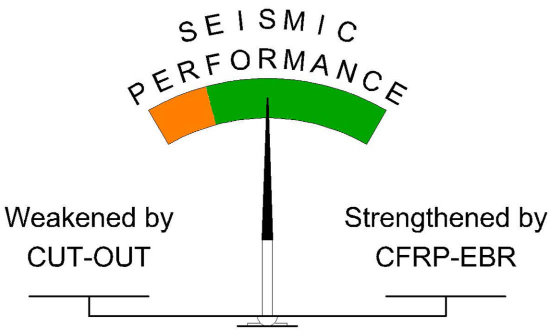

Figure 4. The objectives of the experimental program.

4.2 *As-built / cut-out opening matrix*

An outline of the test program can be structured in three levels. The first level is represented by a bare solid wall, see Figure 5, which was the reference specimen. The second level comprises two bare walls with cut-out openings, which were identical in all aspects with the solid reference, except the presence of the cut-outs. The difference between the elements of this level was the width of the door opening. The third level is composed by two pairs of strengthened specimens, which corresponded in all regards to the second level walls and were additionally retrofitted. Besides the opening size, the difference between the specimens of the third level consisted in the state of the walls at the time of retrofitting: after sustaining a number of damaging load reversals, the specimens of the second level were upgraded to the third one by repair and post-damage strengthening, whereas their counterparts were prior-to-damage strengthened.

The concrete outlines and reinforcing details of the solid reference specimen are depicted in Figure 6. The dimensions of the web-panel were 2750 mm length, 2150 mm height and 100 mm thickness. The cross-sectional area of the solid web-panel was 2750 cm^2 and its aspect (height-to-length) ratio was 0.8. Similarly to the original large panels, shear keys were formed along the edges of the web-panel to improve the sliding shear resistance. For the same reason larger set-backs were provided at the panel corners. The wings were composed of a short in-plane connection zone and a flange perpendicular to the wall plane. Web-panel reinforcement consisted in a single curtain composed of a welded wire mesh of ϕ4 mm diameter cold drawn wires at 100 mm centres, horizontal deformed bars of 10 mm diameter at 265 mm centres and 2ϕ14 mm diameter vertical continuity bars. The flanges of the end-wings were reinforced by spatial cages made of 4ϕ14 mm longitudinal deformed bars and ϕ8 mm plain transverse hoops at 85 mm centres and a ϕ16 mm vertical continuity bar. The web-to-wing connection was realised through anchoring the horizontal ϕ10 mm panel-bars into the confined core of the flange. The wall-to-foundation anchorage was provided by lap-welding of the 4 vertical continuity re-bars to the starter bars of the foundation. The results of the material tests performed on cube samples and steel re-bars are shown in Table 1. The hot-rolled OB- and PC-type reinforcement stress-strain relationship is ductile response whereas the cold-drawn wires are brittle.

A comparison line is defined as a series of at least two specimens or tests that are identical in all regards except one variable. These lines are set up in order to assess the effect of the investigated variable on the behaviour of the specimens. The present program contains three comparison lines, each of them comprising of three tests. The first comparison line was set to assess the weakening effect of doorway cut-out. The reference specimen of this line is the solid specimen while the variable is the cut-out width. The second and third comparison lines are referred to as strengthening effect of CFRP-EBR, with reference specimens being the bare walls with narrow and wide door cut-out, respectively and the variable being the strengthening condition.

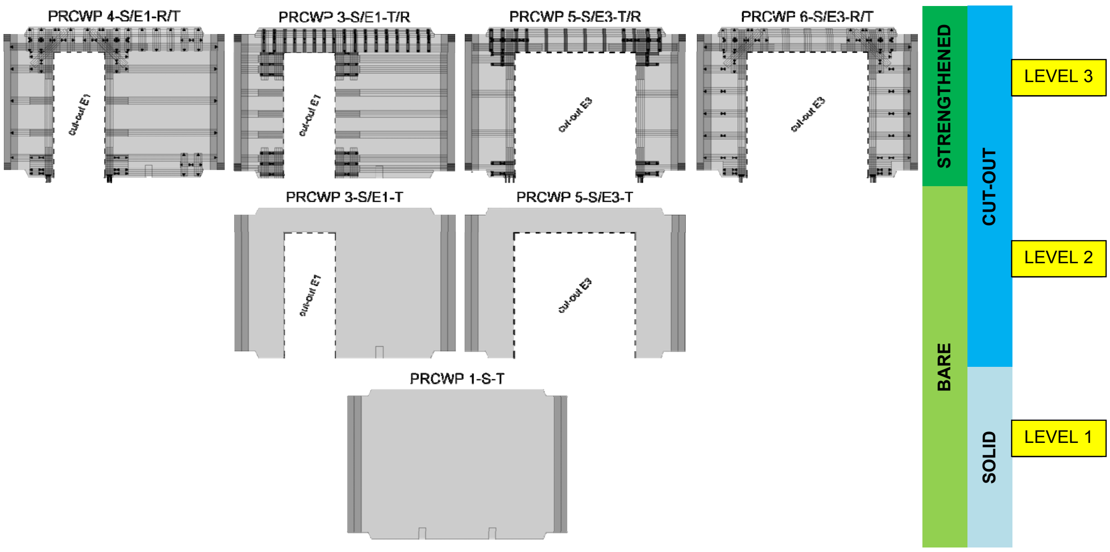

Figure 5. Variables of the experimental program.

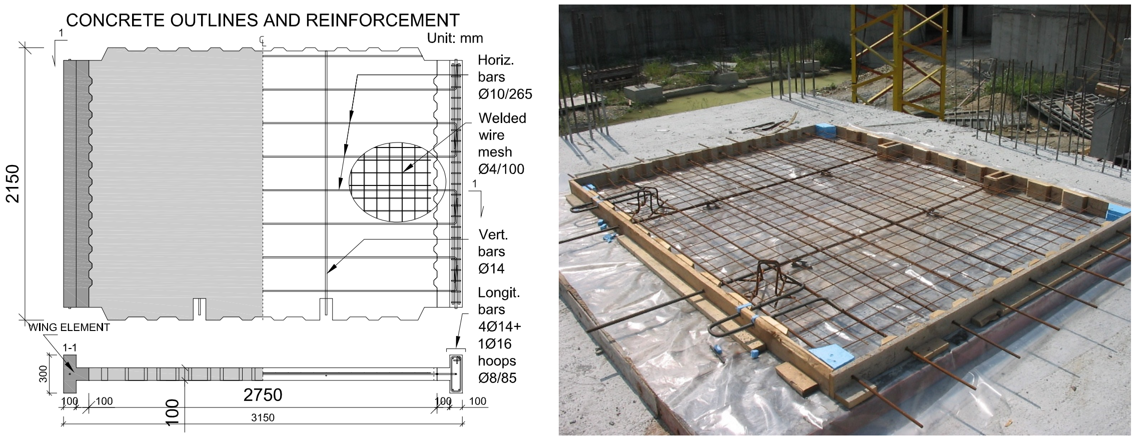

Figure 6. Concrete outlines and reinforcement.

Table 1. Material properties

Concrete	Mean cube strength $f_{cm, cube}$ (MPa)	17.5 (web) 39 (wing)
	Concrete class	C8/10 (web)
Steel reinforcement	Yield strength f_y (MPa)	450 (ϕ10 mm hot-rolled ribbed) 618 (ϕ4 mm cold-drawn ribbed wire)
	Tensile strength f_t (MPa)	564 (ϕ10 mm hot-rolled ribbed) 667 (ϕ4 mm cold-drawn ribbed wire)
CFRP	CFRP tensile strength (MPa)	4100 (S1) 3900 (S2)
	CFRP tensile strain at break (%)	1.5
	Impregnation resin tensile strength (MPa)	30÷45

4.3 *Seismic performance vs. shear span conditions*

As presented in Figure 7, three types of boundary conditions can be used in testing, namely cantilever, restrained rotation and additional moment. These are the concerted effect of the test set-up, the loading procedure and the elements adjacent to the wall ends. The present experimental program is featuring a restrained rotation type boundary condition for the wall specimens, with a series of special traits inside this category. The restrained rotation boundary condition is promoting the shear behaviour as opposed to the flexural one, by reducing the shear span, that is, the base moment corresponding to the base shear. The test set-up adopted in the experimental program (see Figure 8) is featuring a zero overall base moment trait by the hinged end connections, although in the case of the specimens with openings there are interior moments possible to develop through the wall to base beam interface. The development of the moments is limited in both cases by the increasing axial loads, which acts against the vertical tensile forces. Therefore it can be stated that the shear span and the shear span ratio is negligible compared with the bending moment in the case of the solid wall, while it is slightly greater for the wall piers. The exact value is quiet difficult to evaluate, due to the variable axial loads, differences in the anchored vertical reinforcement in the two loading directions and the coupling effect of the spandrel beam. Consequently, shear behaviour is extensively stimulated.

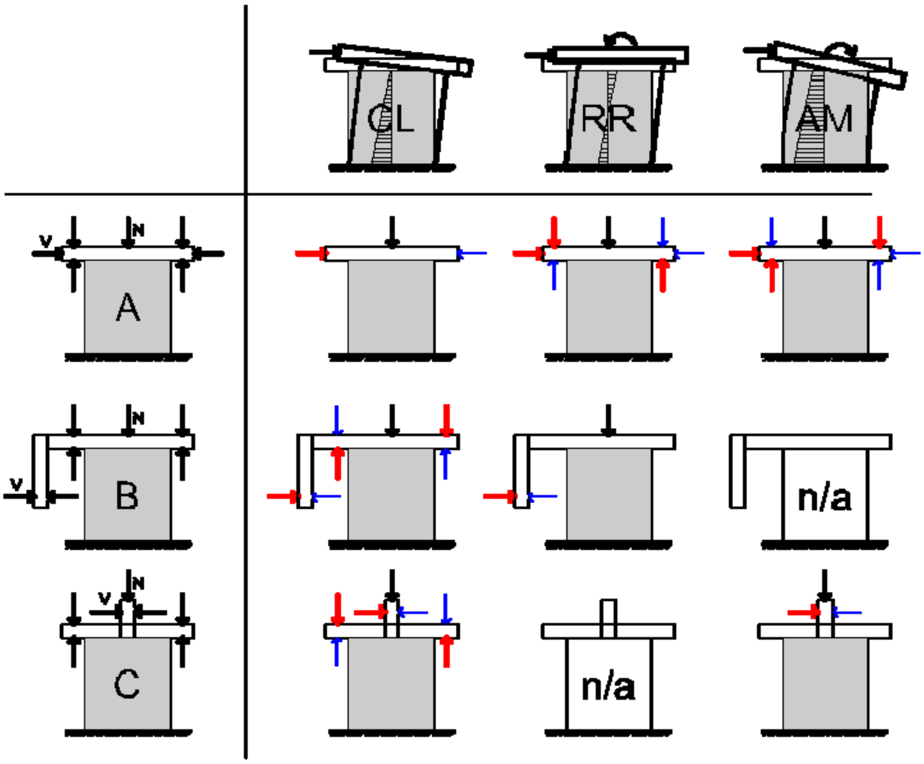

Figure 7. Test set-up types and boundary conditions.

There are two principal shear transfer mechanisms, namely diagonal compression and diagonal tension. The third one would be the dowel effect of the kinking vertical reinforcement associated to the sliding shear failure. The boundary conditions of the present program eliminates the sliding-dowel mode by the construction of the two loading beams through the shear steps and the diagonal tension mechanism by the lack of vertical reinforcement anchored to the cap beam and by the variable but always in compression axial loads. Consequently, the only mechanism that is permitted is the diagonal compression shear transfer. In these conditions the present boundary conditions can be referred to as a subtype of the restrained rotation, namely diagonal compression dominated shear transfer.

Besides the model-to-prototype issue, the question remains to be addressed is the adequacy of the adopted boundary conditions to reproduce the as-built real situation during a seismic event. The experimental elements are modelling a prototype ground floor wall, part of a large panel building. In general the free behaviour of an element may be significantly altered with respect to the condition when it is restrained/constrained to interact with other structural members connected to it. The boundary conditions adopted in the experimental program were aimed to reproduce the outrigger effect, deemed to be of high importance in the behaviour of lateral load resisting structural systems.

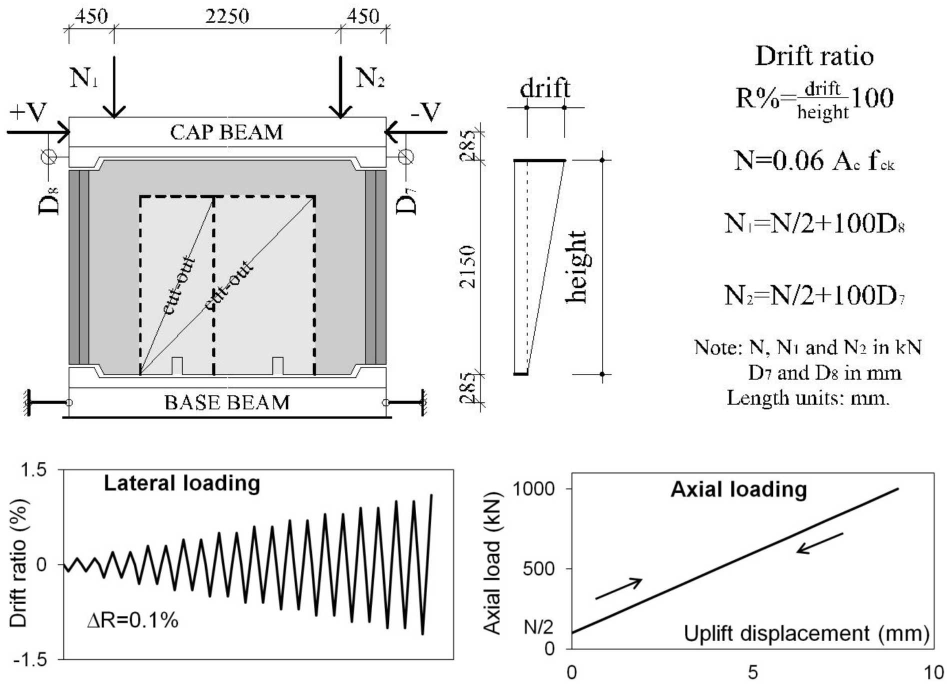

Figure 8. Test set-up used in the experimental program and the loading procedure.

This effect was mentioned by Abrams (1991), but it was abandoned and only recently is gaining wider attention. The core idea is that the either of the extremities of a vertical structural member is restrained from rotation by the counterbalance exerted by the structural members on the uplifting side. This effect can be conveyed by a rigid diaphragm floor or directly through the vertical edges from orthogonal walls, the latter being the case for the large panels. The uplifting end attracts additional axial loads from the nearby elements to the extent which these axial loads are available, for the total amount is finite. It is interesting to note that the dynamic condition may increase the available axial loads due to a vertical uplifting acceleration that may be added or subtracted from the vertical acceleration of the ground motion. The amount of additional axial load available for a specific lateral load resisting element is a matter of structural system configuration and relative stiffness.

5 EXPERIMENTAL RESULTS

5.1 *General commentary on the results*

In Figure 9 the responses were plotted to commensurate load and drift limits along the three comparison lines of the experimental program. As presented earlier the first comparison line was aimed to assess the weakening effect of the doorway cut-outs. It is impressive the loss of load resistance of the specimens with cut-out door with respect to the solid reference. Comparison lines 2 and 3 were meant to assess the performance improvement achieved by CFRP-EBR strengthening for the narrow and wide door cut-out conditions, respectively. Both lines comprised a bare, a post-damage strengthened and a prior-to-damage strengthened wall test of the same opening condition. One can remark the increased load and displacement capacity and the enlarged hysteresis loops of the strengthened specimens with respect to the bare references.

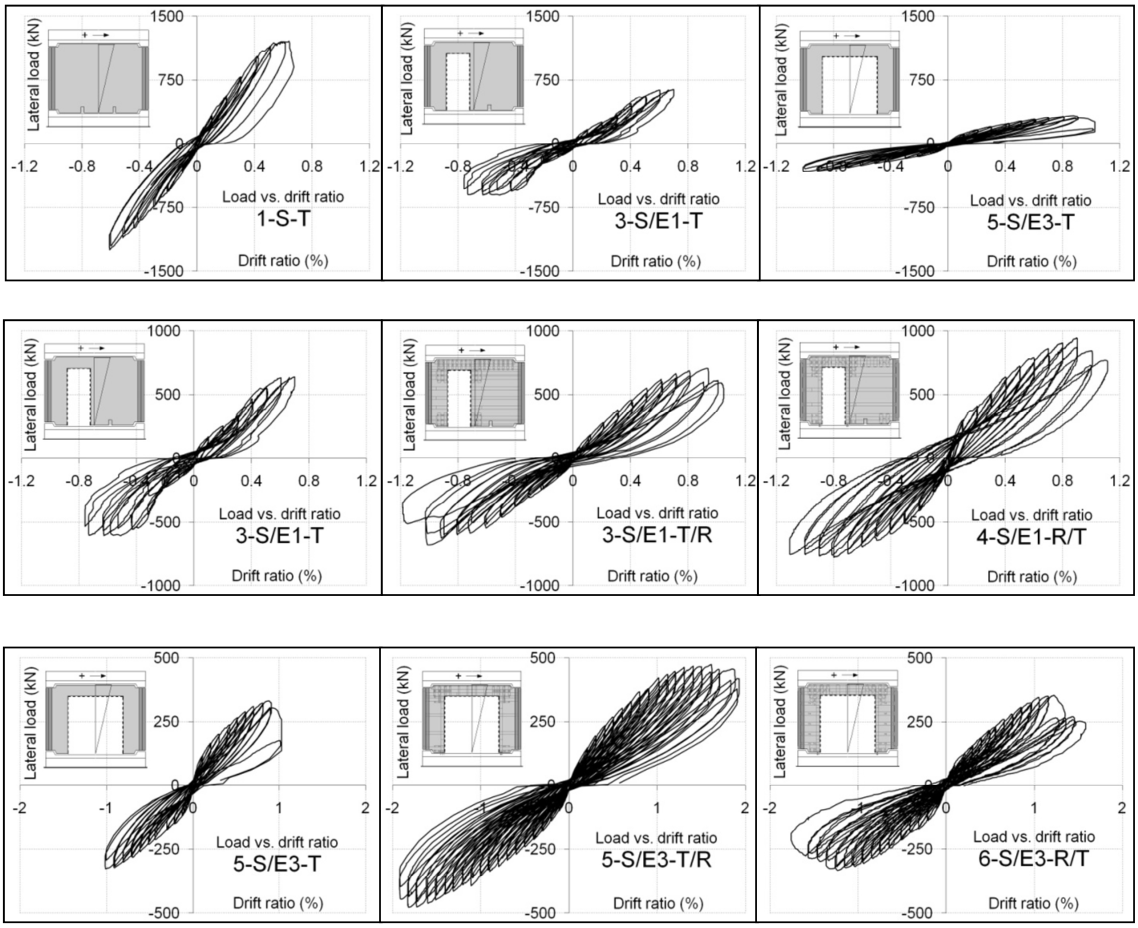

Figure 9. The load-displacement responses arranged along the comparison lines.

5.2 *Weakening caused by cut-out door openings*

The experimental results regarding the weakening effect of the door cut-outs on the seismic response of the solid reference wall are presented in Figure 10. The cut-out ratio is a measure of the opening size relative to the solid reference wall calculated either as the horizontal cross section ratio or as the square root of the in-plane area ratio (peripheral ratio). The performance ratio indicates the response characteristic of the weakened specimen normalised to the corresponding characteristic of the sound (solid) reference. The proportionality between the performance ratio and the cut-out ratio is represented by the dashed line joining the unities of the two axes. One can observe that there is experimental evidence on the proportionality between specific performance and opening ratios: the strength and stiffness performance ratios are the complement of the peripheral ratio, whereas the energy dissipation rate (Demeter, 2011) in performance ratio is proportional of the cross sectional ratio.

Practicing engineers can use the experimental results to quickly approximate the response characteristics of the precast RC walls weakened by doorway cut-outs according to the following equations:

$$R_{weak} = R_{sound} \cdot \alpha_p \tag{1}$$

where

$(R)_{weak}$ is the response characteristic of the weakened member in terms of shear resistance, initial stiffness or energy dissipation rate;

$(R)_{sound}$ is the response characteristic of the sound (solid, as-built) member in terms of shear resistance, initial stiffness or energy dissipation rate;

α_p is the performance ratio.

Note that expression (1) was derived from the AIJ recommendation (AIJ, 1999, quoted in Warashina *et al.*, 2008); however, the AIJ equation is reportedly (Warashina *et al.*, 2008; Taleb, 2010) applicable only for peripheral opening ratios less than 0.4 and it refers only to the shear strength and stiffness. In the present research the above equation was experimentally verified for two opening ratios (0.48 and 0.73); in-between these values one can assume linear performance ratio-to-peripheral ratio relationship. Moreover, it is important to bear in mind that the relationship given in equation (1) was validated for the specific loading and boundary conditions applied in the present experimental program (outrigger effect by additional axial loads); further investigations are required to widen the loading and boundary conditions range.

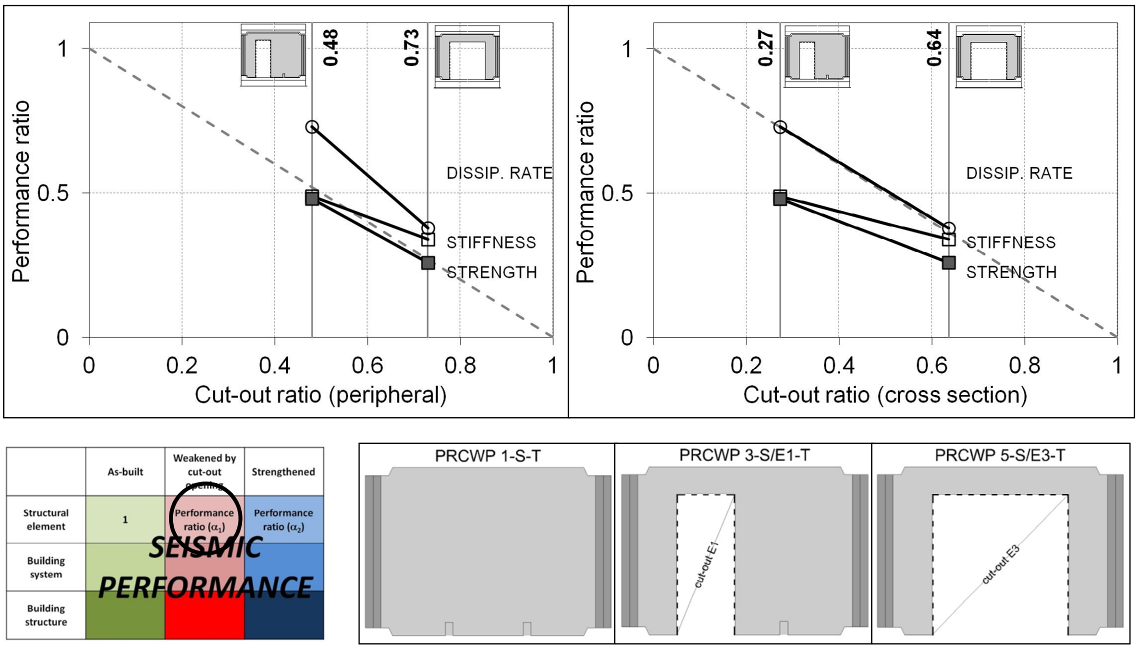

Figure 10. Weakening effect of the cut-out openings.

5.3 *Strengthening attained by CFRP-EBR*

The effect of the FRP-EBR strengthening on the seismic response of the cut-out weakened specimens is presented in Figure 11; the performance ratio indicates the response characteristic of the FRP-strengthened specimen normalised to the corresponding characteristic of the cut-out weakened bare reference. It can be remarked that the response characteristics were differently influenced by the CFRP-EBR strengthening (generally in the range of 0.8÷1.9 performance ratio); outstanding improvement was achieved in terms of energy dissipation. Furthermore, one can assess the differences the timing of the strengthening (post-damage or prior-to damage) had on the response. Note that the results should be viewed in the light of the concrete strength performance ratio (in the range of 0.62÷2.3) and of the loading and boundary conditions. As regards the contribution of the three components (flexural, shear and confinement) of the FRP strengthening to the above performance, it can be concluded that the confinement FRP strips show the most stable response; the shear FRP strips debond in the vicinity of the inclined cracks; and the flexural CFRP-strips subjected to alternating tension-compression reversals parallel to fibre direction are likely to fail prematurely. In order to assess more clearly the components' contribution further subject-oriented investigations are necessary.

Practicing engineers can use the experimental results to evaluate the seismic response modifications which can be expected by CFRP-EBR retrofitting of the cut-out weakened precast concrete wall panels. CFRP layouts similar to the ones presented would yield the following results: the shear strength increases in average by 25%; the peak drift increases by 50%; the initial stiffness and the energy dissipation rate remain roughly the same; and the cumulative energy dissipation at ultimate increases by 2÷4 times. One should bear in mind that in reversed cyclic applications the flexural CFRP-EBR is susceptible to premature failure; thus, the author recommends a safety factor of 3 for the flexural FRPs.

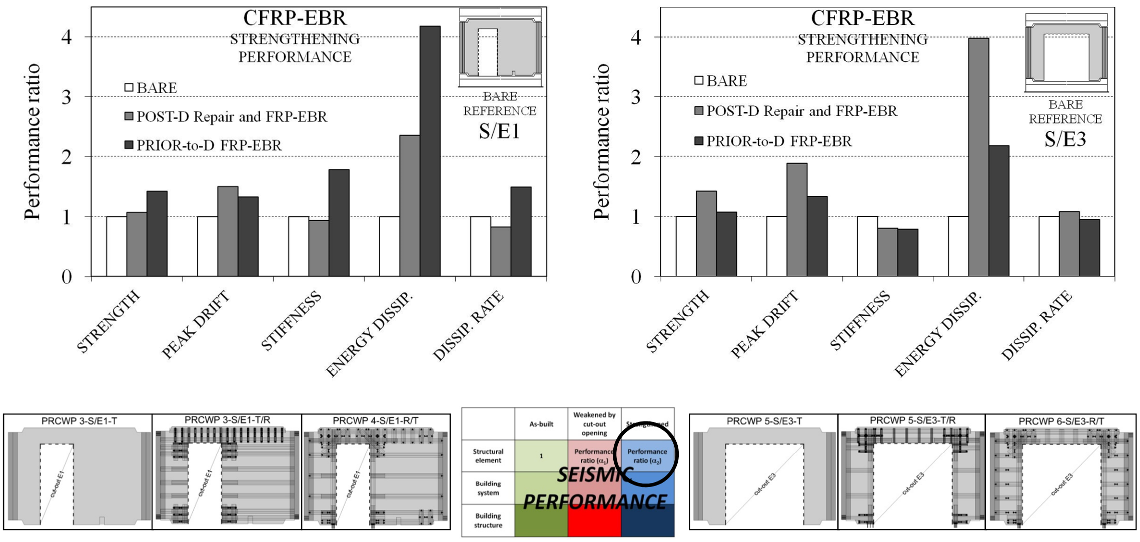

Figure 11. Strengthening attained by CFRP-EBR strengthening.

6 CONCLUSIONS

Within this study it was shown that in given circumstances the response of the reinforced concrete large wall panels is characterized by very high shear resistance and about 10% energy dissipation ratio. The weakening effect of the cut-out opening was found to be in agreement with the predictions provided by the AIJ equation (Warashina *et al.*, 2008. The relationship given in (1) was experimentally validated for the specific loading and boundary conditions applied in the present program; further investigations are required in order to widen the loading and boundary conditions range. Regarding the CFRP-EBR strengthening, the experimental results indicated that the energy dissipation capacity of the walls retrofitted by this technique increased significantly, whereas the other response characteristics were influenced in a smaller degree. This improvement of the seismic performance should be attributed primarily to the confinement and shear components of the strengthening system. The flexural FRPs were found to be susceptible to premature failure; however, it is not clear whether this type of failure is triggered by concrete substrate deterioration, i.e. local spalling and crushing, or directly by the adverse loading conditions (tension-compression reversals).

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Structural strengthening/retrofitting of RC slab panels using CFRP composite materials

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ABSTRACT: The paper presents a series of specific issues of Reinforced Concrete (RC) slabs with openings and cut-out openings, along with technological and design recommendations for strengthening of such RC slabs by using CFRP (Carbon Fiber Reinforced Polymer) composite materials. Moreover, the paper reports results obtained by experimental tests on such specimens. The research program that is discussed within the paper was conducted at the Politehnica University of Timisoara, Romania and covers tests on two-way slabs with and without cut-out openings. All elements were large scale ones, prismatic, rectangular in-plane and were tested in horizontal position, being simply supported along the edges and loaded gravitationally. The effectiveness of the proposed strengthening/retrofitting solutions was evaluated by theoretical and experimental research for the particular case of cut-outs created in the corners/edges of the slabs. The aim of the paper is to present the experimentally obtained results and to discuss the conclusions drawn by monitoring the tests.

1 OPENINGS IN RC SLABS

1.1 *General issues*

Almost without exception, structural RC plates within civil, industrial or agricultural buildings have openings, as this is required due to a number of functional reasons. These openings may be rather small in order to allow fitting of various pipes (heating, sewage, water supply, rainwater, etc.) or may have large sizes, needed for installation of elevators and/or stairs. Most of these openings amend the capacity of slabs, the yield lines scheme being changed, as their corners are often areas where the cracking and failure phenomenon are initiated. The modified yield lines schemes will almost inevitably be ones that characterize lower bearing capacity than the original scheme of yield lines (without openings). In contrast, in almost all cases, the total load that the slab is subjected to decreases after inserting an opening in that slab, as no loads act onto the area of the cut-out. Actually, the magnitude of the total load variation is most of the times directly proportional to the opening's dimensions.

By overlapping the conditions mentioned previously, from one situation to another, different behaviours of the elements result. If two slabs (a homogeneous slab and one with openings) subjected to similar loads, uniformly distributed on their surface are compared, it can be established that, depending on a series of parameters, the ultimate capacity (by loaded area unit) can be higher for either one of the slabs.

As mentioned, probably the most important structural parameter, influencing drastically the capacity of the slabs, is the size of the openings. Hence, very small gaps do not usually affect the overall behaviour of a slab, whilst large ones are crucial for the capacity and stiffness of the slabs inside of which they are generated. The dimensions of the openings should always be analyzed along-side with their position, as this proves to be yet another crucial aspect that influences the behavior of RC slabs. Considering the moment of their inclusion in the slabs, the openings can be further categorized into initially designed and cut-out openings.

1.2 *Initially designed RC slabs*

When discussing the presence of openings inside RC slabs, and the approach for eliminating undesirable effects caused by the presence of small holes, a straightforward method is to place, along the edges of the opening, reinforcing bars having an equivalent area to the bars interrupted by the opening. The issue of initially designed openings in RC slabs is approached by several national codes, such as the USA (ACI 318-08) [ACI 318-08:2008], the Swedish (BBK 04) [BBK 04:2004] or the Polish one (PN-B-03264) [PN-B-03264:2002] and by some specialists works.

The Swedish Code BBK04 approaches the problem of initially designed openings in uniformly loaded slabs in two distinct ways, varying with the opening's dimensions related to the slab's geometry. Thus, an opening is considered to be small if its length is less than one third of the slab`s shortest side length, otherwise it is considered as large opening. In the case of small openings, the plate is designed as a homogeneous element. Afterwards, bending moments acting on the two directions in the central area of the opening are split and added to the moments acting along the edges of the respective opening. With this approach, a series of calculation strips around the opening are obtained. These strips are parallel to the edges of the opening and their width is less than three times the slab's thickness. The supplemental reinforcement which is placed in order to undertake the added efforts developed in the plate due to the opening will be embedded in the width of these strips. Graphical representation of this procedure is illustrated in Figure 1.

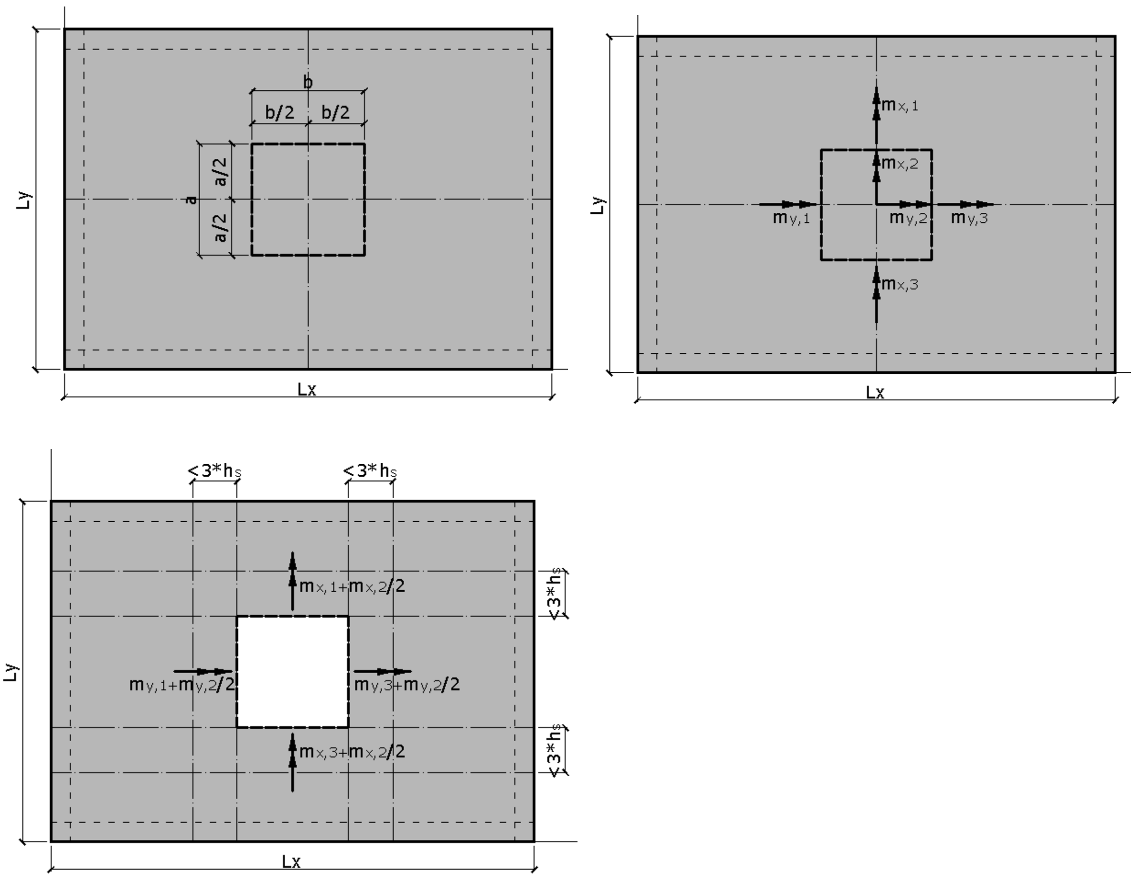


Figure 1. BBK04 method for designing RC slabs with small openings.

The Polish Code PN-B-03264 also provides a series of prescriptions for designing of slabs with openings considered in the initial design process. The first difference from the Swedish approach is that the code limits the maximum edge length of the opening to a quarter of the length of the corresponding side of the slab (parallel side to the edge of the opening). The calculation method also shows a different approach from the Swedish code, assuming the design of the plate to be the same as for a homogeneous plate, but with the amount of reinforcement missing due to the void being distributed around it. In contrast to the Swedish code, it is allowed that the added bars placed around the opening to be shorter, but proper anchoring is still required. At the same time, the Polish code limits the magnitude of the uniformly distributed load acting on the slab's surface to a value of 10 kN/m^2. This code makes no recommendation on the strip width, where the additional reinforcement required around the voids should be placed. Recommendations of the PN-B-03264 code and the steps for the design are illustrated in Figure 2.

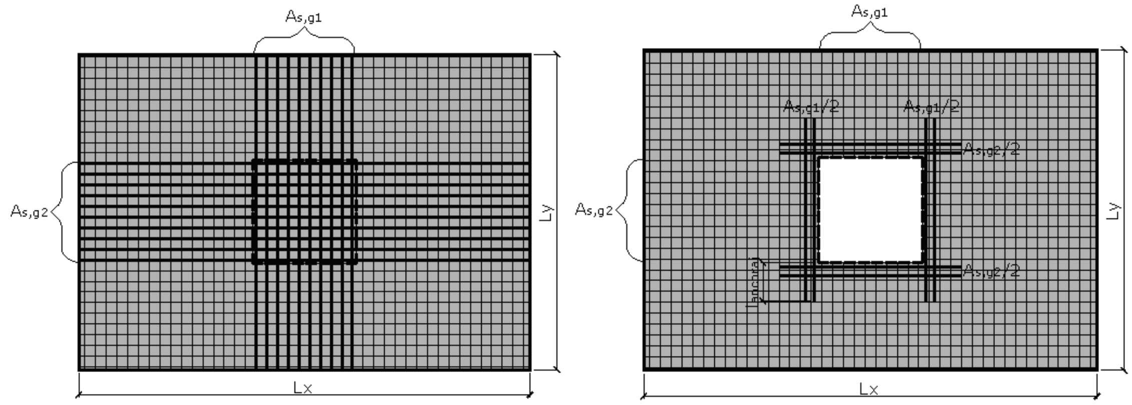


Figure 2. PN-B-03264 method for designing RC slabs with small openings.

As a general statement, valid for all slabs (beamless or supported on beams), the American ACI 318-08 code declares that any type of opening may be designed, if proven by computation that the slab will conform with all requirements regarding load bearing capacity and serviceability. In order to avoid a cumbersome analysis, the code issues a series of recommendations only valid for the beamless slabs (flat plates or flat slabs):

1. openings of any size can be designed in the area of intersection of two perpendicular field strips, but it is mandatory to keep the entire reinforcing area resulting from the calculations for the homogeneous slab;

2. in the areas corresponding to an intersection of support strips, no more than an eighth of the strip width that can be disrupted by an opening. An amount of reinforcement equivalent to the one discontinued by hole will be added to the plate, along the opening's sides;

3. in the area corresponding to an intersection between a support strip and a field strip, no more than a quarter of each strip reinforcement will be interrupted by openings. Equivalent amounts of reinforcement to those interrupted by the presence of the openings will be placed along its edges.

A common feature of all three recommendations stated above consists in the mandatory layout of the entire reinforcing area, as it results from calculation of the homogeneous panel, on the element with cut-out by placing reinforcement bars of equivalent area around the edges of the opening. These recommendations are presented graphically in Figure 3 and are valid for the situation where $L_2 \geq L_1$.

Another method for design of two-way slabs with openings is to consider the slab divided into a number of slab-panels. All these panels are supported on three sides, as shown in Figure 4. Thus, it is considered that the panels 2 and 3 rest on the panels 1 and 4, the reactions on the x direction sides of the panels 2 and 3 becoming distributed loads applied on the free edges of panels 1 and 4.

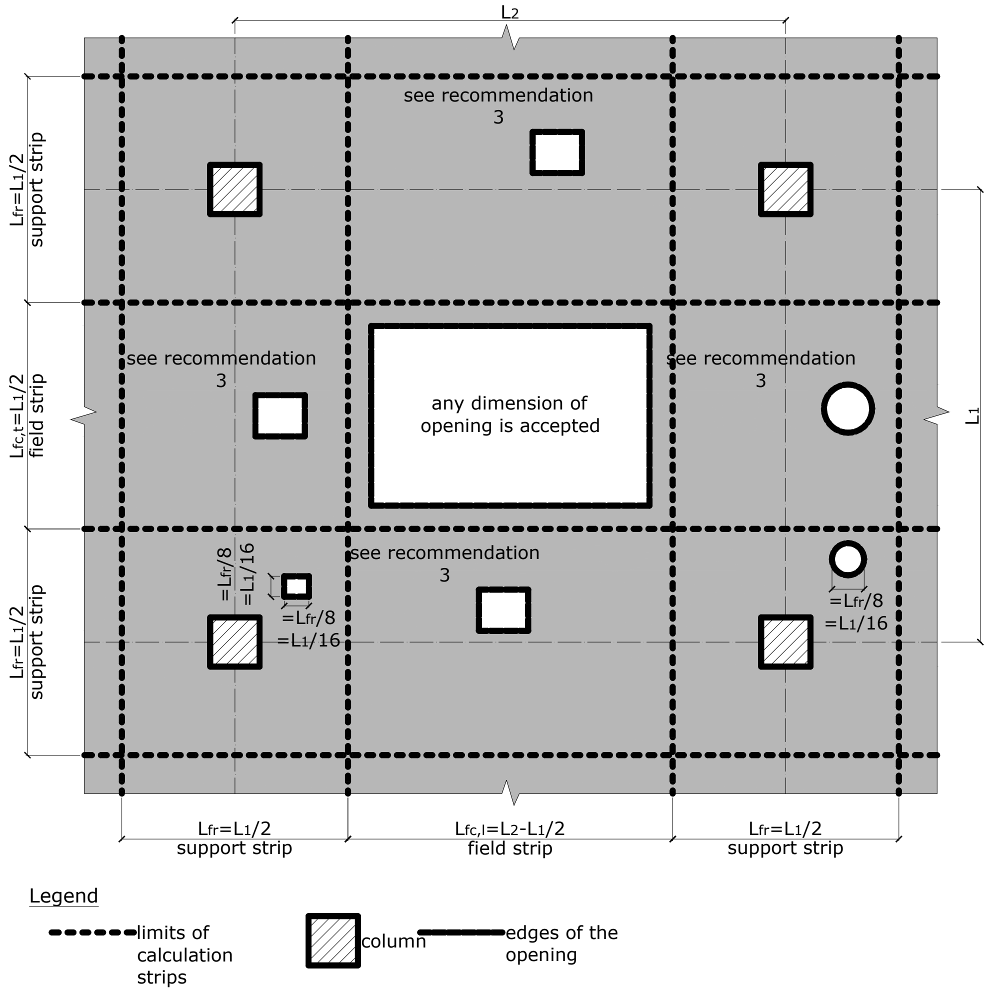


Figure 3. ACI 318 recommendations on the position and sizes of openings for beamless slabs.

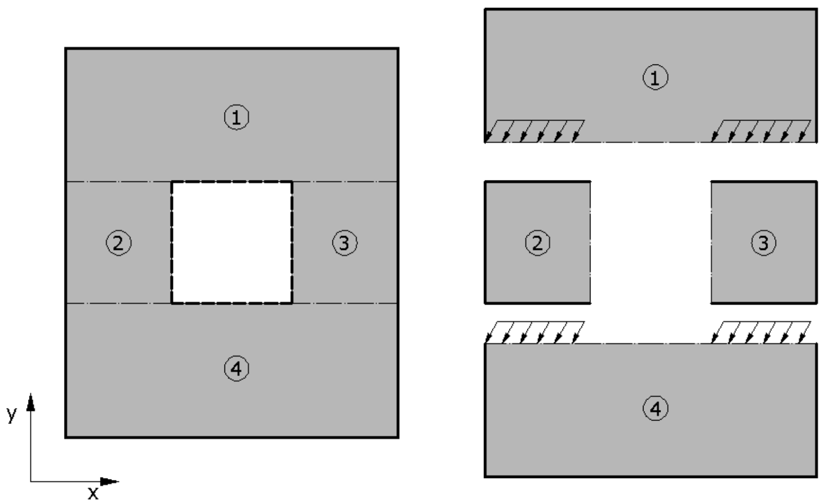


Figure 4. Approach for designing of slabs with large openings.

1.3 *Cut-out openings inside RC slabs*

As any intervention work on structural elements, "cutting openings in existing slabs should be approached with caution and avoided if possible". Normally, structural engineers should have a strong say in sizing of cut-outs and in choosing their location. Therefore, knowledge of recommended areas in order to limit the adverse effects arising from the establishment of cut-outs is imperative. [Newman, 2001].

Since the size and location of cut-out openings in RC slabs is clearly a matter of slabs' structural behavior, it is obvious that the issue may be approached differently for one-way slabs and two-way slabs.

Usually, one-way RC slabs are part of floors with multiple spans, the slab being structurally continuous. This continuity is on one hand beneficial, as it allows some bending moment redistribution. For example, a plate weakened by creating a mid-span cut-out has reduced flexural capacity in this area, but may be acceptable when there are reserves of bearing capacity in the support areas. On the other hand, due to continuity, inserting of larger cut-outs may disrupt the structural balance of the plate. [Newman, 2001].

In order to determine the most suitable location for creating cut-out openings, the structural engineer should have detailed knowledge on plate`s characteristics (most of all: reinforcement pattern). Then, by calculation, it has to establish, which reinforcement is determined for the overall slab bearing capacity limit (the upper reinforcement at the supports or the bottom reinforcement between supports). In situations that the amount of inferior reinforcement in the mid-span is inadequate, it is strongly recommended for the cut-out to be inserted in the vicinity of support area (e.g. Figure 5 - cut-out 1). Similarly, insufficient superior reinforcement at the supports is a sign that cut-outs should be inserted close to the mid-span (e.g. Figure 5 - cut-outs 2 and 3). As mentioned previously, another important parameter is the orientation of the cut-out. Accordingly, a cut-out with its long edge parallel to the short side of the span (e.g. Figure 5 - cut-out 2) cuts off less rebar than one with its long edge parallel to the long side of the mesh plate (e.g. Figure 5 - cut-outs 1 and 3).

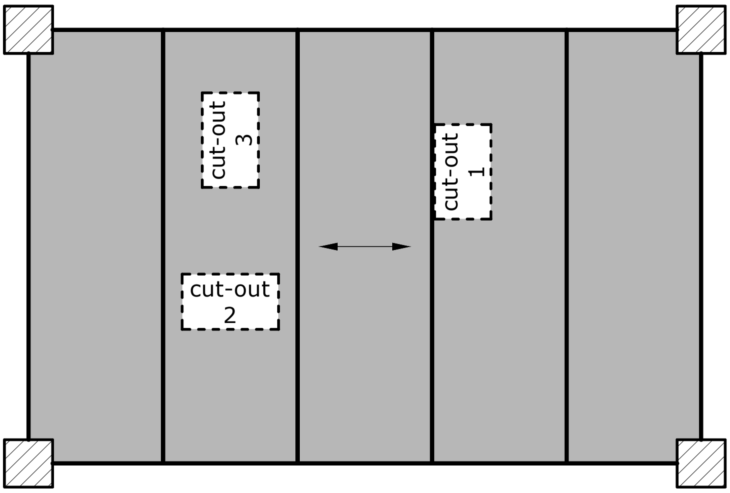


Figure 5. Provisions related to the position and orientation of cut-outs inside one-way slabs.

In the case of two-way slabs, there are a series of guidelines and recommendations that may be used, at least in a groundwork evaluation phase, for determining the optimal location of the cut-out. In order to establish if, in an explicit situation, strengthening/retrofitting interventions are required due to insertion of a cut-out in a slab, the recommendations proposed by Newman A. [Newman, 2001] are quite suitable. These recommendations are graphically illustrated in Figure 6 for slabs resting on contour beams and for flat slabs and flat plates. The procedure that leads to this is similar as that used for dividing flat slabs into field and support strips, leading to three kinds of areas, marked with digits 1 to 3. Area numbering indicates the preference for creating cutouts, 1 - the most recommended, 3 - the least recommended.

The preference is also related to the allowed dimensions of the cut-outs, without the need of strengthening/retrofitting interventions to be applied. Clearly, larger cut-outs are allowed inside areas marked with 1 while smaller dimensions of cut-outs are allowed inside areas marked with 3.

For slabs resting on contour beams, in the support strips intersection area (type 1), there can be created cut-outs sized up to a quarter of the span, of course, keeping the beams intact. These corner areas are subjected mainly to shear, which usually is not an issue in terms of the capacity of such items. In areas of type 2, obtained by the intersection of a support strip with a field strip, creating cut-outs is less desirable, a beam design verification being mandatory in order to determine whether they were designed or not as T beams. Area resulting from the intersection of two field strips (type 3) is the least convenient for cut-outs creation, but even in this area, square cut-outs, sized smaller than one-eighth of the span, can usually be created without any strengthening [Newman, 2001]. Cut-outs exceeding those limits require detailed analysis. Naturally, for slabs resting on contour beams it is better to avoid creating of an opening as large as the entire slab panel, a certain width all around the panel has to be kept in order to provide appropriate anchorage for the upper reinforcement in the adjacent panels. By removal of an entire panel, adjacent beams will be subjected to torsion that has not been initially assessed. When removal of an entire panel is required, retrofitting works for beams and adjacent panels are usually needed.

For flat slabs and flat plates, the situation reverses, as detailing these kinds of slabs is usually ruled by the shear capacity of the slab in areas around the columns. For this reason, cut-outs larger than 300 mm should not be cut in areas resulted at the intersection of support strips (type 3). Type 2 areas, resulted from the intersection of a field strip with a support one, are more suitable for creating cut-outs. In these areas, cut-outs not exceeding 15% of the span can be created with no need of strengthening interventions. The most recommended area to create cut-outs lays at the intersection of field strips (type 1). According to some specialists [Newman, 2001] this area can be completely removed, without generating adverse effects, since it would just decrease the load on the slab.

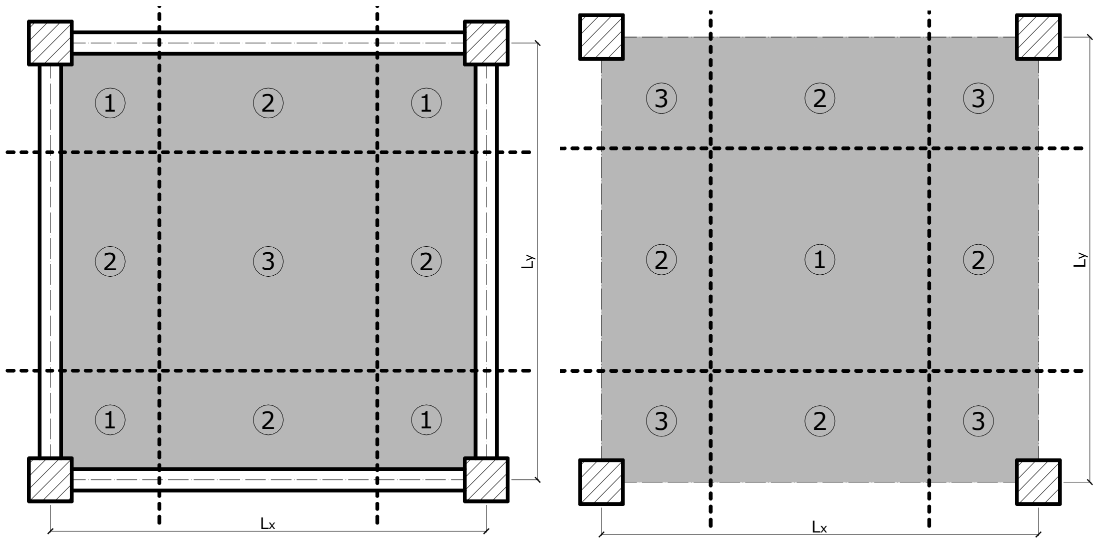


Figure 6. Provisions related to the position and orientation of cut-outs inside one-way slabs.

2 EXPERIMENTAL PROGRAM

The experimental program reported within this paper consisted in testing four reinforced concrete two-way slabs up to complete failure. The elements were large scale ones, prismatic, rectangular in plane, having dimensions of 2650x3950x120 mm. The first specimen (denoted RCS-FS-01) was a full slab, serving as reference. In each of the other three elements a different shape of cut-out was sawn-in. The second slab, denoted RCS-RSC-01 (Reinforced Concrete Slab-Rectangular Small Cut-out), had a small rectangular cut-out inserted into one of its corners. Into the third and fourth slabs, denoted RCS-RLC-01 and RCS-RLC-02 (standing for Reinforced Concrete Slab-Rectangular Large Cut-out) a large rectangular cut-out was positioned on an entire width of these slabs.

The philosophy behind the experimental program was to test all elements in their bare state up to a stage that would assume the need of retrofitting interventions. For all of the slabs, this stage was considered as the maximum allowable deflection ($L/250=2400/250=9.60$ mm) according to EN 1992-1-1 [EN 1992-1-1, 2004]. As this limitation was reached, the test was stopped.

These tests were denoted RCS-FS-UU-01, RCS-RSC-UU-01, RCS-RLC-UU-01 and RCS-RLC-UU-02. Afterwards, a mixed retrofitting solution, combining both near surface mounted (NSMR-FRP) and externally bonded (EBR-FRP) techniques was applied. Finally the retrofitted elements were tested up to their complete failure. The tests on retrofitted specimens were denoted RCS-FS-DS-01, RCS-RSC-DS-01, RCS-RLC-DS-01 and RCS-RLC-DS-02. Actually, the most important objective of the program is to verify the design strengthening solution in respect to its capacity to restore the strength and stiffness for the elements with cut-out in comparison to that of the full slab. The geometrical characteristics of the experimental elements are presented in Figure 8 and Figure 9.

The specimens were placed in horizontal position, resting on a series of RC elements. The interface at the support was provided by a fresh layer of mortar, the elements settling in horizontal position under own weight. This type of simple support blocked gravitational displacements; still it allowed the corners and edges of the elements to uplift. The load was applied gravitationally as it was distributed over a central pad of 1200x600 mm. The load was placed in the center of the full slab, this position being maintained throughout all eight tests; even if asymmetrical, it provided an un-conservative type of loading even for the slabs with cut-outs. A global view of the test setup is presented in Figure 7, along with a transversal cross-section through it.

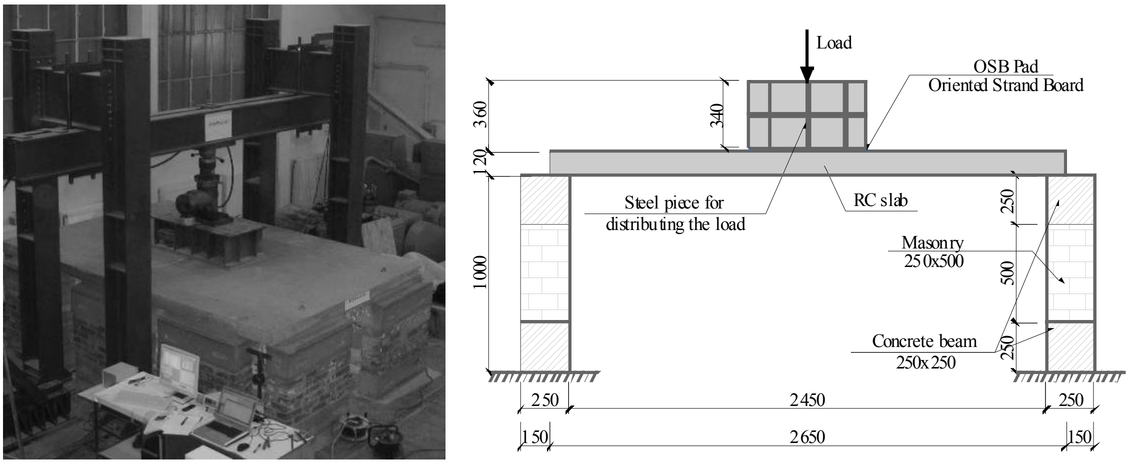


Figure 7. Test set-up.

The slabs were reinforced with steel welded wire meshes at the inferior side (4 mm in diameter with spacing of 100 mm) and with steel rebar at the superior one (6 mm and 10 mm bars). The bars in the steel welded wire meshes had average yield strength between 537 N/mm^2 and 597 N/mm^2. The inferior reinforcement was laid on the entire surface of the slab, while the superior one was placed only along the edges. Since the reproduced situations involved simple supported slabs, the superior reinforcement was designed mainly due to constructive reasons. Based on laboratory tests on samples, it was evaluated that the elements were cast using concrete with cubic compressive strength of 65 MPa (N/mm^2).

3 DESIGN OF STRENGTHENING/RETROFITTING SYSTEM

All of the slabs are tested in bare state, up to the level at which inferior reinforcement on the short direction reaches its yield strength. Thus, considering that this reinforcement has reached its capacity, the slab would have to be retrofitted. The required amount of CFRP is determined analytically. For the full slab, the tensile force that would have been undertaken by the steel reinforcement (that is now yielded) is equalized with the tensile force that will be undertaken by the CFRP. For the elements with cut-outs, the CFRP strengthening material will be placed around the cut-out. The amount of CFRP is determined analytically by equalizing the tensile force that would have been undertook by the steel reinforcement eliminated by creating the cut-out, with the tensile force that will be undertook by the FRP.

$$F_s = F_f \quad \Rightarrow \quad A_f = \frac{f_{yd}}{E_f \cdot \varepsilon_f} A_s \tag{1}$$

In the above formula, the strain in CFRP composite is limited to 0.8%, this value being accepted limit for elements subjected to flexure, according to the strain limitation approach as presented in *fib* bulletin 14 [*fib* Bulletin 14]. This value is much lower than the ultimate strain provided by the producers, being considered the value at which composite action is lost due to premature failure. For strengthening, it was decided to use CFRP lamellas that have a modulus of elasticity of 165000 MPa and a thickness of 1.2 mm and also CFRP sheets that have a modulus of elasticity of 230000 MPa and a thickness of 0.12 mm. In the direction parallel to the short edges of the slabs it was decided to use the NSMR-FRP technique and in the direction parallel to the long edges the EBR-FRP technique.

In Figure 8 and Figure 9, the lay-up of CFRP composites for all of the tested slabs is depicted. As it can be observed in these figures, for the last two slabs (RCS-RLC-01 and RCS-RLC-02) that have the same geometry, the strengthening/retrofitting approach is different, as the goals were quite different. In the case of slab RCS-RLC-01 only retrofitting interventions were applied, as these were meant to restore the initial capacity of the slab. Thus, the CFRP elements were applied only around the long edge of the cut-out. However, for the RCS-RLC-02 slab the objective was to generate an increase of the capacity; this goal was attained by applying strengthening materials on the entire inferior surface of the slab.

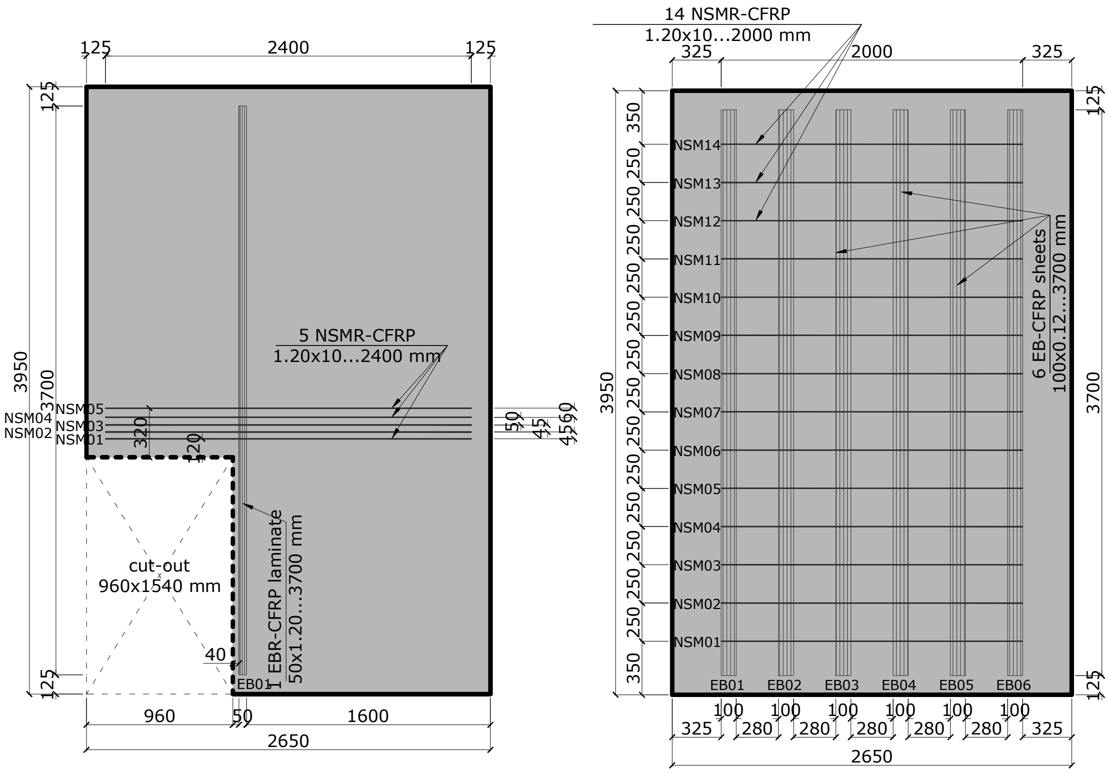


Figure 8. Geometry and lay-out of CFRP composites for the RCS-FS-01 and RCS-RSC-01 slabs.

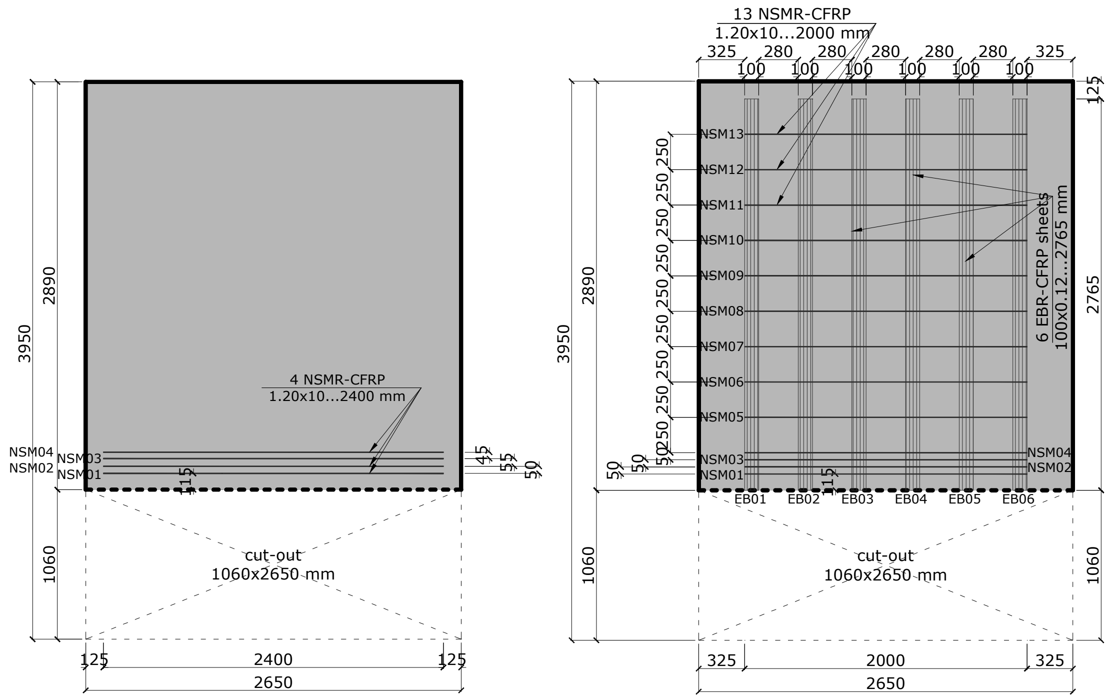


Figure 9. Geometry and lay-out of CFRP composites for the RCS-RLC-01 and RCS-RLC-02 slabs.

4 BEHAVIOR OF BARE ELEMENTS

One of the most important features of the behavior is the small number of cracks that have opened. The crack pattern indicates a larger stress in the area around the cut-outs, these areas being the initiation point of all the cracks.

In the case of the slab RCS-FS-UU-01, four cracks appeared in the direction of the yield lines, at inclinations of 36°, 44°, 52° and 56°. For all of the other tests, a longitudinal crack of quasi-central direction was the first to appear, followed by inclined cracks, at various angles ranging from 30° to 73°. The maximum load level reached during the RCS-FS-UU-01 test was 118.25 kN. Past this value, the strain in numerous reinforcement bars has reached yielding point and the vertical mid-span displacement has past the maximum allowable deflection as provided by EN 1992-1-1 (*L*/250=2400/250=9.60 mm). Moreover, deflection continued to increase without a substantial increase of load. During the test, the maximum vertical mid-span displacement had a value of 10.28 mm.

The maximum load level reached during the RCS-RSC-UU-01 test was 87 kN while the maximum vertical displacement had a value of 11.36 mm, being larger than the maximum allowable deflection. The first crack (the one quasi-parallel to the long side of the slab) was visible at a load of 60 kN.

During RCS-RLC-UU-01 test the maximum recorded load level was 74.5 kN while the maximum vertical displacement had a value of 9.59 mm. The first crack (again the one quasi-parallel to the long side of the slab) was visible at a load of 55 kN. In total, three cracks appeared. For the RCS-RLC-UU-02 test the maximum recorded load level was 66.75 kN while the maximum vertical displacement had a value of 8.88 mm.

All of the load-displacement diagrams are presented in Figure 12 together with the behavior of the retrofitted elements.

5 BEHAVIOR OF STRENGTHENED/RETROFITTED ELEMENTS

The RCS-FS-DS-01 reached a maximum load of 185.5 kN that corresponds to a vertical mid-span deflection of 50 mm. After this level, the deflection increased while the load diminished.

The RCS-RSC-DS-01 test reached a maximum load of 85.75 kN at a central deflection of 27 mm. Maximum deflection was of 33 mm. The RCS-RLC-DS-01 test reached a maximum load of 74.75 kN at a central deflection of 8 mm. Maximum deflection was of 87 mm. The RCS-RLC-DS-02 test reached a maximum load of 147.25 kN at a central deflection of 63.15 mm. Maximum deflection was of 84.13 mm. All of the load-displacement diagrams are presented in Figure 12 while the final crack patterns at the inferior side of all slabs are presented in Figure 10.

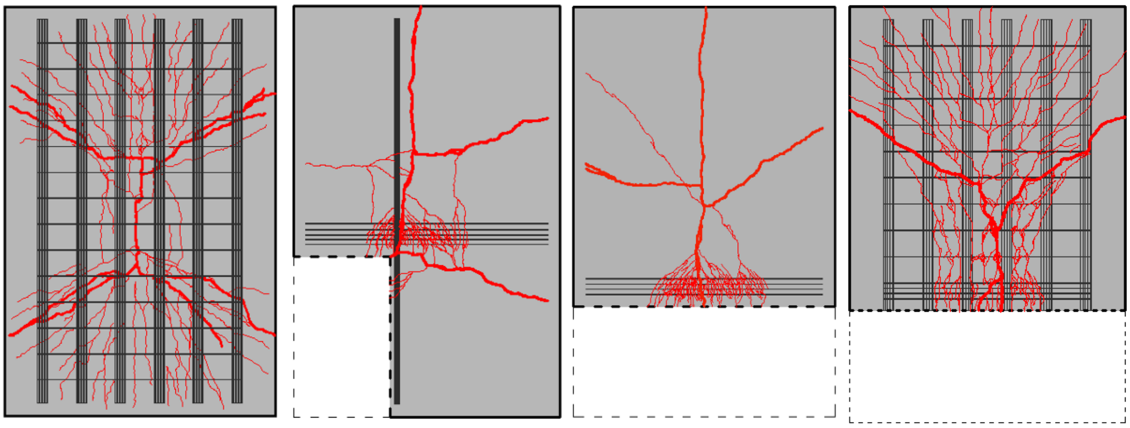
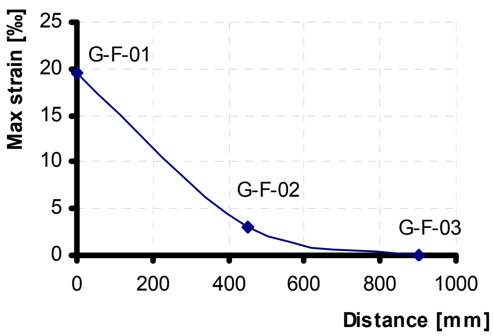


Figure 10. Final crack patterns at the inferior side of all slabs superposed with the CFRP strengthening components.

The strain gauges mounted on CFRP provided some information regarding the way the NSMR-FRP and EB-FRP work. For the RCS-FS-DS-01 slab, nine strain gauges were mounted on CFRP, five of them on NSMR and four of them on EB-FRP. Three of the gauges mounted on NSMR-FRP were placed on the same strip, at various distances from the center of slab. Gauge G-F-01 was mounted right in the center and starting from the center towards the long edges, G-F-02 and G-F-03 were placed at 450 mm and 900 mm respectively. The values of the maximum strain recorded in all of the three gauges are presented in Figure 11 (left). For the RCS-RSC-DS-01 slab seven strain gauges were mounted, four on the NSMR-FRP strips and three on the EB-FRP lamella. Three of the gauges mounted on NSMR-FRP were placed on the same strip (on the strip that was nearest to the edge of the cut-out). Gauge G-F-01 was placed near the corner of the cut-out while G-F-02 and G-F-03 were positioned at 300 and 550 mm respectively, to the left. The principal crack, highlighted in Figure 10 occurred at a very small distance from the gauge G-F-01, this gauge recording the highest strain of all three gauges. The values of the maximum strain recorded with each gauges are presented in Figure 11 (right).



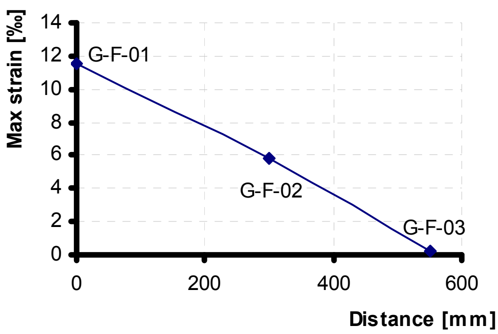


Figure 11. Maximum strain recorded by gauges at various positions.

The variation of the strain in gauges mounted on strips, sheets or lamellas also give some indications regarding development and anchorage length.

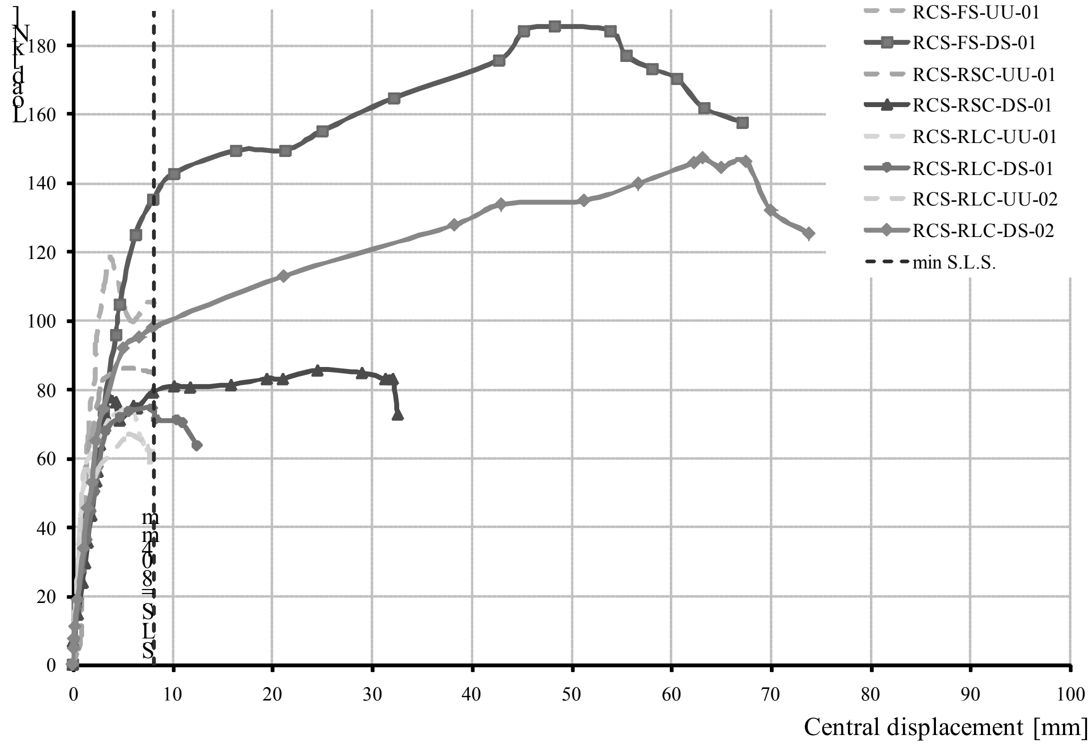


Figure 12. Load-displacement diagrams recorded during all eight tests.

The tests proved that after applying the strengthening solutions, an increase of the ultimate bearing capacity by approximately 57% and 121% was obtained for tests RCS-FS-DS-01 and RCS-RLC-DS-02 comparatively to the capacity of corresponding bare elements (tests RCS-FS-UU-01 and RCS-RLC-UU-02 respectively). Furthermore, by strengthening, slab RCS-RLC-02 gains a capacity that is even higher than that of the bare full slab (test RCS-FS-UU-01). Since one of the objectives of the study was to apply CFRP based strengthening solutions that would lead to an increase of the capacity for the slabs with cut-outs up to the level of the bare full slab, it can be stated that the objective may be easily fulfilled. For the retrofitted elements (tests RCS-RSC-DS-01 and RCS-RLC-DS-01) no increase in ultimate capacity was recorded, the capacity being only restored (again according to the assumed objectives).

In some situations, it is also very important to assess the behavior of specimens at the level corresponding to Service Limit State (SLS). This state was only accounted for in terms of displacement, being established based on the deflection limitation, according to EN 1992-1-1 (L/250=2400/250=9.60 mm) [EN 1992-1-1, 2004], where "L" represents the clear span of the shorter in-plane dimension of the slab. Still, the maximum vertical displacement was not recorded during all tests at the center of the slab (e.g. for the slabs with cut-out, in most situation the maximum vertical displacement is recorded at the corner or along the edge of the opening). Thus, as the tests on bare elements are ended at the moment that maximum vertical displacement reaches control displacement value, in some situations, the central displacement has values below 9.60 mm. In order to compare corresponding capacities, it was decided that for all slabs, the comparison at S.L.S. to be completed at a value of 8.04 mm, as this was the minimum value of all central displacements that correspond to reaching SLS for all elements.

6 CONCLUSIONS

One can consider as a general characteristic of all the four slabs, the fact that the goal of the interventions is achieved, as they prove a regain or an increase in the capacity, after applying the strengthening/retrofitting solution. By applying the retrofitting systems, the capacity of the RCS-RSC-01 and RCS-RLC-01 slabs was restored. The amount of CFRP laid-up around the cut-outs was however insufficient for increasing the bearing capacity of the slabs.

Another important aspect in the behavior of the slabs and of the strengthening/retrofitting system is the fact that all of the CFRP components have failed due to fiber rupture, the only situation in which premature debonding had occurred was related to the failure of the laminate mounted by EBR-FRP on the RCS-RSC-01 slab.

The crack patterns of all tested elements show a greater concentration of cracks for the retrofitted elements in comparison with the reference bare elements, suggesting a more favorable behavior in terms of crack opening. The crack patterns indicate that the failure mode is upon yield lines for the bare elements and upon smeared cracks ("spider shape") for the retrofitted ones.

The failure of CFRP components by fiber rupture along with the crack patterns, have proved the effectiveness of the strengthening solution.

ACKNOWLEDGEMENT

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Sustainable thermal retrofitting solutions for multi-storey residential buildings

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ABSTRACT: The paper presents aspects related to the decisional choice in the retrofitting of residential buildings. The statistical data offered in the first part gives information on the existing Romanian building stock stressing the need for thermal retrofitting. The second part is devoted to retrofitting strategy. The choice of retrofitting solution should be based on an initial evaluation through an integrated analysis. In an integrated design strategy, the retrofitting process is based on a multi-criteria analysis, assessing all the issues that may interfere. In case of thermal rehabilitation of existing buildings at least the technical, structural and economical aspects should be considered in a sustainable assessment. In consequence, a global methodology could be conceived following the basic steps for construction: evaluation – design – construction. The sustainability should be considered as an additional parameter in the design and constructional phase. The paper presents several solutions for thermal retrofitting of existing concrete residential buildings. The retrofitting choice will be discussed according to three decisional solutions: (i) single indicator solution, (ii) multi-axial representation and (iii) the characterization factor method.

1 INTRODUCTION

As shown by various studies (e.g. CIOB, 2008), the building sector, including transportation of materials is responsible for more than half of total carbon dioxide and global warming gas emissions. Changing the point of view, this can also be understood as “*The building and construction industries, and the processes that create, modify and remove built structures, and, the whole-of-life operation of those facilities represent half of our opportunity to resolve today’s climate challenge*” (UIA, 2008).

Thus, the construction industry plays a key-role in the accomplishment of a sustainable environment. However, according to Chartered Institute of Buildings, only 5% of the energy generated is used for construction of buildings while 45% is used to power and maintain them. This can be exemplified by Fig. 1, in which is represented the global environmental impact (expressed in eco-points) of construction materials used in the construction and maintenance of the building in regard to the “consumable goods” (electric power, gas and water) estimated for the building life-time (Ciutina *et al.*, 2011). The example is made for a house that meets the present conditions for thermal insulation of envelope.

In fact the ratio between the maintenance and the embodied energy is different from building to building, and depends on various parameters such as building destination, use time of the building, envelope materials, real service-life of building etc.

It is obvious that using efficient construction materials in the construction phase, the global environmental impact of the building will be significantly smaller though the impact of the construction materials is higher. Adjusting further the maintenance energy one can speak about sustainable buildings, such as *low-energy building, passive, zero energy* or *autonomous house.* The term “*integrated design*” is often used to nominate the design of buildings to take into consideration the environmental and social impact.

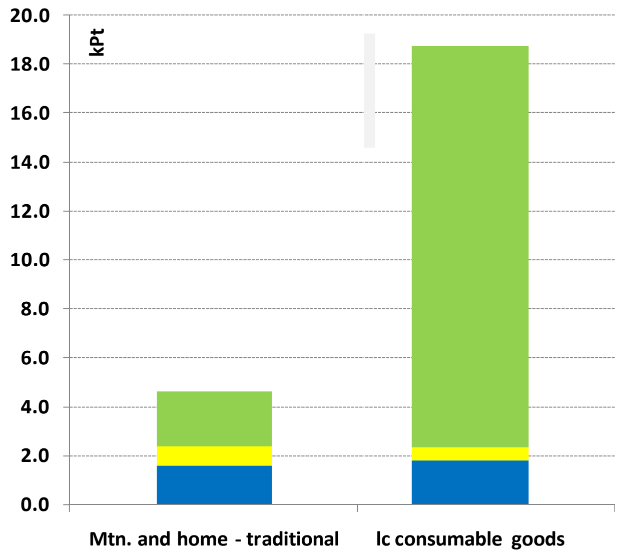


Figure 1. Environmental impact for a building: embodied energy vs. maintenance energy (Ciutina *et al.*, 2011).

Generally, the concept of sustainable buildings is more difficult to be reached in case of old buildings, due to the restrictions imposed by existent building conditions. In these cases, the *sustainable retrofitting* should adjust the initial conditions of a structure in order to fulfil new regulations and requirements.

As in almost all Eastern European countries, a large part of the Romanian built stock is affected by thermal inefficiency of envelope, which leads not only to high operational costs and energy demands but also to human discomfort (as a social parameter) during high and low temperatures in summer and winter respectively. In these circumstances thermal retrofitting of old buildings became a necessity.

2 RESIDENTIAL BUILDINGS IN ROMANIA

Table 1 presents condensed data resulted from the national census in 2003 (INSSE, 2003) regarding the population and buildings. It results very clearly the fact that less than 2% of buildings – collective block of flats – host more than one third of the Romanian population. Most of these 83799 buildings were erected in the 1960-1990 period and have the resistance structure in concrete (57431 units).

Table 1. Existing building stock (INSSE, 2003)

Type	Individual buildings (dwellings)	Coupled buildings	Block of flats (apartment houses)	TOTAL
Number	4 605 412	129 893	83 799	4 819 104
Percentage	95.27%	2.69%	1.73%	100%
Population covered	12 497 000	953 000	7 821 000	21 271 000

The major part of expertise working performed at structural level revealed the fact that from the resistance point of view, the block buildings satisfy in a large majority the actual normative requirements (both Eurocode and national norms). It is to be mentioned the fact that the Romanian territory is a seismic zone and several seismic events were recorded during time (e.g. 1977, 1986 and 1991). Minor structural problems are recorded however in the joints of concrete precast panels, due to bad execution and/or ageing.

Nevertheless, the main problem of these types of buildings is the low thermal efficiency of their envelopes. Taking into account that Romania has predominantly a continental climate, this issue lead to human discomfort during cold and warm seasons, as well as to large amount of energy dissipation.

Table 2 shows the principal typologies of walls, with their description, benefits and drawbacks. The main types of wall systems were using the following resistance typologies:

- Resistance walls in plain brick masonry. Masonry with vertical hollows and stanchions since 1980s;
- Concrete diaphragms plated with different types of thermo-insulation (aerated concrete blocks / mineral wool);
- Reinforced concrete frames with in-fill walls: masonry of plain bricks, bricks with vertical hollows or aerated concrete blocks.

The $R_{0,ef}$ value presented in Table 2 represents the thermal resistances to heat flow, expressed in $[m^2K/W]$ units. This is computed as the sum of thermal resistances to heat flow of all wall layers (exterior to interior).

A very important change in thermal insulation of buildings was performed in 1984, when at the national level it was imposed an energy saving programme and the solutions adopted for buildings were changed. This year represent also a turning point in the Romanian standards regarding thermal insulation (Dan *et al.*, 2007).

Table 2. Design details and characteristics of wall typologies between 1960 and 1994

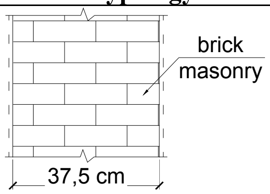
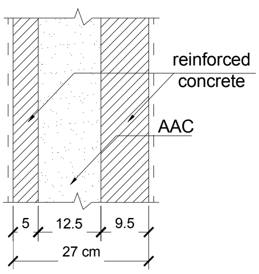
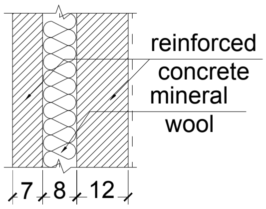
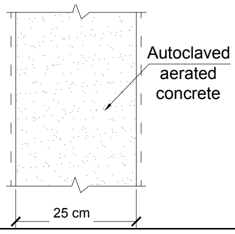
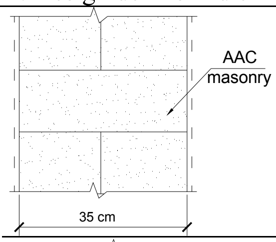
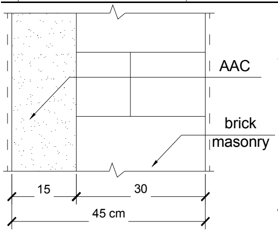
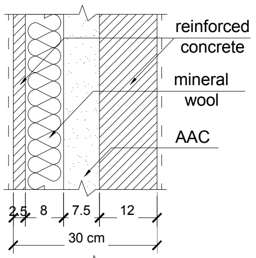
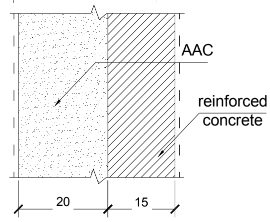
YR	Typology	Description	BENEFITS (+)	DRAWBACKS (–)
1960-1984		1. Exterior plastering 2. Masonry plain bricks of 37.5 cm / bricks with vertical hollows 30cm 3. Interior plastering	- fire resistance: good behaviour - vertical diaphragm action: good behaviour if the masonry correctly executed - thermo-insulation: very low - $R_{0,ef}$=0.57 / 0.54 m^2K/W	- prone to thermal-bridging - local deterioration due to humidity - environmental impact: preliminary studies indicate very high environmental impact due to heat loss
		1. Exterior plastering 2. 1st layer reinforced concrete 5cm 3. Plain aerated concrete masonry 12.5 cm 4. 2nd layer reinforced concrete 9.5cm 5. Interior plastering	- fire resistance: good behaviour - vertical diaphragm action: good response - thermo-insulation: very low - $R_{0,ef}$=0.57 m^2K/W	- prone to thermal-bridging - local damages in bad executed joints - environmental impact: preliminary studies indicate very high environmental impact due to heat loss
		1. Exterior plastering 2. 1st layer reinforced concrete 3. Mineral wool 4. 2nd layer reinforced concrete 5. Interior plastering	- fire resistance: good behaviour - vertical diaphragm action: good response - thermo-insulation: very low - $R_{0,ef}$=0.93 m^2K/W	- local damages in bad executed joints - environmental impact: preliminary studies indicate high environmental impact
		1. Exterior plastering 2. Plain aerated concrete masonry 25 cm 3. Interior plastering	- fire resistance: good behaviour - resistance: assured through frame behaviour - thermo-insulation: very low - $R_{0,ef}$=0.68 m^2K/W	- prone to thermal-bridging - local deterioration due to humidity - environmental impact: very high due to heat loss

Table 2. Design details and characteristics of wall typologies between 1960 and 1994 (contin.)

		1. Exterior plastering 2. Plain aerated concrete masonry 35/45 cm 3. Interior plastering	- fire resistance: good behaviour - resistance: assured through frame behaviour - thermo-insulation: fair - *$R_{0,ef}$=1.84/2.43 m^2K/W*	- prone to thermal-bridging - local deterioration due to humidity - environmental impact: fair
1984-1994		1. Exterior plastering 2. Plain aerated concrete masonry 15/45 cm 3. Masonry plain bricks of 30 cm 4. Interior plastering	- fire resistance: good behaviour - vertical diaphragm action: good behaviour if the masonry correctly executed - thermo-insulation: low - *$R_{0,ef}$=1.38 m^2K/W*	- prone to thermal-bridging - local deterioration due to humidity - environmental impact: high environmental impact due to heat loss
		1. Exterior plastering 2. Mineral wool 3. Plain aerated concrete masonry 4. Reinforced concrete	- fire resistance: good behaviour - vertical diaphragm action: good behaviour - thermo-insulation: fair - *$R_{0,ef}$=1.63 m^2K/W*	- prone to thermal-bridging - local damages in bad executed joints - environmental impact: low due to heat loss through wall joints
		1. Exterior plastering 2. Mineral wool 3. Plain aerated concrete masonry 4. Reinforced concrete	- fire resistance: good behaviour - vertical diaphragm action: good behaviour - thermo-insulation: fair - *$R_{0,ef}$=1.61 m^2K/W*	- prone to thermal-bridging - local damages in bad executed joints - environmental impact: low due to heat loss through wall joints

The first Romanian normative requirements regarding heat transfer were given in 1960s for exterior walls, flat roofs and floors over basement. Table 3 presents briefly the variation in required thermal resistance of building envelope elements.

During the last 50 years the *R* values have been changed more than forty times in new and changed issues of national standards, but always increasing values were required. Thus, the heat transfer requirement increased 2.5 times for external walls, 5 times for flat roofs and 3.5 times for floors and basements. Unfortunately the changes in the heat transfer requirements were not followed by the up-dating of the envelopes of the existing building stock. This is in fact the main reason of having in present a very large building stock that do not fulfil the actual norms regarding the heat flow transfer.

In year 2000, the Romanian government issued an Order (29/2000) regarding the thermal rehabilitation of the existing buildings and stimulation of energy saving. Its first purpose is the improvement of hygienic and thermal comfort of inhabitants, decrease of heat flow and energy loss. Although it is based on a very interesting financial support from the state (50%) the program has made only shy steps up to now in real implementation.

Table 3. Romanian normative requirements for thermal resistance of envelope elements (values in m^2K/W)

Year	Standard	Ext. walls	Flat roofs	Floor/basement
1962	6472-61	0.76	0.96	0.82
1984	NP15-84	1.20	1.55	1.08
1997	C107/3-1997	1.09	1.46	1.25
2010	C107/3-2010	1.80	5.00	2.90

Various studies (Dan *et al.*, 2007, Botici *et al.*, 2012) have concluded that the living conditions in such buildings are under the actual standards requirements. Several problems were identified, such as small usable area, high density (greater than one person per room), inadequate sanitary conditions, high urban densities in neighborhoods etc. Many of these problems can be resolved by coupling of adjacent apartments and/or creation of extra-spaces through over-roofing. Among the principal problems related to collective buildings, the thermal comfort plays an important aspect.

The usual stratifications used in collective residential buildings (see Table 3) are far from assuring the actual thermal resistance requirements. It results that in many cases the existing layers can assure at most half of the required thermal resistance. Moreover, the thermal insulation layer is in many cases out-dated or damaged due to ageing.

In consequence, an integrated design (ID) for retrofitting such structures should include as a necessity the thermal upgrading of exterior walls. The compatibility of the thermal retrofitting solution with the existing structure must be assured.

3 INTEGRATED DESIGN OF BUILDINGS

The aim of the Integrated Design (ID) of buildings is to incorporate in usual architectural, structural and technical design additional requirements related to sustainability. Hence, the ID of buildings maximizes the overall life-cycle response through structural, economic and environmental performances. The way in which the social (structural, comfort, architectural etc.), economic and environmental performances are assessed is rather a complicated matter due to the complex definition of a building, but, nevertheless, in literature it is largely accepted that ID of buildings is characterized by the following key attributes (Landolfo, 2012):

- it is a methodology oriented on the Life-Cycle Approach (LCA);
- the ID represents a multi-performance based design approach;
- the evaluation of safety and serviceability, durability, life-cycle costs and environmental impact is based on quantitative design procedure.

The main problem in performing an ID based on LCA is related to the long-life period of buildings in comparison with other products. The difficulties arise due to the uncertainties occurred during the use period and end-of-life.

The ID of existing buildings is even more complicated due to the restrictions imposed by the existent building conditions. The sustainable retrofitting solutions should be adapted to the initial conditions of structures and adjust them in order to fulfil the updated regulations and requirements (Ungureanu *et al.*, 2012). As a consequence, the modern design regulations for structural and thermal retrofitting of buildings integrate new concepts in the evaluation and design of buildings: design performance objectives, acceptance criteria linked to performance level, sustainability issues and analytical techniques for performance assessment. The rating systems (LEEDS, BREAM, SBTOOL etc.) could offer a measure of building performance both prior and post-retrofitting. However in case of existent buildings an ID solution should integrate both structural and thermal resistance aspects. It is obvious that independent interventions are deficient. An integrated retrofitting solution should be based on the following basic criteria (adapted after Dubina et al., 2008) – other specific criteria can be added in function of the specificity of the project:

A. Structural aspects:

- Capability to achieve requested structural performance objective (only after building structural evaluation);
- Solution compatibility with the actual structural system;
- Adaptability to change of design actions (including seismic if necessary);
- Adaptability to change of building partitioning.

B. Technical and comfort aspects:

- Reversibility of intervention;
- Durability;
- Operational;
- Comfort (thermal, phonic, space);
- Functionally and aesthetically compatible and complementary to the existing building;

- Technical support (Codification, Recommendations, Technical rules);
- Availability of material/device;
- Quality control.

C. Economic aspects:

- Costs (Material/Fabrication, Transportation, Erection, Installation, Maintenance, Preparatory works).

D. Environmental aspects:

- Measures to lower the operational energy;
- Use of ecological and friendly materials.

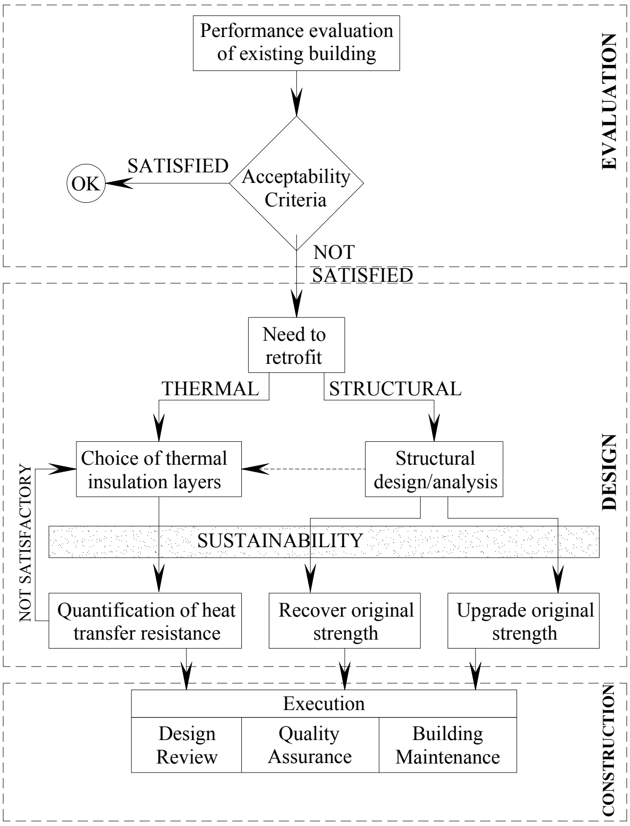


Figure 2. Integrated design in retrofitting of buildings: conceptual flow.

Figure 2 shows the conceptual flow in building retrofitting by considering the ID strategy. It represents in fact an iterative process in which the evaluation, design and construction phases should be considered for the achievement of the desired performance level. The aspects related to structural safety, comfort and sustainability should be considered in each step and judged as margins of safety through which the interventions should be considered.

The *evaluation phase* has rather a decisional purpose, based on satisfaction of acceptability criteria considered for comfort and safety. The thermal and/or structural retrofitting decision relies on specific engineering analyses and sustainability indicators.

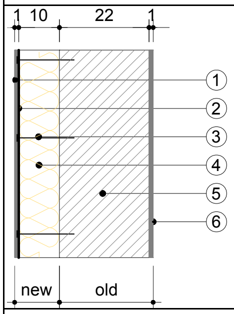
The *design phase* should consider an ID approach in which a mechanical, physical and functional compatibility should coexist with the existent system: structure, envelope, internal partitioning and installations. The sustainable indicators should be considered as filters in the decisional matrix.

The basic purpose of retrofitting is the *execution phase*. By considering an ID approach, the execution should be closely linked with the design process. The continuous quality assurance process which normally includes designers should prove the conformity of the erection with the project, while the non-applicable procedures should be noticed to designers for design reviews. After erection the retrofitted buildings must be maintained through repairing, renovation or restorations.

4 RETROFITTING SOLUTIONS

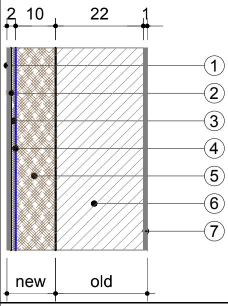
Figure 3 shows eight solutions used for thermal retrofitting the concrete external walls through external over-cladding. The original stratification chosen as case-study in the present paper is type II, according to Table 2, which corresponds to the T770 collective building standardized project, built in the 1975-1985 period. The solutions name is given by the insulation material used or by the name of the company offering the integrating solution.

Solution 1 – "Polystyrene



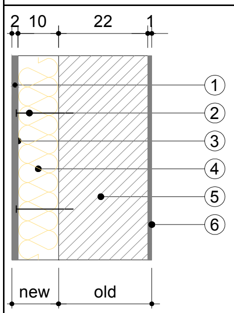
1. Exterior plastering
2. Glass fibre wire lattice
3. Fixing screws (steel screws and plastic fixings)
5. Thermal insulation: extruded polystyrene 10cm
6. Reinforced concrete
7. Interior plastering

Solution 2 – "Cellulose"



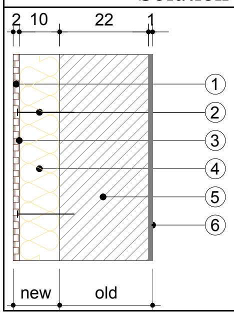
1. Exterior plastering
2. Glass fibre wire lattice
3. Oriented Strand Board
4. PVC vapour barrier
5. Thermal insulation: untied cellulose fibre 10cm
6. Reinforced concrete
7. Interior plastering

Solution 3 – "Glass Wool"



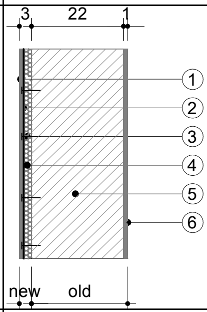
1. Polyvinyl exterior plates
2. Fixing screws (steel)
3. Ventilation void
4. PVC vapour barrier
5. Thermal insulation: Glass wool 10cm
6. Reinforced concrete
7. Interior plastering

Solution 4 – "Mineral Wool"



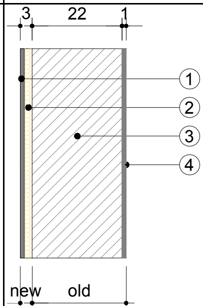
1. External brick siding
2. Fixing screws (steel)
3. Ventilation void
4. Thermal insulation: Mineral wool 10cm
5. Reinforced concrete
6. Interior plastering

Solution 5 – "Rigid foam"



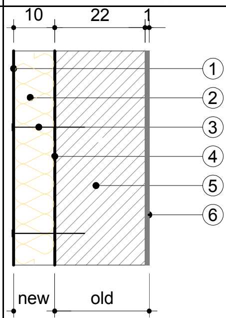
1. Exterior plastering
2. Glass fibre wire lattice
3. Fixing screws (steel)
4. Thermal insulation: Plastispan HD and Durofoam HD 10cm
5. Reinforced concrete
6. Interior plastering

Solution 6 – "Polyurethane Foam"



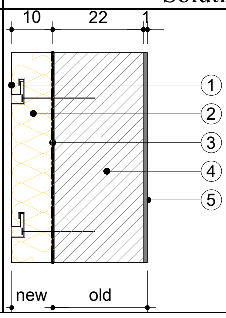
1. Acrylic paint
2. Thermal insulation: polyurethane foam 10cm
3. Reinforced concrete
4. Interior plastering

Solution 7– "Ruukki"



1. Exterior sandwich steel plate
2 Thermal insulation: Basaltic wool 10cm
3. Interior sandwich steel plate
4. Fixing screws (steel)
6. Reinforced concrete
7. Interior plastering

Solution 8– "Lindab"



1. Lindab steel cassette
2 Thermal insulation: Basaltic wool 10cm
3. PVC vapour barrier
6. Reinforced concrete
7. Interior plastering

Figure 3. Solutions for thermal retrofitting the existing concrete walls.

First of the solutions proposed represents the common solution of thermal rehabilitation of buildings, through a thermo-system assured by a polystyrene layer (100 mm in this case) and exterior plastering adherent on a glass fibre. The next five solutions are similar as conception, by considering a thermal insulation layer on cellulose, glass, mineral or rigid basaltic wool and polyurethane foam respectively. The external siding – plastering, polyvinyl or brick siding – is fixed either directly on the thermal insulation layer either on thin walled cold-formed profiles fixed on concrete wall.

The last two solutions represent integrated solutions offered by specialized companies on external wall siding: the Ruukki solution is a sandwich panel with embedded thermal insulations while in the case of siding cassettes offered by Lindab the thermal insulation layer is chosen by the owner. The two systems are fixed on steel profiles, pre-fastened on the concrete bed.

5 MULTI-CRITERIA ANALYSIS AND CHOICE OF SOLUTION

5.1 *Criteria considered in the selection of solution*

Three criteria were considered for the final selection of thermal retrofitting solution, corresponding to the sustainability pillars:

- social: *thermal insulation* resistance. It measures the ability of each solution of offering adequate internal comfort, while its implication is also on the building energy use. The values given in the Table 4 consider the thermal resistances of existent and additional layers, but disregard the existent thermal insulation layer which in many cases is not efficient. All the solutions were adjusted to offer values close to the thermal resistance normative requirements (1.80 m^2k/W);
- economic: the economic assessment is considered through *integrated costs* for materials, mechanical fasteners and labour. The values offered in Table 4 are computed according to the current economic situation in Romania per square meter of retrofitted wall;
- environment: the *environmental impact* was considered through Life-Cycle Impact Analysis (LCIA) on new added materials, per square meter of wall using the SimaPro (SimaPro, 2012) computer tool. The values are given in eco-points, by considering the EcoIndicator 99 as method of analysis. The LCIA inventory was constituted from average weights of materials divided to the total covered area. For the life cycle approach the production and end-of life of materials was considered. For the end-of-life, a reasonable scenario for reuse, recycling and disposal of materials was envisaged (see Table 5). Figure 4 shows graphically the LCIA results for all seven solutions considered.

It is to be noticed the fact that the safety criterion was not included in analysis as this was assured for all solutions (excluded by boundary conditions).

Table 4. Thermal, costing and environmental impact estimations for thermal retrofitting solutions

Sol. No.	Sol. Name	Effective thermal resistance [m^2k/W]	Price [eur/sqm]	Environmental impact [Pt]
1	Polystyrene	2.04	35.36	2.26
2	Celluloses	1.95	20.51	0.99
3	Glass Wool	2.09	45.43	0.68
4	Mineral Wool	2.10	37.10	0.62
5	Rigid Foam	2.05	24.57	0.85
6	Polyurethane Foam	2.34	31.64	0.65
7	Ruukki	2.08	21.88	0.55
8	Lindab	1.98	53.41	1.73

Table 5. End-of-life scenario for main building materials

Material	*Reuse [%]*	*Recycling [%]*	*Burn [%]*	*Disposal - Landfill [%]*
Steel materials	--	100	--	--
Wooden materials	30	--	70	--
Concrete, mortar	--	--	--	100
Other inert materials	--	--	--	100
Other combustible materials	--	--	100	--

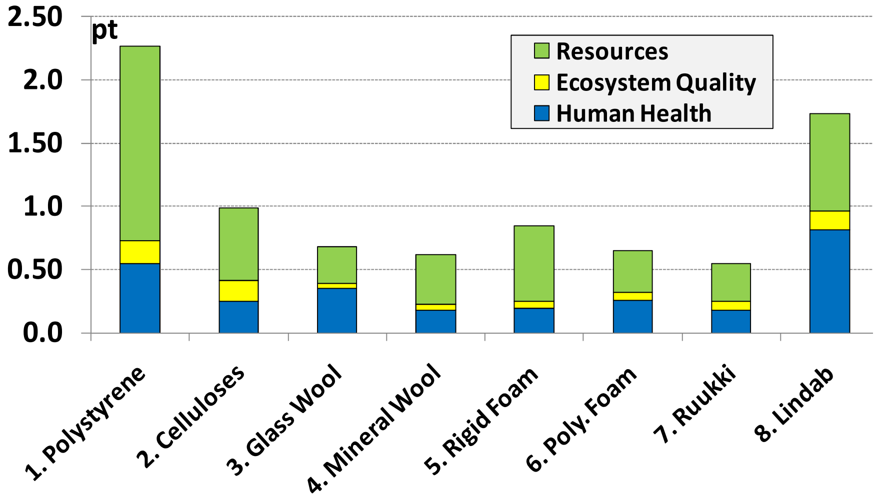


Figure 4. LC environmental impact for retrofitting solutions (tool: SimaPro, Method: Ecoinventor 99).

5.2 *Selection of solution by considering indicator-oriented methods*

The choice of solution through indicator-oriented method represents the easiest way of selecting among solutions. The willingness to pay is the most used factor on selecting goods on the economic market.

Solutions 2, 6 and 7 represent in turn the best choices considering individual indicators: price, thermal resistances and environmental impact respectively. In consequence, judging strictly on one of these criteria, one of the solutions is chosen.

5.3 *Selection of solution by considering multi-axial representation method*

The solution selection through multi-axial representation considers an axis for each individual indicator. The representation is possible for three indicators but the solution remains valid even for more indicators.

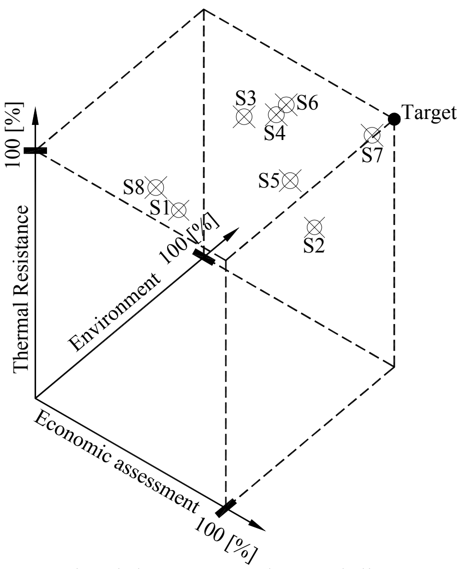
The first step of the method is the normalization of results: the solutions having the best performance in regard to a certain indicator is maximized to 100% while the rest of indicators are normalized to this value in percentages as shown in Table 6.

The second step is the computation of the distance to an ideal target, defined by the point of maximum coordinates (100,100,100). This can be easily done by computing the vector between the real coordinated points and the ideal target through the square root of sum of squares. Figure 5 shows the 3D representation by considering the three indicators considered in the case-study. Also, the figure shows the computed distances to the target.

Table 6. Normalization of indicator values

Sol No.	Th. Resistance		Price		Environmental Impact	
	[m^2k/W]	Normalisation	[€/sqm]	Normalisation	[pt]	Normalisation
1. Polystyrene	2.04	86.90	35.36	58.00	2.26	24.42
2. Celluloses	1.95	83.41	20.51	100.00	0.99	55.93
3. Glass Wool	2.09	89.08	45.43	45.15	0.68	80.70
4. Mineral Wool	2.10	89.51	37.10	55.28	0.62	88.89
5. Rigid Foam	2.05	87.56	24.57	83.48	0.85	65.09
6. Polyurethane Foam	2.34	100.00	31.64	64.82	0.65	84.53
7. Ruukki	2.08	88.95	21.88	93.74	0.55	100.00
8. Lindab	1.98	84.33	53.41	38.40	1.73	31.91

The smallest distance to the target is obtained for the seventh solution (12.70) which by far is better than other thermal rehabilitation systems. It could be noticed that the first solution which is largely used in real rehabilitation projects is almost the furthest to the target point. The bad scoring is due to the bad environmental impact and also the price.



Sol. No.	Distance to target
1. Polystyrene	87.45
2. Celluloses	47.09
3. Glass Wool	59.17
4. Mineral Wool	47.26
5. Rigid Foam	40.57
6. Polyurethane Foam	38.43
7. Ruukki	12.70
8. Lindab	93.15

Figure 5. Tri-axial representation and distance to target for solutions 1-8.

5.4 *Selection of solution by considering characterization factor method*

The method is based on using characterization factors in accordance to the importance of a specific indicator in the final decision choice. The factorized values multiply the normalized values which are finally added in a final score (aggregated value). The highest value represents the best score.

The difficulty of the method is finding the right characterization factors reflecting the importance of indicators. Usually a block of experts can be consulted for finding adequate factor values. One solution is by considering factors in unitary ratios.

Table 7 shows the factorized values and final scores using the following characterization factors for specific the three indicators considered:

- $c_t = 0.45$ for the thermal resistance;
- $c_p = 0.30$ for the economic assessment;
- $c_e = 0.25$ for the environmental impact.

Table 7. Factorized values and final scores for different solutions

Solution No.	Thermal Resistance		Economic assessment		Environmental impact		
	Normalised value	Factor-ised value	Normalised value	Factorised value	Normalised value	Factorised value	*Final score*
1. Polystyrene	86.90	39.10	58.00	17.40	24.42	6.11	*62.61*
2. Celluloses	83.41	37.54	100.00	30.00	55.93	13.98	*81.52*
3. Glass Wool	89.08	40.09	45.15	13.54	80.70	20.18	*73.80*
4. Mineral Wool	89.51	40.28	55.28	16.58	88.89	22.22	*79.09*
5. Rigid Foam	87.56	39.40	83.48	25.04	65.09	16.27	*80.72*
6. Polyurethane Foam	100.00	45.00	64.82	19.45	84.53	21.13	*85.58*
7. Ruukki	88.95	40.03	93.74	28.12	100.00	25.00	*93.15*
8. Lindab	84.33	37.95	38.40	11.52	31.91	7.98	*57.45*
Ch. Factor	*x 0.45*		*x 0.30*		*x 0.25*		

According to this method again the seventh solution with an integrated sandwich panel, presents the best scoring. This fact is due primarily to an integrated optimization of the solution, combining several parameters such as:

- adequate thermal insulations, adjusted through the width of the insulation layers;
- good pricing due to the intensive industrialized processes;
- relatively low environmental impact by using high recyclable materials (such as steel).

However, good results are obtained also for the polyurethane foam and cellulose solutions, which might be considered as good alternatives for thermal insulation.

6 CONCLUSIONS

The study presents the main problems related to the existent stock of residential collective concrete buildings in Romania. One of the immediate needs for assuring the thermal comfort of habitants and also the efficient use of operational energy is the thermal insulation. Different techniques can be applied but they have to be compliant with existent structure and envelope.

In an integrated retrofitting design, the techniques employed in thermal insulation should consider the conditions of the existing structure. Moreover, by considering a sustainable design, the environmental criterion should be present in the decisional matrix, among other economic and technical criteria.

The choice of a multi-criteria analysis in thermal retrofitting of existing buildings is a decisional task which may employ several methods. Usually, the indicator-oriented methods are deficient due to ignorance of non-considered criteria. This is why other methods, such as the multi-axial representation or the characterisation factor method could clear the choice for a solution.

In case of the present study, the steel-intensive solutions such as sandwich panels can offer a good solution for thermal rehabilitation of concrete structures. The reliability of solution is due to the use of highly recyclable materials and economic advantages due to the industrialized processes used in manufacturing.

ACKNOWLEDGEMENT

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Cost effectiveness of energy retrofit solutions – Results from generic calculations with a reference building in Romania

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ABSTRACT: Energy retrofit of the existing building stock is needed at higher rate compared to today, if the European Commission's 20-20-20 goals are to be realized. Economic arguments are not exclusive drivers of the retrofit choices of the privately owned buildings. However, it is certainly important to identify the cheapest solutions to achieve highest CO_2 reduction impact, in order to find the most effective ways to improve the existing buildings. Cost effectiveness is an important priority, since it allows more to be achieved with the same monetary resource. For a given building typology, located in a certain economic environment, it is far from trivial to choose the most cost effective technologies for renovation. It may be that the cheapest solutions based on immediate cost are readily identified by the stakeholders, but once life time costing is brought into the picture the long term efficiency is much harder to asses. In this paper the cost effectiveness of several renovation packages is assessed in relationship with the multi-family prefabricated concrete buildings, which occur widely in the building stock in Romania. The results show several of the building envelope's retrofit solutions to be cost effective in mitigating CO_2 emissions in these buildings. It is also found that changing the heating method from the currently predominant district heating to more decentralized systems can also lead to both important cost savings and CO_2 emission reductions, in particular if heat pumps are used.

1 INTRODUCTION

The results here are based on analysing a generic building instead of case-specific configurations. As basis for defining the generic building typology, the statistical data from the panel building stock in Romania has been used. While economic arguments are known not to be the exclusive driver of retrofit choices in privately owned buildings (Bomee, 2007, Botici *et al.*, 2014), in this study the focus is on cost optimal choices, ignoring all forms of co-benefits.

1.1 *Location of the collective buildings*

In Romania 7,821,169 inhabitants lived in 83,799 collective block of flats type buildings in 2002 [INNSE, 2003], totalling 2,868,820 households of this type. From the 83,799 collective buildings 57,431 were made of large prefabricated concrete panels (PCP). Altogether 79,077 buildings were located in municipalities and cities and only 4,722 in rural settlements. The concrete panel typology is the main focus for the study presented here, but because the renovation technologies may also be applied to collective buildings built of bricks, in the general statistics the two are treated together. The total area of apartments in collective buildings is about 108 million m^2, about 1/4th being located in the capital Bucharest (24 million m^2), and over 4 million m^2 in each of the four counties with large cities. Other seven counties hosting the cities with more than 250,000 inhabitants, according to the 2002 census, have also quite high shares of collective buildings in living areas (see Figure 1).

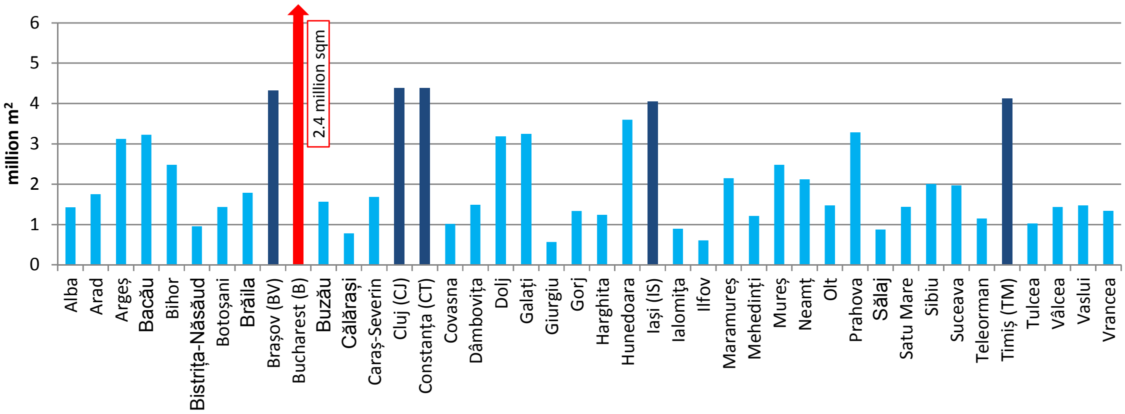


Figure 1. Total area of housing located in collective buildings by county.

The geographical location of the building, in relationship with the prevailing climate in Romania is presented in Figure 2. It can be noticed that a large number of collective buildings are located in quite different climate areas ranging from cold, sunny and sheltered from wind (e.g. Cluj) to warmer, windier and sunnier (e.g. Timisoara), down to the seaside zones, with very strong wind (e.g. Constanta).

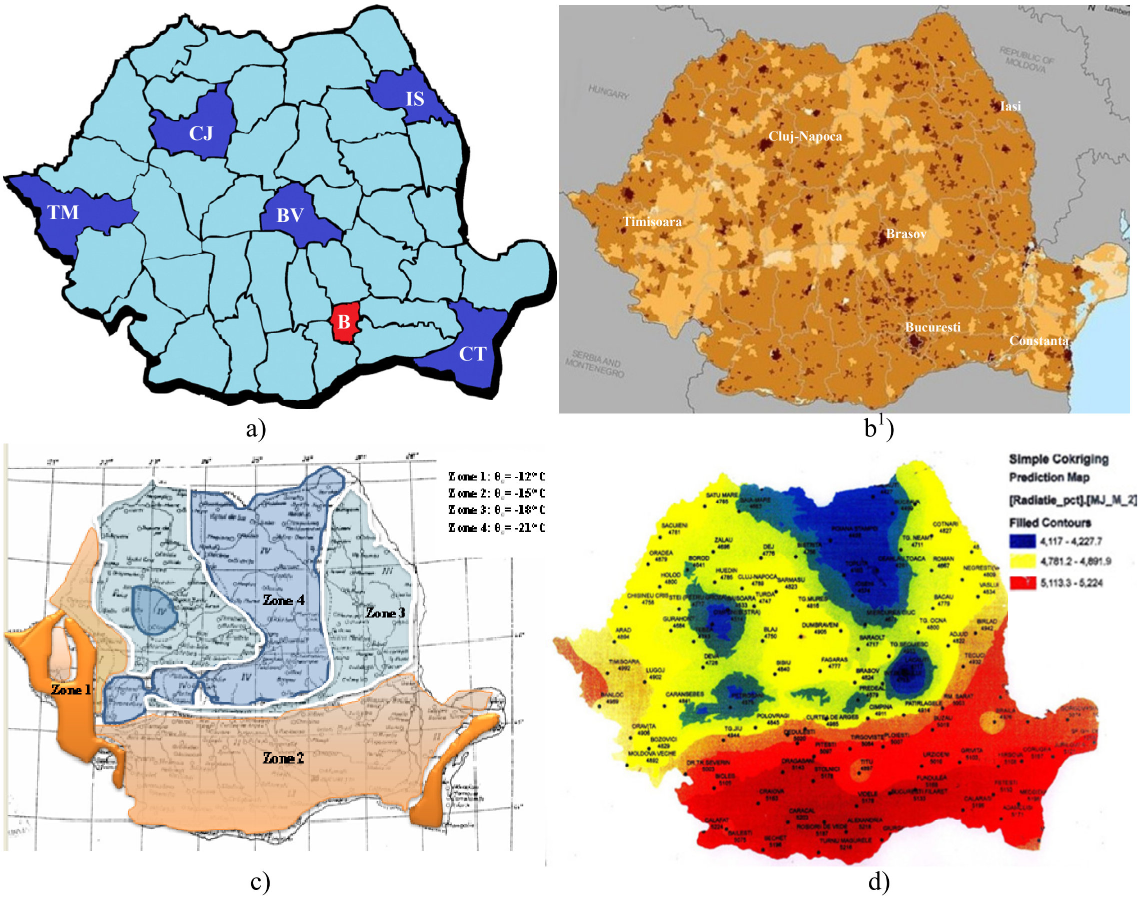


Figure 2. (a) Counties with large number of collective buildings as also highlighted in Figure 1 and (b) high density urban areas within counties collared with darker brown; (c) climatic zones and their design temperatures; (d) solar radiation.

[1] http://sedac.ciesin.columbia.edu/data/set/grump-v1-population-density/maps/2?facets=region:europe

Analysing the distribution of the multi-storey buildings in connection to the general population distribution, one can notice the relatively high proportion (> 40%) of people living in multi-family dwellings in the same seven counties as mentioned before (see Figure 3). The outliers in Figure 3 are the capital Bucharest, with a proportion of close to 80%, and the county surrounding Bucharest (Ilfov) with very few multi-apartment dwellings. It can also be noticed the particular case of Hunedoara county, with a very high proportion of multi-apartment dwellings, without hosting major urban centres. This situation is resulting due to the high level of industrialization of this county in the period 1950-1990.

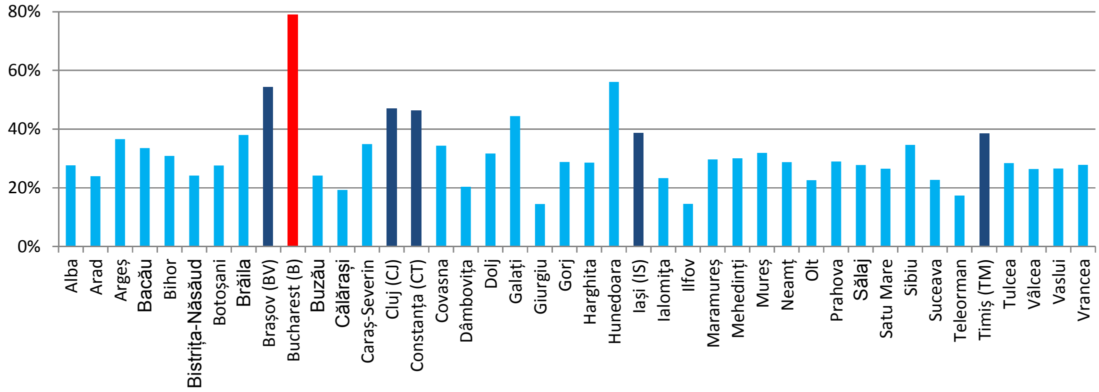


Figure 3. Percentage of people living in multi-dwelling houses by county.

1.2 *Prevailing building typologies*

From the collective buildings 57,431 are made with the prefabricated concrete panel (PCP) technology. Most of the other buildings have brick walls and hollow core concrete floors. Many of the refurbishment measures suggested in this paper are equally applicable for the two typologies. In fact, the main configuration difference between the two building types is in the average number of apartments they host (42 in PCP's vs. 26 in the brick typology). It is reasonable to assume that the difference is due to the fact that PCP buildings have been used for taller buildings, since load bearing brick walls are not accepted for buildings over 5 storeys, due to reason of earthquake safety. The other configuration parameters are quite the same on average: apartment size about 34-35 m^2, 2.2-2.3 rooms and 2.3-2.6 occupants for each apartment.

In Romania, most of the currently inhabited 57,431 PCP buildings were built between 1960 and 1990 (see Figure 4), and 41,540 of them have 5 storeys. A second group of important typologies are the 9, 10 and 11 storeys totalling 9,180 buildings. The two most widespread configurations in Romania are the 5 storeys and the tower (9, 10, 11 storeys) typologies.

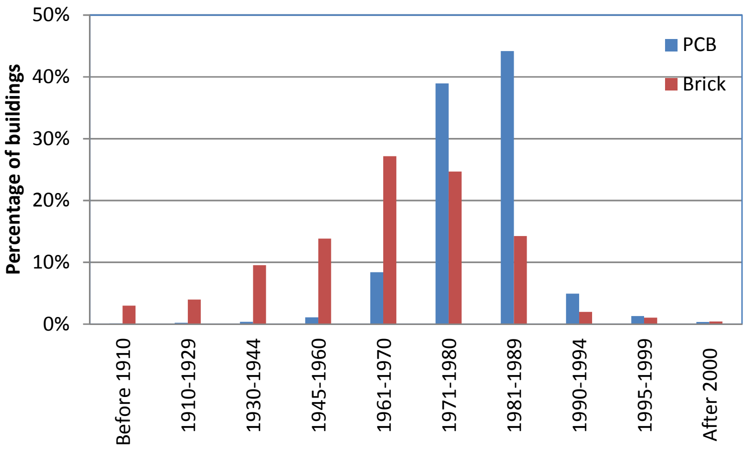


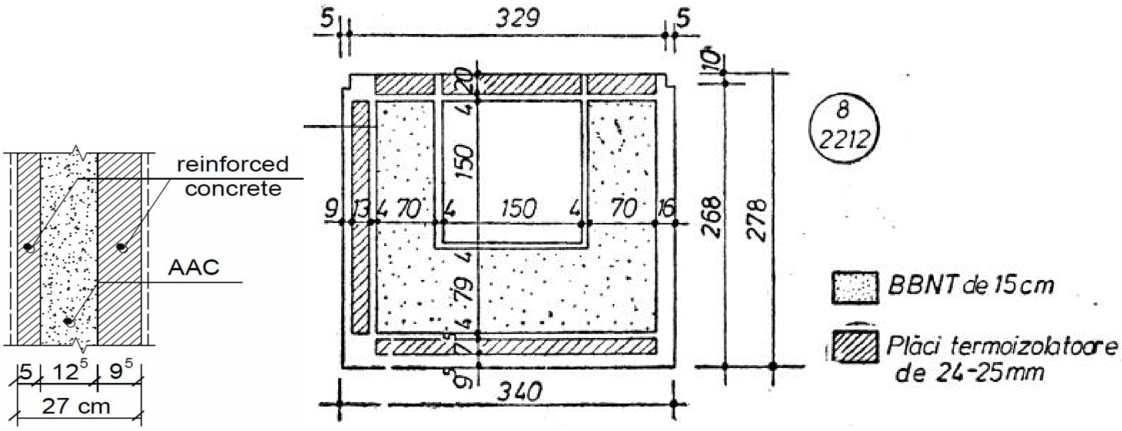
Figure 4. Percentage of buildings built in the different periods.

As a summary, the PCP stock is younger and contains probably almost all the buildings from the tower configuration, while the brick building are older and are limited to maximum 5 storeys.

1.3 *Structure and detailing of the building envelopes*

The usual way of building-up the structures from prefabricated concrete panels was by creating "boxes" from panels around each main volume of the apartments (rooms, kitchens, halls etc.). This results in strict architectural lines of the buildings.

Internal walls were fabricated only for load bearing purpose from about 20 cm thick concrete plates, acoustic insulation and other functions of the internal walls being fulfilled by default with this thickness of concrete. External walls were formed using 3 layers, the internal layer being of the load bearing concrete (9-12 cm), a middle insulation with material and thickness depending on the climatic region, and an external façade layer of 5 cm concrete (see Figure 5.a). Usually the two layers of concrete are connected by strips of concrete which penetrate the insulation (Figure 5.b). This detailing ensures a secure connection of the façade layer, but also results in thermal bridges on 5-10% of each panel's surface. From the refurbishment point of view the removal of the façade concrete, which is often done in case of lightly anchored façades in Nordic countries (see concept T1b in Peuhkuri *et al.,* 2012), is quite difficult.



a) b)

Figure 5. (a)Typical layers and (b) insulation distribution in the prefabricated panels

2 MODELLING METHODOLOGY

Different strategic options were considered for increasing efficiency of primary energy use and reducing greenhouse gas emissions within building renovation. The different strategic options influence each other. There may be synergies or trade-offs. In this paper the focus is on the relationships between the improvement of the energy performance of the building envelope, the change of the heating system, and the increase in the efficiency of electricity consumption.

For investigating different intervention solutions, first the calculations are carried out for a fossil fuel based system as a reference heating system. The effects of different single renovation measures on costs, energy consumption and carbon emissions are determined. Based on these results, renovation packages are composed, starting with the most efficient renovation measure, and adding more and more measures which are less cost effective. The calculations are replicated for other heating systems.

It is assumed that within the building retrofit the heating system needs to be replaced by a new one. Therefore, an investment in the heating system is done also in the reference case. Similarly, assumptions are made regarding the necessity of rehabilitating the building in the reference case. E.g. for façades it is presumed that periodic maintenance (i.e. simple painting) needs to be done anyway, so for the cost effectiveness of providing thermal insulation it is the difference between an energetic renovation and an anyway renovation for maintenance which matters.

The effects of the different renovation packages are displayed showing greenhouse gas emissions or primary energy use on one axis, and life cycle costs on the other axis, always on a yearly basis. The numbers are indicated per m^2 of gross heated floor area. The detailed steps to calculate the above indicators are:

- energy consumption for space heating is determined by calculating energy loss to colder environment outside due to transmission and ventilation losses and by accounting for passive solar and internal heat gains as energy gains. Factors used in this calculation also include thermal capacity, insulation and thermal bridges.
- the methodology for calculating useful heating needs is based on the Swiss Norms SIA 380/1:2009 for calculating thermal energy use in buildings . This norm uses the same calculation principles as the standard ISO 13790:2008 "Energy performance of buildings - Calculation of energy use for space heating and cooling" and the common general framework for the calculation of energy performance of buildings according to the European Energy Performance of Buildings Directive 2010/31/EU from May 2010.
- depending on the heating system, greenhouse gas emissions and primary energy factors (PEF) are applied, taking into account the efficiency of the heating system.
- to this calculation energy used for hot water is added.
- the unit used to compare size of buildings is the gross conditioned floor area (or simply "conditioned floor area"): The horizontal projection of that portion of space which is contained within exterior walls (including the walls themselves) and which is conditioned directly or indirectly by an energy-using system.

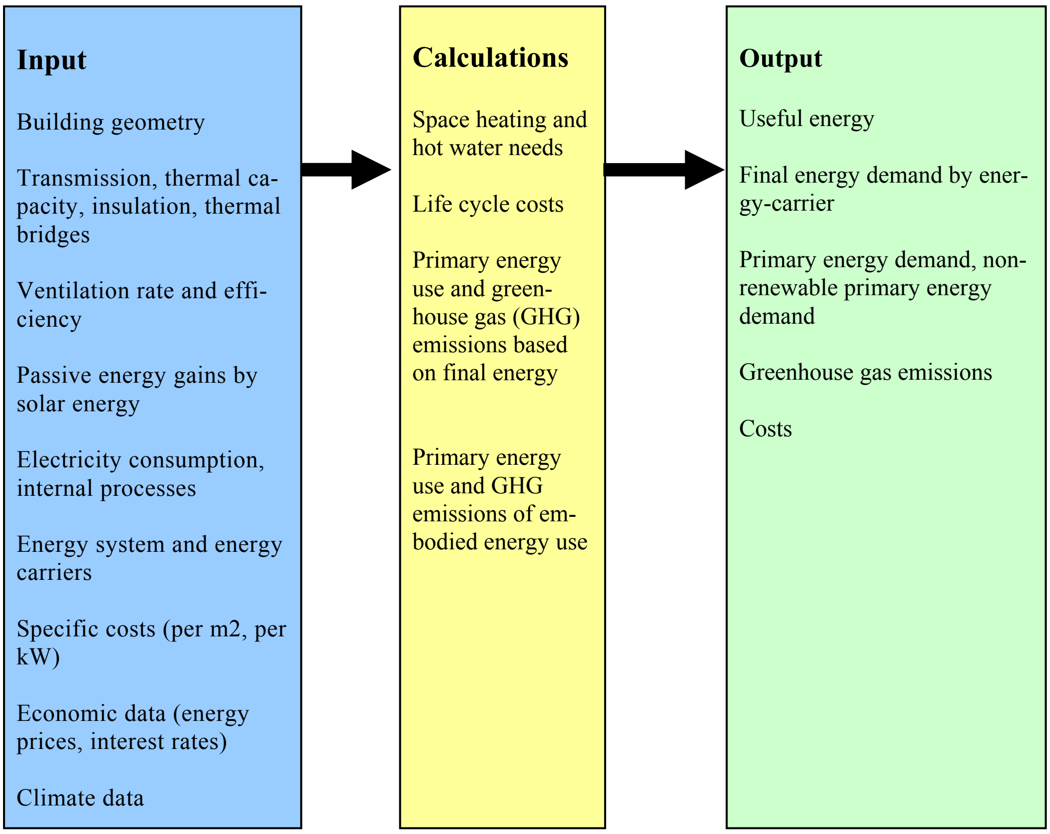


Figure 6. Sketch of the calculation procedure.

2.1 *Choice on the generic building typology and the climate*

From the point of view of yearly temperatures the territory of Romania can be divided into two regions. The division is following the zoning map of the standard SR 1907-1/97 (see Figure 2). Zones 1 and 2 are considered the warmer region, and Zones 3 the colder region. About 50% of the population lives in the two regions, but more panel buildings are in the warmer region due to the presence of Bucharest there. Climate profile of Bucharest was chosen for the calculation reported in this paper (see Table 1).

In SR 1907-1/97 the conventional design temperatures for Bucharest is given as θ_e=-15°C. In order to account for year by year fluctuations, representative yearly temperature values were chosen from the US Department of Energy, Energy Plus weather data for the multi-annual energy modelling[2]. The representative weather year is from a period of 30 years record to be suitable for long term heating/cooling load calculation. Solar radiation was estimated using the same weather files as data source, and applying the projections to the different surfaces with the software package Autodesk Ecotect Analysis.

Table 1. Assumed climate parameters.

Month	Monthly average temp[1] °C	Monthly average global rad. from East on vert. surface[3] MJ/m^2	Monthly average global rad. from West on vert. surface MJ/m^2	Monthly average global rad. from South on vert. surface MJ/m^2	Monthly average global rad. from North on vert. surface MJ/m^2	Heating degree days HDD's (interior temp. 22°C)
January	-1.7	66	57	141	42	735
February	0.8	115	90	231	51	599
March	5.0	184	151	278	79	527
April	11.4	209	184	242	114	318
May	16.5	275	219	250	137	171
June	20.4	308	237	233	144	48
July	22.7	303	263	252	131	-22
August	21.8	259	220	287	107	6
September	16.2	191	166	291	83	174
October	11.2	134	111	253	61	335
November	4.5	75	57	140	40	525
December	0.1	66	49	144	32	679

Based on the available building statistics data (INNSE, 2003), and a series of assumptions on the building typologies to which the total number of buildings are distributed, 5 generic concrete-panel buildings were distinguished. These correspond to the building periods of, before 1944, 1945-1970-1970-1989 and starting from 1990. While, these typologies are only generic, they are representative to certain typologies. The total quantities known from the INNSE date are respected during this division. In essence, the known total number of buildings, total number of apartments, total m^2 areas and total number of occupants from the INNSE date are respected. Only the division into categories is sometimes based on estimates, where no data exist. For example, the exact window to floor ratio is not reported for each building in the INNSE dataset. So a generic value, based on the prevailing building typologies and design standards used in the different periods was used for each of the five types. Similarly, it the orientations of each building are also not reported, so we presumed that equal areas of the windows are oriented to the four cardinal directions. These choices may be refined, since for example designs were prescribing advantageous orientation for main windows of the apartments, but we used them as initial guesses for the calculations.

The calculation in this paper is carried out for one generic 5 storey building built between 1970-1989 (see Table 2). CO_2 and cost savings are reported for this on generic building, but one can calculate the effect of the retrofit measures to the whole building stock knowing the number of buildings.

[2]http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=6_europe_wmo_region_6/country=ROU/cname=Romania

[3] Projected from the Energy Plus weather data to the N-S-E-W surfaces with Autodesk Ecotect

Table 2. Generic building typologies based on statistical properties of the building stock.

	Multi-family residential buildings "PCP Type" – 5 storeys			PCP – above 7 storeys (85% is 9,10 & 11)	PCP – 5 storeys
Years of built	built before 1944	built 1945-1970	built 1970-1989	built 1970-1989	1990-2012
Estimated number of buildings	455	5456	36957	10750	3813
Gross heated floor area (GHFA) [m^2]	1951	1951	2225	4450	2337
Façade area (excl. windows) [m^2]	1188	1555	1774	3426	1863
Roof area flat [m^2]	390	390	445	445	467
Total windows/glazing area [m^2] (Assumed to equally distribute to North/South/East/West directions)	134	253	288	552	303
Area of ceiling of cellar [m^2]	390	390	445	445	467
Typical indoor temperature [°C]	22	22	22	22	22
Average electricity consumption per year and m^2 (excluding heating, cooling, ventilation) [MJ/m^2]	65	65	65	65	65
U-value façade [$W/(m^2*K)$]	0.93	0.93	0.52	0.52	0.52
U-value roof [$W/(m^2*K)$]	0.99	0.99	0.83	0.83	0.83
U-value windows (Uw-value) [$W/(m^2*K)$]	2.56	2.56	2.33	2.33	2.33
g-value windows	0.7	0.7	0.7	0.7	0.7
U-value floor [$W/(m^2*K)$]	0.93	0.93	0.78	0.78	0.78
Energy need for hot water [kWh/m^2]	72	72	54	54	47

2.2 *Assumed emission and primary energy factors*

Emission and primary energy factors used refer to greenhouse gas emissions or primary energy use of energy carriers consumed including upstream emissions associated with the production, transport and delivery of these energy carriers. Emissions from CH_4 and N_2O are converted into CO_2 equivalents using the UNFCCC global warming potentials of 21 for CH_4 and 310 for N_2O. Country mixes for electricity are based on electricity sources as demanded by the market, and not the national production. The emission factors and primary energy factors used are presented in Table 3.

Table 3. Greenhouse gas emission factors and primary energy factors.

	Oil	Natural gas	Country mix for electricity	Country mix for district heating
GHG Emission factor [kg CO_2 eq/MJ]	0.083	0.066	0.194[4]	0.0833[5]
Primary non-renewable energy factor	1.1	1.12	2.78	1.51
Primary energy factor	1.1	1.12	2.96	1.56

2.3 *Energy prices and discount rates*

Energy prices were considered for the three main sources of energy in the panel blocks, district heating, natural gas and electricity (see Table 4). Other sources, like wood pellets and oil were disregarded, as they are less likely to be used for collective buildings for practical or safety reasons. Prices refer to assumed average prices over the next 20 years as used in calculation for life cycle costing (LCC).

[4] Technical annex to the SEAP template instructions document www.eumayors.eu/IMG/pdf/technical_annex_en.pdf. National Authority for Energy Regulations (www.anre.ro) gives for 2008 0.138kg CO_2/MJ (496g/kWh), http://www.anre.ro/activitati.php?id=323

[5] EH&P 2009, http://www.euroheat.org/

Table 4. Assumed prices for main energy sources in panel buildings.

Parameter	Oil	Natural gas	Wood pellets	Electricity	District heating
EUR/kWh	-	0.021[6]	-	0.07[7]	0.06[8]

Interest rates for the purpose of LCC calculations were estimated based on the date of the National Bank of Romania (BNR). Interest rate applied by credit institutions in Romanian Lei (RON) denominated loans was analysed in the period 01.2007-03.2011. BNR reports an annual percentage rate of charge (APRC) on loans to households for house purchases in the range of 8.63%-14.76%[9], with an average value of 11.2%. We took the APRC values into the LCC calculations, since these are covering all the hidden cost beside the interest rates practiced by the banks. Also, loans for house purchases were considered to better resemble the financing scenarios for house renovation than simple consumer loans (which would have a larger interest rate).

The development of inflation is also reported by BRD[10] and the same period 01.2007-03.2011 has been used for reference. The range of inflation was between 3.66%-9.04%, with an average value for the period of 6.18%.

The RON based costs were transformed in Euros and 3% has been chosen for yearly real interest rate (taking into account inflation) for residential loans. LCC calculations were carried out in Euros.

2.4 *Assumed renovation packages*

The impacts of seven packages of measures on the building envelope are calculated. The effects are distinguished for three different heating systems: a district heating system, a centralized gas heating system and a water/ground source heat pump. The reference case for the water source heat pump, without measures increasing the energy performance of the building, contains a district heating system as well. In the case of a district heating system, no investment costs are assumed to occur on the side of the building owner.

The different packages applied to the building envelope are:

- Ref: In the reference case, the mortar patching and the coating of the wall is restored, the wall is repainted, and the roof is refurbished with a 1-layer rubber bitumen membrane; all those measures do not improve the energy performance of the building.
- M1: The wall is insulated with 5 cm of EPS and a cement coating of 10 mm.
- M2: The wall is insulated with 10 cm of EPS and a cement coating of 10 mm.
- M3: Additionally to M2, the cellar ceiling is insulated with 5 cm of EPS.
- M4: Additionally to M3, the flat roof is insulated with 10 cm thermal insulation mineral wool, a timber structure and bitumen based water insulation.
- M5: Additionally to M4, windows are replaced with new windows with a plastic frame and a U-value for the entire window of 1.3
- M6: Additionally to M4, windows are replaced with new windows with a plastic frame and a U-value for the entire window of 1.0
- M7: Additionally to M4, windows are replaced with new windows with a plastic frame and a U-value for the entire window of 0.8

Table 5 describes the characteristics of the different renovation packages that are taken into account. Costs of energy renovation have been estimated by averaging two independent offers from suppliers active on the market (www.ursa.ro, www.steelcenter.ro). The energy need was calculated based on the input parameters for the different building envelope elements taking into account both the original U-values of the buildings and the changes due to the renovation.

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[6] E-On Romania (Accessed 01.10.2013: www.eon-energie-romania.ro/cps/rde/xchg/SID-570DA5ED-5EB66F92/eon-energie-romania/hs.xsl/3786.htm)

[7] E-On Romania (Accessed 01.10.2013: www.eon-energie-romania.ro/cps/rde/xchg/SID-570DA5ED-5EB66F92/eon-energie-romania/hs.xsl/3784.htm)

[8] Average value based on data from the National Authority for Public Utilities (www.ANRSC.ro)

[9] http://www.bnro.ro/StatisticsReportHTML.aspx?icid=801&table=580&column=7815

[10] http://www.bnro.ro/Inflation-Reports-3343.aspx

Table 5. Data for different packages of renovation measures M1 to M7.

Parameter	Unit	Reference / new heating system without further measures	M1	M2	M3	M4	M5	M6	M7
Wall - Costs	EUR/m^2 wall	12	22	24	24	24	24	24	24
Wall thickness of insulation material	cm	-	5	10	10	10	10	10	10
Wall - insulation material	W/mK	-	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Wall - lifetime of renovation measure	a	50	50	50	50	50	50	50	50
Window - Costs	EUR/m^2 window	-	-	-	-	-	156	213	267
Window - U-Value	W/m^2K	2.33	2.33	2.33	2.33	2.33	1.5	1	0.8
Window - g-value		0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.5
Window - lifetime of renovation measure	A	25	25	25	25	25	25	25	25
Roof - Costs	EUR/m^2 roof	16	16	16	16	75	75	75	75
Roof - thickness of insulation material	Cm	-	-	-	-	10	10	10	10
Roof - insulation material	W/mK	-	-	-	-	0.04	0.04	0.04	0.04
Roof - lifetime of renovation measure	A	50	50	50	50	50	50	50	50
Cellar ceiling - Costs	EUR/m^2 cellar ceiling	-	-	-	7	7	7	7	7
Cellar ceiling - thickness of insulation material	Cm	-	-	-	5	5	5	5	5
Cellar ceiling - insulation material	W/mK	-	-	-	0.04	0.04	0.04	0.04	0.04
Cellar ceiling - lifetime of renovation measure	A	-	-	-	50	50	50	50	50
Energy need for heating	MJ/m^2	366	309	284	262	224	164	142	134
Peak heating capacity required	kW	88	77	72	68	61	49	44	43

3 RESULTS

3.1 *Primary results of the modelling*

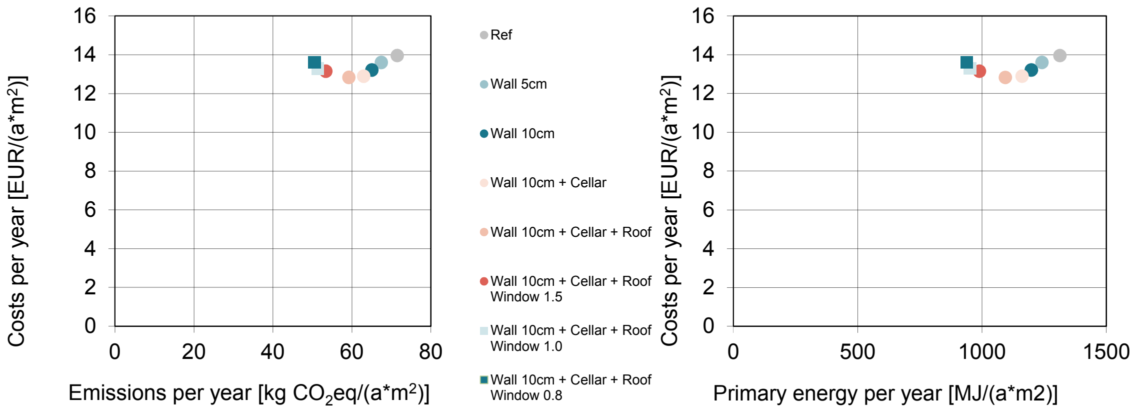
Primary results of the calculation are shown graphically in Figure 7, with the reference case shown as a grey dot based on the situation with a replacement of the district heating system, rehabilitation works on the wall and the roof, and no energetic improvements on the building envelope. All renovation packages investigated are cost effective compared to the reference case. The changes in the heating system dominate the effects on costs, greenhouse gas emissions and primary energy use.

The most cost efficient renovation packages include the installation of natural gas heating system or a water/ground source heat pump. Both have about similar costs, yet the water/ground source heat pump has significantly less CO_2 emissions. Primary energy use is for both similar.

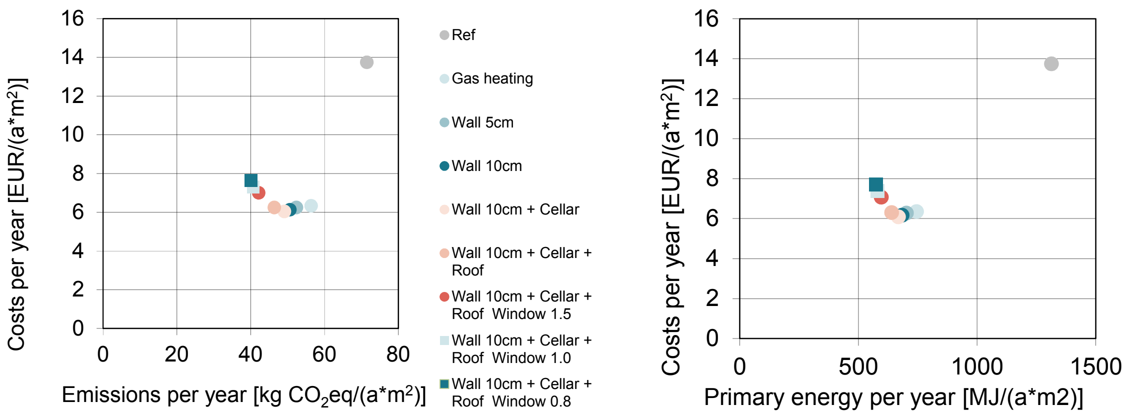
When installing a water source heat pump, the most cost efficient renovation package is M3, which includes the insulation of the wall with 10 cm of EPS and an insulation of the cellar ceiling with 5 cm EPS. For a gas heating system, the same renovation package is cost optimal. For a district heating system, however, significantly more renovation packages are cost effective, up to the package M6 which includes also the insulation of the roof, and the replacement of the windows with new windows with an U-value of 1.0.

The effects of different renovation packages on greenhouse gas emissions and primary energy use are comparable for all three heating systems.

District heating



Natural gas



Water source heat pump

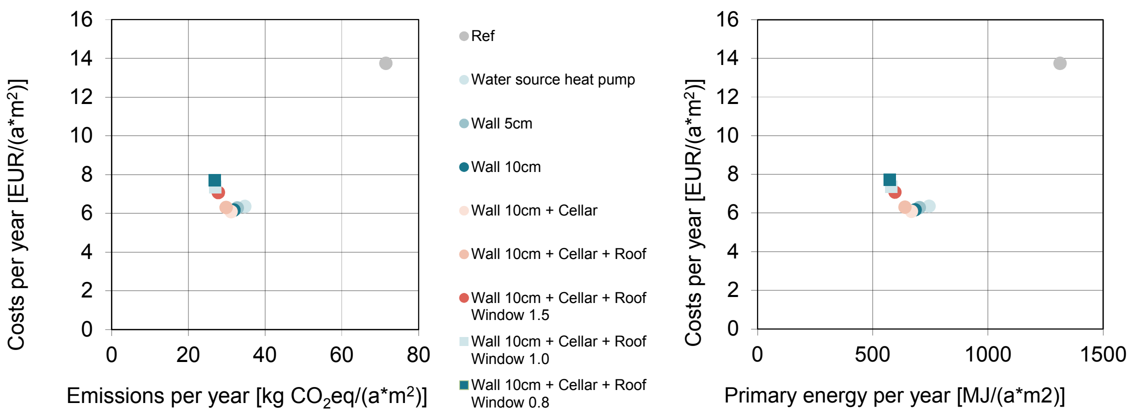


Figure 7. Impacts of different renovation packages on costs, greenhouse gas emissions and primary energy for a reference multi-family building.

3.2 *Independent verification of the results*

In order to verify the values obtained by this modelling we compared the results with the TABULA project web tool output (TABULA, 2013). This offers an independent verification for a limited number of results, since the TABULA tool is more restrictive in terms of renovation choices and the climatic conditions of Romania are not covered. Therefore, the comparisons are only estimative, in order to check the ranges of our results.

Two similar generic building configurations have been chosen for comparison. The CZ.N.MFH.04.Gen, multifamily house configurations from the Czech Republic, built in the period 1961-1980. The building has 459.17m^2 floor area. The second configuration is the PL.N.MFH.03.Gen configuration from Poland. These buildings are from 1967-1985 and have a floor area of 1584.4m^2. Both building are supplied with energy by central system, both for heating and hot water. Since the buildings are from former Eastern Bloc countries built in the heydays of the communist housing campaigns, it is likely that they have similar performance parameters as the ones studied in the INSPIRE project.

The total primary energy consumption reported for heating and hot water is 191.5kWh/(m^2×year) for the CZ building and 320kWh/(m^2×year) for the PL building. The CO_2 emissions are 60kg/(m^2×year) and 102.1kg/(m^2×year); and the cost are 11.5€/(m^2×year) and 18.8€/(m^2×year) for the un-refurbished configurations. With basic measures of refurbishment the primary energy use can be reduced to 131.9kWh/(m^2×year) and 151 kWh/(m^2×year), the CO_2 emissions to 40.2kg/(m^2×year) and 47.6kg/(m^2×year), and the energy costs to 8.1€/(m^2×yera) and 8.4€/(m^2×year), for the CZ and the PL buildings respectively.

Considering the climatic differences between the countries, the ranges of results are reasonably covering the values obtained in the INSPIRE study, hence providing an independent confirmation on the validity of the modelling.

3.3 *Discussion and conclusions*

When comparing a natural gas heating system and a water source heat pump system, no significant differences are found regarding the cost effectiveness of different renovation measures on the building envelope. However, such differences exist when comparing district heating and natural gas or water source heat pump. The reason is that for a district heating system, there are no energy installation costs to the building user; instead, heating costs are just proportional to the energy need; this may partly explain why in the case of a district heating system, investments in saving energy are more cost effective than for other heating systems. This is based on the assumption that the fixed amount that needs to be paid per month, is not high compared to the costs for the actual energy consumed; if this was the case, the cost effectiveness of measures on the building envelope would decrease for district heating systems.

The energetic renovation of the wall and the insulation of the cellar ceiling are cost effective measures for all heating systems. Windows did not feature as cost effective renovation measures; however, windows have other advantages than saving energy. Despite being not a cost effective measure in terms of saved energy use vs. investment costs, it may nevertheless be an attractive option to install windows because of co-benefits such as noise reduction, improved indoor climate or others.

Water source heat pumps are attractive both in terms of cost effectiveness and in terms of CO_2 reduction; however, there is still little experience with such heating systems in Romania, and it may therefore be difficult to find installers with the necessary experience to ensure proper functioning of such systems.

ACKNOWLEDGEMENT

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Overview of retrofit practice in Finland

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ABSTRACT: The purpose of the article is to provide an overview of Finnish renovation experience, particularly in terms of energy efficiency of the buildings. First paragraphs describe the development of energy regulations and gives statistics on building stock and home ownership, then the management and maintenance of the buildings is clarified. Also the practical energy saving measures used in Finland is presented and their potential is estimated. Finally, a brief overview of the renovation needs, renovation market and available products is made.

1 FINLAND IN STATISTICS

1.1 *Population*

Finnish population is 5.4 million. Population growth is concentrated in larger cities, particularly in the Helsinki Metropolitan Area (see Figure 1). Only ten cities of Finland have more than 50,000 residents and even the largest cities are not densely built up by international standards. Todays any smaller settlements and rural areas are suffering from depopulation, due to migration to the growing centers.

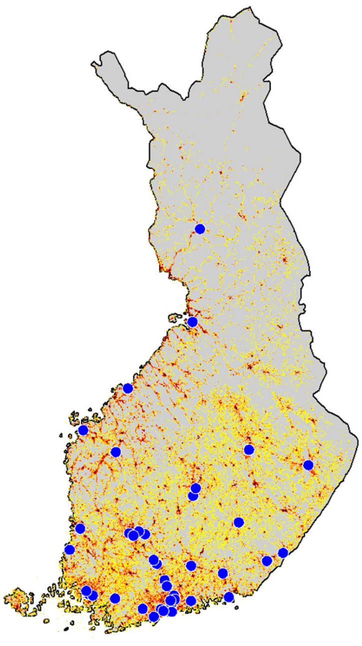

Figure 1. Population centers, where at least 30,000 inhabitants live inside a 10km radius (www.kunnat.net).

1.2 *Housing*

There are about 1.5 million buildings in Finland, from which about half are residential houses. About 50% of the people live in single-family houses and 35% in blocks of flats (see Figure 2). About 60% of the people live in owner-occupied flats and 30% in rented flats.

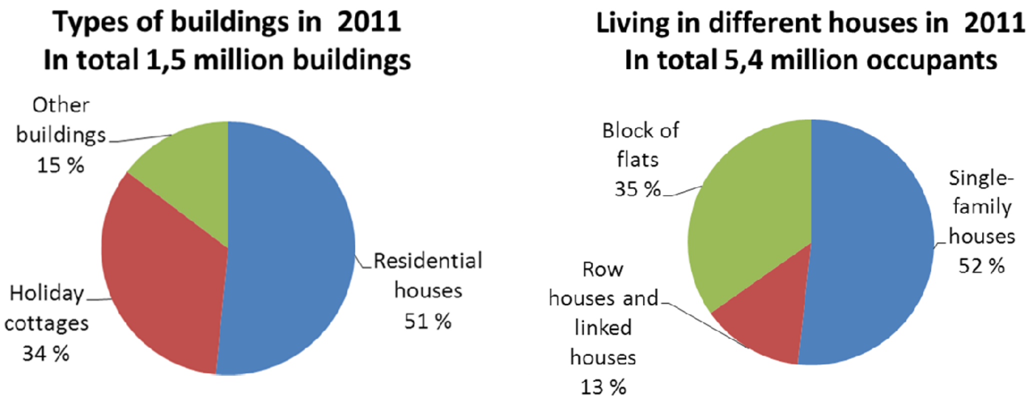

Figure 2. Types of buildings and number of people living in different houses (data: www.stat.fi).

Half of the rented apartments in Finland are privately owned, and other half have been built with state support (by ARAVA loans). ARAVA buildings are owned by municipal housing companies (60%), non-profit national corporations (15%), corporations for specific groups (20%), and by banks and insurance companies (5%).

1.3 *Ownership of flats*

Just over half of owner-occupied flats are one-family houses; other flats are owned and operated under housing companies. A housing company consists of one or more buildings and it also owns, or has in long term rental, the land surrounding the buildings (e.g. own parking spaces, playgrounds and green areas). The occupants own shares of the housing company, which entitle the management of a certain flat. Common areas are managed by the housing company. In Finland there are 80,000 housing companies comprising in all 600,000 flats.

Housing company is a special form of company, which is regulated by the Housing Companies Act, which defines the rights, duties and responsibilities between the company and its shareholders. Housing company arrangement will ensure that the renovation of the entire property maintenance is managed and financed, and that the common areas, such as stairways, elevators, parking places and other outdoor areas are maintained properly. Residents pay monthly fees to the housing company to cover common maintenance expenses, heating costs and the water charges.

The housing company has a governing body (at least 2–3 elected residents), which is responsible for the management of the company. Policies of the housing companies are defined by residents at open meetings.

According to Finnish legal terms, in the housing company arrangement, the transfer of a home owned by a housing company is seen as the sale of shares, not as a real estate transaction. However, the perception of the occupant is very strongly that he/she owns the apartment. So much so, that “owner-occupied” is regularly used in everyday life for this type of ownership.

1.4 *Age of the building stock*

The average age of Finnish building stock is 30–35 years. This is due to strong growth of construction in 1960 and 1970's. The renovations in apartment houses are still increasing, because most of the buildings have not yet reached the age of 50 years (see Figure 3).

Before repairs in buildings the performance, comfort and energy efficiency criteria are evaluated, so that the repairs correspond to today’s requirements for buildings. Often elevators are added to old buildings, because elderly people are increasingly living at home and families with babies or disable persons require them. Therefore, by attracting a larger client base, elevators also increase the value of the apartments. Small part of the housing companies finance the renovation costs by additional rooms, for example the attic or basement spaces can be taken for residential use.

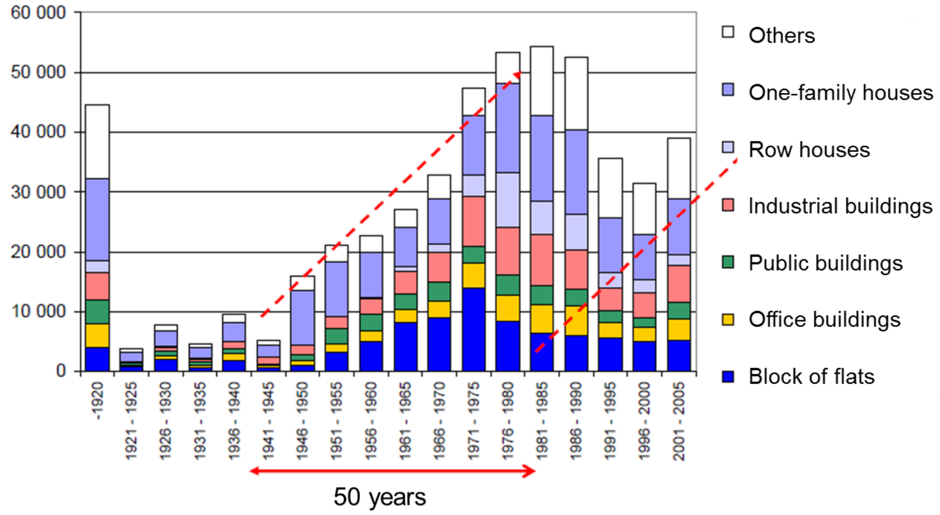

Figure 3. Finnish building stock by 5 year periods (vtt.fi).

2 REAL ESTATE MANAGEMENT

2.1 *Management*

In practice all bigger housing companies have a house manager, who takes care of daily routines. Normally the house manager is taken from a house management agency. In Finland there are in all about 800 agencies, employing 5,000 workers and serving 50,000 housing companies. Most of the companies have 1–4 employees; the largest having hundreds of workers and serving thousands of housing companies.

House managers have usually a professional examination and the house management agencies have an authorized licensing system, which is managed by the building managers' authorization association.

2.2 *Duties of house manager*

The work of a house manager covers a variety of responsibilities. He is taking care of the general management of the housing company, relating for example general meetings, safety and insurance issues, economic management, monitoring of building condition, survey of repair and renovation needs, preparing of the work schedules and contracts for repairs and renovations, maintenance of equipment (heating equipment, water and sewage pipes, air-conditioning and refrigeration equipment, elevators, electrical equipment), taking care of sanitation (waste disposal, removal of snow, sanding for preventing slippery, cleaning of common rooms) and taking care of maintenance of courtyard area (lawns and plants, children's playgrounds, car parking areas, hedges).

2.3 *Maintenance manual of buildings*

Building maintenance manual is required by the Land Use and Building Act. The manual has to be done in housing companies for all residential and commercial facilities that are purposed at permanent living or working. The purpose of the manual is to manage and maintain the necessary information in real estate management.

The manual covers the basic information on the building, already carried out inspections, maintenance and repairs, information on energy and the annual water consumption, general inspection procedures and device-specific maintenance instructions. The target is also to plan and monitor the maintenance, e.g. by including a maintenance program (usually with a 5 years planning horizon) and maintenance cycles of building components and devices. The manual displays also the target values for indoor climate conditions and indicative values for energy and water consumption. In addition it presents property management goals and target levels for property quality.

3 LAWS AND REGULATIONS

3.1 *Supervision and regulatory control*

Ministry of the Environment is responsible on regulatory control of housing administration. The ministry works to improve the quality of housing construction and residential environment through laws, regulations and guidelines. Municipal building authorities are responsible for drafting and approving the land use and also for construction supervision. The municipalities have a building inspector's office, which inspects all building actions which need building permits.

Requirements are set for strength, fire safety, hygiene, health, environmental impacts, user safety, noise prevention, energy use, insulation and durability. The requirements are based on The Land Use and Building Act, which covers both land use planning and construction planning and which targets to develop and maintain high quality living environments. The act aims to promote sustainable development, to ensure open land use planning and processes, and to ensure that a wide range of planning expertise is available. The act also implements the EU directives, for example concerning energy efficiency in renovation and alteration of the buildings.

3.2 *Development of energy regulations*

Development of the energy regulations for new buildings has been very fast. In 2003, 2007 and 2010 new regulations were issued for the energy performance of new buildings (see Table 1). The latest 2012 regulations base on the total energy need (E number) and are about 20% more demanding than 2010 regulations.

Table 1. Development of energy requirements 1976–2010

	1976	1978	1985	2003	2007	2010
U-values						
Wall	0.4	0.29	0.28	0.25	0.24	0.17
Ceiling	0.35	0.23	0.22	0.16	0.15	0.09
Floor	0.40	0.40	0.36	0.25	0.24	0.16
Window	2.1	2.1	2.1	1.4	1.4	1.0
Door	0.7	0.7	0.7	1.4	1.4	1.0
Air tightness, n_{50}	–	–	–	–	4	2
Yearly heat recovery from exhaust air	–	–	–	30%	30%	40%

3.3 *Energy regulations for new buildings from 2012*

New building energy regulations are based on the total energy analysis (E- number). The regulations promote renewable energy; they take into account the primary energy consumption and source of heating in perspective the efficiency of energy production. The change encourages the use of district heating and renewable energy. The energy coefficient for fossil fuels is 1, for electric 1.7, for district heating 0.7, for district cooling 0.4 and for renewable fuels 0.5. E-number is the total energy need multiplied by the energy coefficient.

The limit value of E is 200 kWh/m^2 for small (max 120 m^2) single-family houses, 150 kWh/m^2 for row houses, linked houses and large single family houses and 130 kWh/m^2 for blocks of flats. The regulations are also applied to larger summer residences which are built for winter use.

The renewal of building regulations is a control tool for saving energy and to reduce emissions. The new calculation method allows for a gradual transition to nearly zero-energy building by 2021. Tighter rules result in an average of 20% improvement in energy efficiency compared to earlier 2010 requirements. The effect on investment costs is small compared to the costs resulted from 2010 change in regulations.

3.4 *Energy regulations for renovation from 2013*

The new 2012 Land Use and Building Act takes into account the EU Directive for Energy Performance of existing buildings. The target is to reduce energy consumption of the existing building stock by about 25% and CO_2 emissions by about 45% by 2050. Therefore also new energy regulations for renovation were given and they will come into force in September 2013.

Energy efficiency study will be required if the repair actions provide permission from building authorities. Building permission is usually required for example in the case of a heavy facade repair, in pipeline renovation, in installation and expansion of ventilation or in changing the use of building.

The effects of energy savings throughout the building stock have been calculated to be about 6% by 2020. The savings arise from the reduction of heat losses, more efficient heat recovery equipment, and more efficient use of electricity and renewable energy sources, such as increasing the use of geothermal energy.

Energy efficiency should be improved when it is technically, functionally and economically feasible. Cost-effective solutions are those which have payback period less than the design lifetime (e.g. facades 40–50 year, ventilation machines 20 year).

There are three options for improving energy efficiency. First option is to improve the thermal insulation of building elements and efficiency of technical systems so that they fulfill the given requirements. U-value (overall coefficient of heat transfer) of walls and roofs shall be decreased at least by 50%, or the walls, roofs, windows and floors shall fulfill the requirements for new buildings. In addition the requirements for recovery from exhaust air shall fulfill the requirements of new buildings. Second option is to limit E-number. The limit for E value is 180 kWh/m^2 for single-family houses, row houses and linked houses, and 130 kWh/m^2 for blocks of flats. Third option is to decrease the E number of the building. The reductions shall be 20% in the case of single-family houses, row houses, linked houses, and 15% in the case of blocks of flats.

4 ENERGY SAVING MEASURES

4.1 *Finnish climate*

Winters of southern Finland (daily temperature below 0 °C) last usually three months (see Figure 4) and typically the snow covers the land from about late November to mid-April.

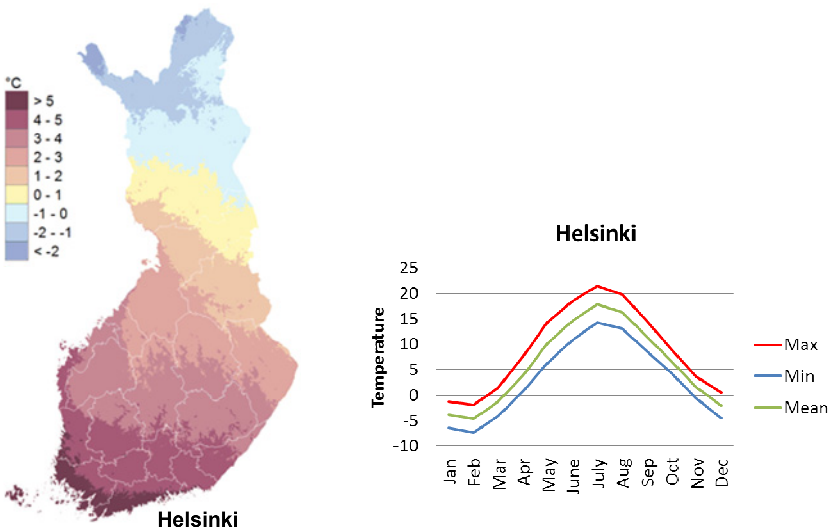

Figure 4. Annual average temperature in Finland and average monthly temperature in Helsinki (ilmasto-opas.fi).

The coldest days are in January–February and the warmest days are in July. Yearly temperatures can vary from -30 to +30°C. The winters of the northern part last usually 6–7 months and the snow covers the land from about mid-October to early May. Winters in the north are very long and summers are quite short, only two or three months. The temperatures can vary from -40 to +30°C.

4.2 *Heating energy*

The clearest change in Finland during last two decades is that oil heating is not any more used in new single-family houses and that the share of ground source heat pumps has grown considerably (see Figure 5). Also the popularity of electric heating in new single-family houses is decreasing. The 2012 new energy regulations will very possibly reduce substantially the amount of electric heating in new houses and also in renovation. In the future, electric heating in single-family houses will be replaced by different heat pumps and hybrid solutions. The share use of wood heating has remained roughly at the same level for the past ten years.

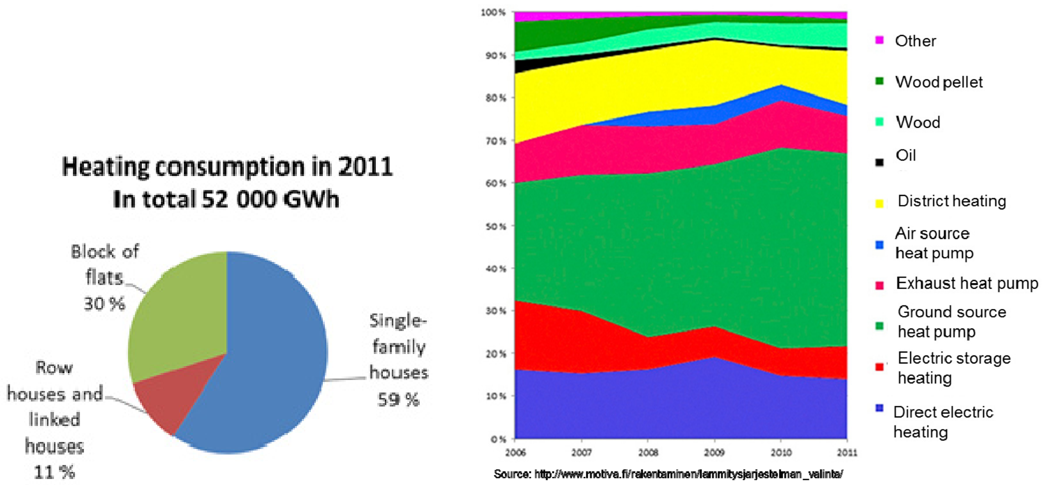

Figure 5. Heating consumption (data: www.stat.fi) in residential buildings and source of heating energy (motiva.fi) in new single-family houses.

4.3 *Energy saving potential*

Most of the heat energy in 1960–1970's built prefabricated blocks escapes through forced air exhaust (36%), wastewater (22%), exterior walls (17%) and windows (15%) (Figure 6).

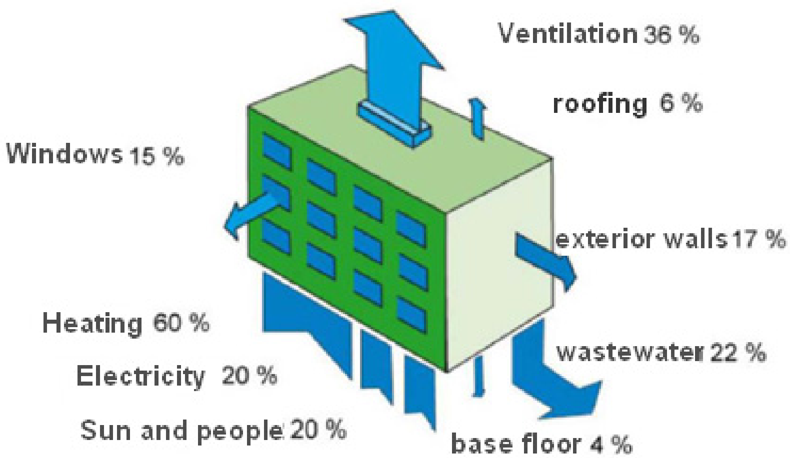

Figure 6. Average energy flows in 1960–1970's built, prefabricated apartment buildings (Lindstedt & Junnila, 2009).

Experience has shown that it is both technically and economically possible to renovate also quite old buildings even to passive house performance (see Table 2). Important is to note that improving indoor condition to today's requirements only by mechanical ventilation without any heat recovery may significantly increase the energy consumption.

Table 2. The estimated heating energy saving potentials (vtt.fi)

	Shear of energy consumption in an old house	Energy saving potential
Improving tightness and insulation envelope	30%	-10…-30%
Renewing windows	26%	-15…30%
Improving indoor condition by mechanical ventilation	37%	+5…+25%
Renewing HVAC technologies		-30…-40%
In total	100%	-60…-80%

4.4 *Heat recovery*

The loss resulting from ventilation is more than one third of the whole heating loss. Ventilation and heating energy consumption can be reduced by more than half by recovering heat from exhaust air and tightening accessible structures. Heat recovery became mandatory in new buildings already in 2003. The new renovation energy regulations in 2013 require that heat recovery shall be at least 45% of the exhaust air heat energy, when the ventilation system is changed.

4.5 *Apartment-specific water meters*

The energy losses resulting from waste water can be reduced by reducing the use of hot water. One person uses about 150 liters of water per day. Reduction of 20 percent in water consumption reduces water heating energy by about 10% and need for the building's overall energy is reduced by 5%. Apartment-specific water meters in new buildings became mandatory in Finland in 2011. In 2013 they will come mandatory also for existing buildings in context of large pipe renovations. The estimated reduction in water consumption is in average about 10% which reduces energy consumption about 3%.

4.6 *Energy-saving windows*

Energy efficient windows are justified whenever the windows have to be replaced. Old 1960-1970's windows with double-glazing have U-value of 2.0–2.7W/m^{2}K. Existing, new energy efficient windows with quadruple glazing have U-value of 0.7–1.0W/m^{2}K.

The U-value alone does not tell all about the window's energy efficiency. Therefore reference E value (unit kWh/m^{2}a) was developed for the energy rating of the windows. It is based on the window’s U-value, G-value and air tightness. G-value indicates how well the window exploits solar radiation energy.

4.7 *Improved thermal insulation*

In 1950–1975 the heat insulation requirements were significantly less than today. Therefore in planning the facade and window repairs, the chances to improve the thermal insulation should always to be considered. Concrete sandwich element was the most common exterior wall solution in 1960–1970's buildings. The facade element were typically built-up by an inner concrete panel of 80mm or 150mm, an insulating mineral wool layer of 80–100mm and an outer concrete panel of 60–80mm. The U-value of the structure was about 0.4–0.5W/m^{2}K. Today in in new low-energy houses, U-value is less than 0.15W/m^{2}K and insulation thickness is 275–300 mm.

Although the heat dissipation through building's façade is significantly lower in a new building than in an old building, additional thermal insulation based only on the energy savings is usually not economically viable. The best benefit of energy repairs is obtained when extra insulation is connected to other repair actions, such as window replacement or repair of exterior wall surface.

4.8 *Air tightness*

Air tightness is a very important topic. Poor airtightness in apartments causes uncomfortable air circulation, which increases the need of heating. Good air tightness and well-controlled ventilation together with heat recovery systems provide the greatest benefits. The need for heat in the old residential buildings is 10–30% higher than today in the new airtight buildings.

4.9 *Adjustment of ventilation*

Ventilation adjustment brings the operation of the system at the optimal level. Basic adjustment should be carried out whenever the circumstances of ventilation (such as air tightness) are changed. The energy consumption can be reduced by shortening the run times of the fan, by air flow control and by fan maintenance. Inappropriate settings in control and monitoring devices and incorrect response of control circuit will increase energy consumption.

4.10 *Adjustment of heating*

Proper adjustment of heating network ensures that all the apartments have right room temperature. Removal of over and under temperatures improves comfort and saves energy. It is estimated that approximately in 75% of Finland's housing stock the heating is inadequately adjusted. Temperatures in apartments can vary 1–3°C. One degree drop in temperature reduces costs by about 5%. Therefore by basic adjustment can be achieved 10–15% savings in building energy consumption.

Heating network control requires that all balancing valves work properly, only after that it is possible to adjust the water streams. Usually all or at least most of the radiator valves are renewed in context of heating adjustment. Heating network control should be done whenever the building heat demand changes. It may change, for example, when the use of rooms is changed, when extra insulation is added or when windows are replaced.

5 RENOVATION NEEDS AND RENOVATION MARKET

5.1 *Renovation needs*

Most of the renovations are made to improve the comfort and functionality of the dwelling, or to reduce the overall wear and tear (see Figure 7). Most of the renovations are small repairs. However, the total market material and workmanship used in renovation is large.

The main items in housing companies are repairing of water and sewer systems, bathrooms, windows and exterior doors, facades, balconies and heating systems (see Figure 8). Lesser items are repaired heating systems, public spaces, ventilation systems, electrical and computer systems, foundations and elevators. More and more the reason for the renovation is higher energy costs, improvement of the building's heat economy or replacement of the heating system.

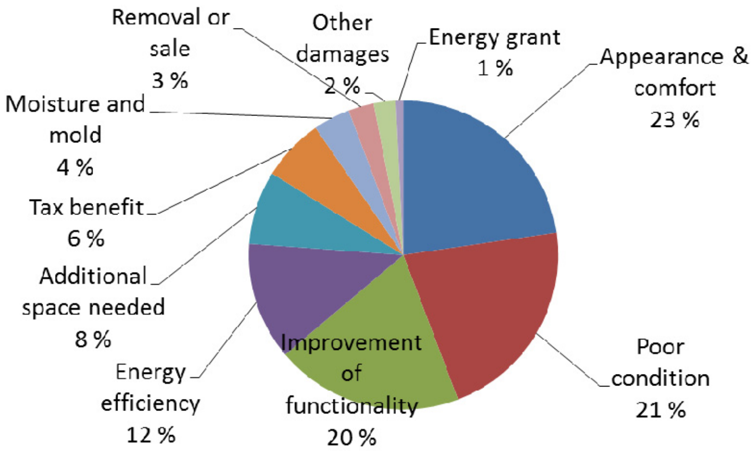

Figure 7. Residents' reasons for renovation (data: Vainio, 2011).

The most significant dilatory factor to start of the repair is that the people have to live in the apartments during the renovation or they have to make special arrangements. Project start-up is also delayed because of the lack of shareholders ability to pay the costs and because of the decision-making problems in the housing company.

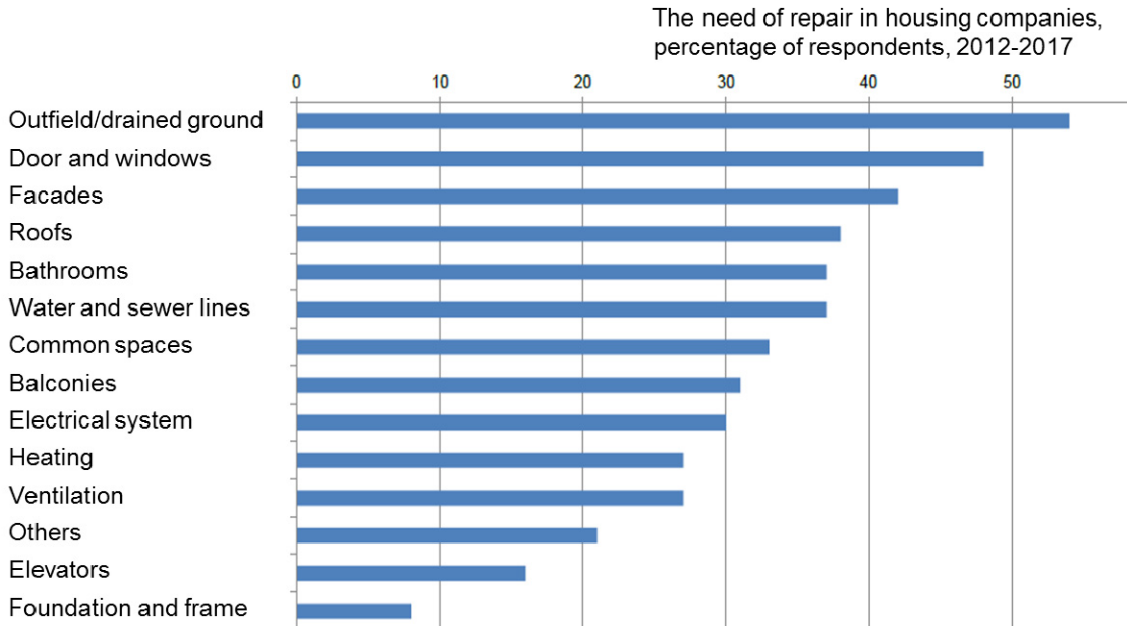

Figure 8. Reasons for renovation in housing companies, based on renovation barometer 2012 (Kiinteistöliitto.fi).

5.2 *Renovation market*

The focus in construction industry is changing from new construction to renovation. Today the share of renovation is about half of the total value of building construction (see Figure 9). More than half of the renovations are in residential buildings. The repairs in housing companies are still increasing in Finland because more and more buildings are reaching the age of renovation. Also low interest rates will support large renovations.

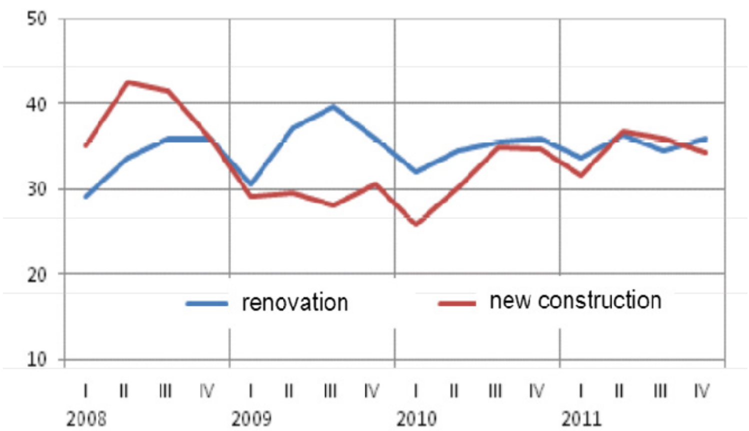

Figure 9. Working hours in construction (stat.fi), million hours.

Repair costs of housing companies were in 2011 about 1.3 billion euros (see Figure 10), which is about 75% of the renovation costs of all residential buildings. More than half of the renovation costs are focused on building HVAC systems, such as repairs of plumbing renovations. About a quarter of all the renovation costs are focused on non-structural repairs of buildings, such as the exterior walls, roofs, windows, outside doors and balconies. Share of renovation in flats and inside structures is less than 10% of all renovation cost. Also the share of 6% of foundation structures is notable.

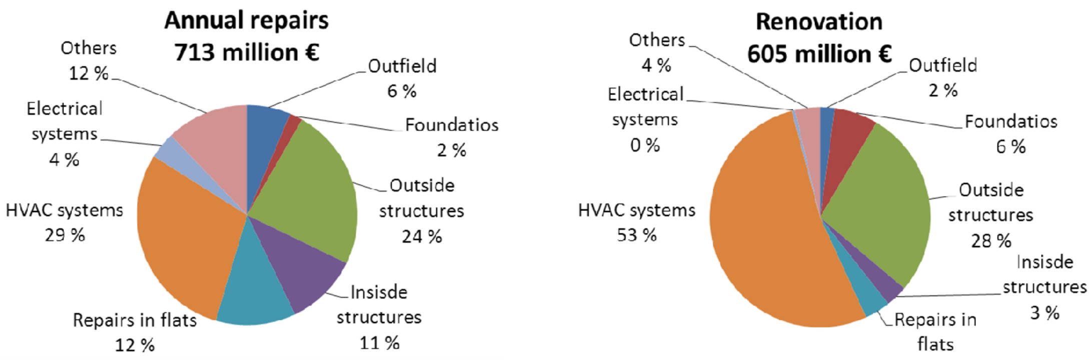

Figure 10. Costs of annual repairs and renovation in housing companies (data: stat.fi).

5.3 *Prefabricated products for renovation*

Prefabricated building components are widely used in Finland, because they reduce the amount of on-site work. This reduces the working time and disturbance of residents. Prefabricated element solutions are often used for encapsulation new pipelines and for construction of partition walls or raised floors (see Figure 11). New bathroom and balcony modules are also used. For facade renovations there are panel systems and for balcony renovations there are glazing systems. In addition there are modular constructions for inside or outside elevators or staircases in buildings where the lift does not exist, and block attic modules for buildings where an additional top floor is wanted. Facade systems, balcony modules and lift modules fit best to applications where the architectural look of the building is not an obstacle to the change.

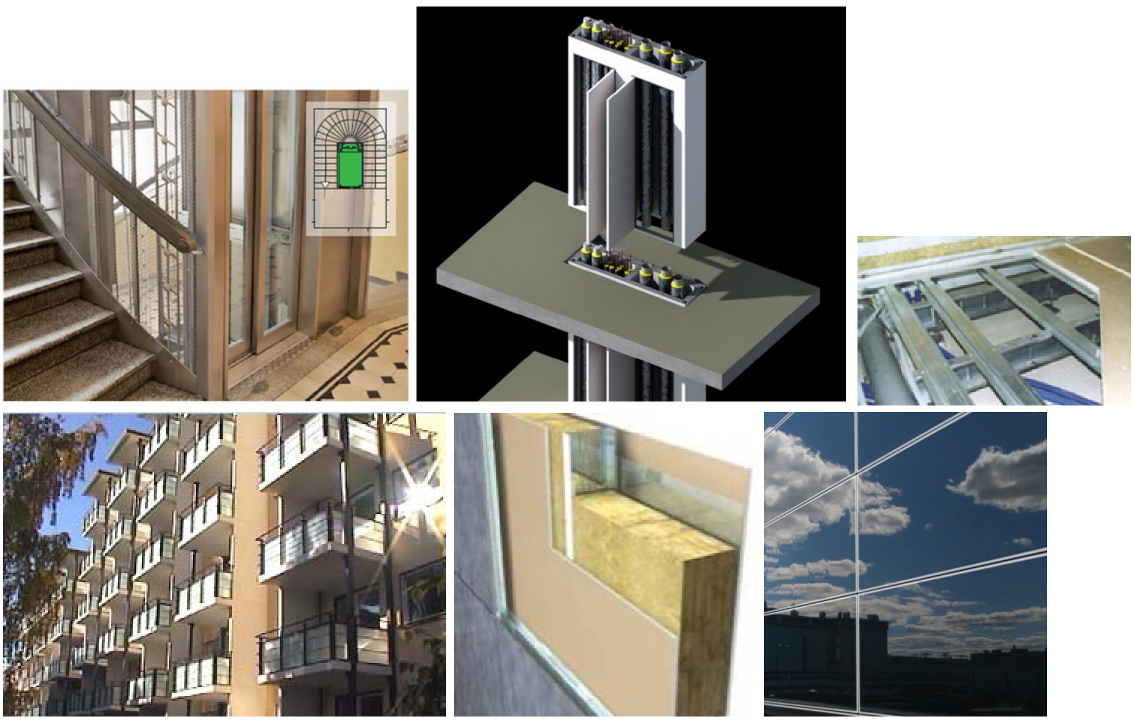

Figure 11. Some examples of prefabricated products for renovation (kone.com, harmiton.com, aulislundell.fi, cm-rakentajat.com, ruukki.com).

6 CONCLUSIONS

The review of energy regulations shows that the requirements for new buildings have tightened many times during last ten years, but first energy regulations for renovation are just coming into force. The latest energy regulations are based mostly on EU targets and directives, which are precisely implemented in Finland. The fast development of requirements has caused many challenges for builders and property owners.

The repairs of apartment houses can be relatively easily implemented in Finland. The collective ownership model, in which the owners of the apartments are shareholders of the housing company, helps the decision-making and financing of the renovations. The housing companies can have own savings and get own bank credits and state subsidies, since they can present the properties as collateral. Another important factor is that building maintenance manual is required in housing companies and therefore all repairs are planned in advance and residents have time to adapt the actions.

In last few years the value of renovation market has been almost half of the total value of building sector. Because most of the buildings have not yet reached the age of 50 years, the value of renovations is still increasing. The most important impact in terms of energy savings in renovations will depend on how well the new 2013 energy regulations for renovation will be implemented.

ACKNOWLEDGEMENT

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Are we too capitalists for a comfortable life? Business models for future and existing flat building administration

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ABSTRACT: After the changes in Romania in 1989 most flats in existing, state owned, buildings were sold to the occupants. This was a sort of "getting back" for those people who lost their private property, but another reason for this decision was the lacking of centralized management capacity of the state administration. Looking back and analyzing how the private property was defined at that time, we can say with no doubts: it was made in a wrong way, and as time passed this became a disaster. Tremendous progress was made in the last twenty years in every area of life, but the existing stock of flat buildings still regresses from all points of view. On one hand the reason can be found in the way private property division was done, defining individual property at the level of each apartment in a building unit. On the other hand the so called "owner administration" model cannot work efficiently due to the lack of knowledge, division, overemphasizing individual interest etc. This paper makes an up-to-date analysis of present Romanian situation and proposes business models for existing and new flat building administration in order to improve the comfort and life quality of the owners.

1 INTRODUCTION

The idea of Liverpool city engineer John Brodie, to build houses from prefabricated concrete panels, has come a long way from its beginnings in 1906. Interestingly, prefabricated concrete panel buildings gained popularity not in the UK, but in East European countries, the former Soviet Union and Nordic countries. The technology has been picked-up later in many parts of the world, where fast development created need of affordable housing at mass scale. The rise of the concrete panel buildings in East Europe has been fuelled by post war housing shortage, and the forced industrialization programs in the 1950s.

1.1 *Historical overview*

The mass application of prefabricated concrete panel buildings in East Europe can be traced back to Khrushchev's 4-5 floor panel buildings without balconies and elevators, built in the 1950's in the Soviet Union or even earlier, to the ideas of "*flat buildings for workers*" in the Soviet Union of the 1920s-1930s, aimed for the population that came from the countryside in order to work in factories in the big cities. The political administration adopted quickly the prefabricated panel buildings system as it proved to be quick and cheap to erect. When erecting flat buildings the emphasis was not on comfort or on the building's energetic consumption but rather on the construction time and price. The early version, built before '60s were named "kommunalki[1]" and the tenants had to share the kitchen and bathroom. Later, the legendary Khrushchevka's, often joked about in popular culture, were also not designed with comfort to occupants in focus. Luckily, these typologies became unpopular very early and the technology has not been exported abroad.

In other East European countries the large panel-house building programs started somewhat later: 1965 Hungary (Kecskés, 2006), 1956-58 in Czechoslovakia, and 1958-1960 in Romania. By the end of the 1970's prefabricated concrete panel buildings became the dominant form of construction.

In Romania, most of the currently inhabited 57.431 prefabricated panel buildings have been built between 1960 and 1990. The overwhelming majority, 41.540 buildings have 5 floors. A second group of important typologies are the 9, 10 and 11 floors totaling 9180 buildings. All other configurations total only 7.440 units, 300 taller than 11 floors, 4.920 buildings lower than 5 floors and 2.220 buildings having 6, 7 or 8 floors (see Fig. 1). Practically the two most widespread configurations in Romania are the 5 floors and the tower (9, 10, 11 floors) typologies, with very few other configurations.

One important milestone in the panel building program in Romania has been the Vrancea earthquake in 1977, which determined the authorities to implement several changes in the building configurations in order to increase earthquake safety. E.g. the 11 stories tower configuration, most commonly used in the 1970's, has been replaced by the 9-storey configuration for the 1980's (Demeter, 2006). But the 5-storey configurations have been affected only at the level of detailing connections between panels, and the quality requirement for materials.

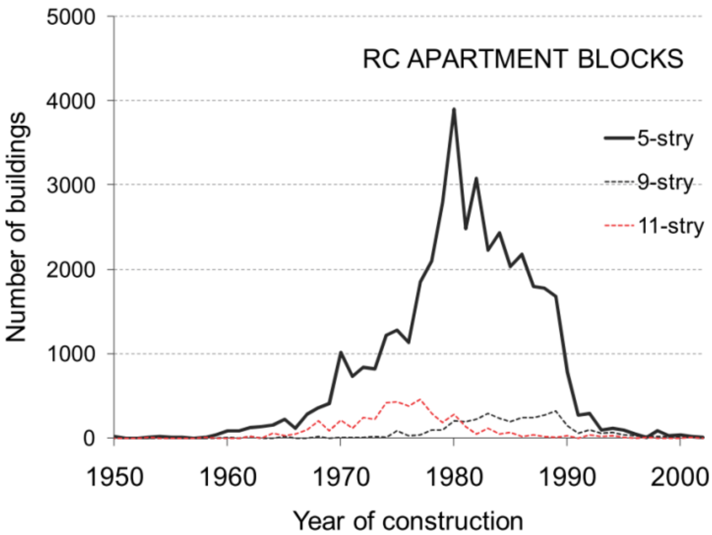

Figure 1. Number of buildings each year (Demeter, 2011).

1.2 *Historical review of panel buildings in Romania and Central and Eastern Europe*

In Romania, as in the Eastern and Central Europe the erection of panel buildings started to grow once the communist regime gained power. As the key objective was to strengthen the economy, the industry developed with a high annual rate and therefore more and more man power was needed in the urban areas. The need of new dwellings increased significantly and a massive construction program started using state funding. Housing developments were promoted as the grand "achievements" of Communist central planning. Charming urban neighborhoods were bulldozed to make room for the rectangular, pre-fabricated concrete panel buildings that would hold countless more people - family over family, box over box (see Fig. 2).

The main technical disadvantage of the buildings erected before the '60s is that there were no seismic design codes. In 1963 the first seismic design codes were adopted. Therefore panel

[1] http://kommunalka.colgate.edu/cfm/photos.cfm

buildings built after ‘60s had some improvements regarding the structural design and the functionality of the apartments as well (i.e. little kitchens and bathrooms for each apartment). The panel buildings built after 1964 have the concrete class B200 (C12/15) whereas the ones build before only B150. The seismic design codes in Romania were reviewed in 1971 and again immediately after the earthquake in 1977. Since 1971 it became compulsory to use the concrete class B300 (C18/22.5).

During 1965-1989, 4 million dwellings were built, more than 150.000 dwellings each year, according to the National Institute of Statistics. The reports had as a “measurement unit” of a conventional apartment, with a living surface of 29 square meter, therefore the larger apartments might have been counted as more dwellings. After 1989, 700.000 apartments were built, around 35.000 apartments per year. The great difference in the number of new buildings can be partly explained by the market needs: 7.7 million people were born in 1970-1989 and only 4.2 million in 1989-2009. Today the tendency is not to build new buildings but to retrofit the old ones: thermal insulation, plumbing changing, and structural consolidation - issues that depend strictly on the homeowners.

Figure 2. Typical apartment block area.

1.3 *Current housing situation*

Comfortable housing in a safe environment is a fundamental necessity which is still a challenge for many European families. In 2009, 41.8% of the European population lived in flats, 34.4% in detached houses and 23.0% in semi-detached houses[2]. Proportions are similar in Romania. According to the Census of Population and Housing of 2011, the country had 19.0 million inhabitants. They were living in 8.5 million dwellings with 22.7 million rooms, having a total living area of 398 million m^2. The average dwelling has 2.7 rooms and 2.66 inhabitants. 52.8% of the population is urban population – most of the flat buildings are concentrated in the urban areas. The number of flat buildings was 84.000 (of which 57.431 made of concrete panels), with 2.5 million apartments.

The 387 dwellings for 1000 inhabitants are slightly less than the European average – and the average living space of 14.98m^2/person suggests problems with overcrowding. This conclusion is also reported by Rybkowska & Schneider (2011), concluding that over 50% of the population lives in overcrowded conditions (see Fig. 3(a)).

On the other hand, home ownership rate is very high (see Fig. 3(b)), and buying with credit is not a common or desired choice. Only the young generation is open to enter credit schemes and, following the lessons of the economic crisis of 2008-2009, reluctance is strengthened.

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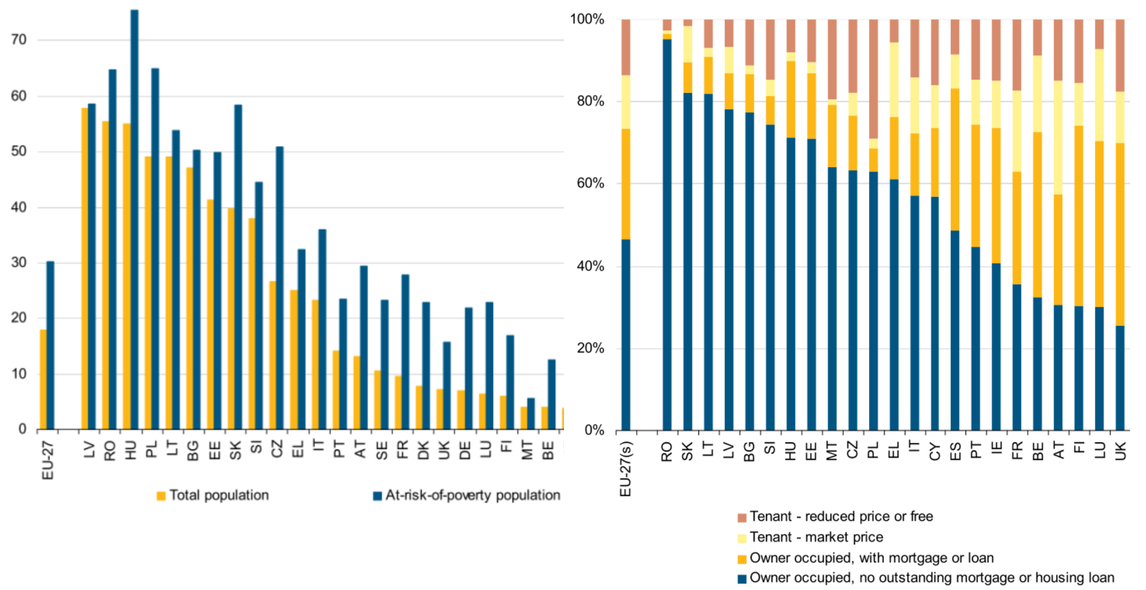
[2] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Housing_statistics



(a) (b)

Figure 3. (a) Overcrowding rate (% of population) and (b) distribution of the population by tenure status in 2009 (Rybkowska & Schneider, 2011).

2 REVIEW OF TECHNOLOGIES

2.1 *The large panel system*

The panel system refers to multi-storey structures composed of large wall and floor panels connected in the horizontal and vertical direction in order to enclose the rooms within a building, forming box-like structures (see Fig. 4)

The basic elements of the prefabricated blocks are the wall panels and floor panels. If the panel is exterior, it is usually made of three layers of material, 2 concrete layers for load bearing and protection against weather, and between them one thermal insulation layer which is usually mineral wool. The panels are lifted to place during assembly one by one, and the edges are connected together using on-site welding and concreting of the specially prepared locking elements. In order to gain efficiency, the panels are delivered to site with as many readymade details as possible, to eliminate the manufacturing processes on the site.

The wall's thickness ranges between 120mm for the interior walls and 300mm for the exterior ones. The floor panel thickness is 60mm. In some cases the exterior façade is made of lightweight concrete. The panel connections – horizontal and vertical - are the key structural details of a panel building. Depending on the construction technology, they can be wet (with cast-in place concrete poured between the concrete panels) or dry (realised by bolting together steel plates cast into the ends of the panels).

The quality of the design, but also of the materials and details realized at the site varies widely depending on the era of building, but the fundamental outcome of this building technology is a system of boxes with a standardised layout depending on the size of the panels. Another characteristic is that all walls of the system are load-bearing and they are indispensable for the integrity of the whole building.

Depending on the wall layout there are three basic configurations of panel buildings:

- Cross-wall: the main load bearing walls are placed on the short direction;
- Longitudinal- wall: the walls resisting vertical and horizontal loads are placed on the longitudinal direction;
- Two-way system: the walls are placed in two directions. This is the main configuration used for the Romanian panel buildings.

In Romania, the lateral stability is ensured by tying the wall panels. Splice bars welded to the transverse reinforcement of the adjacent panels ensures the unity of the panels Brzev & Guevara-Perez (2011).

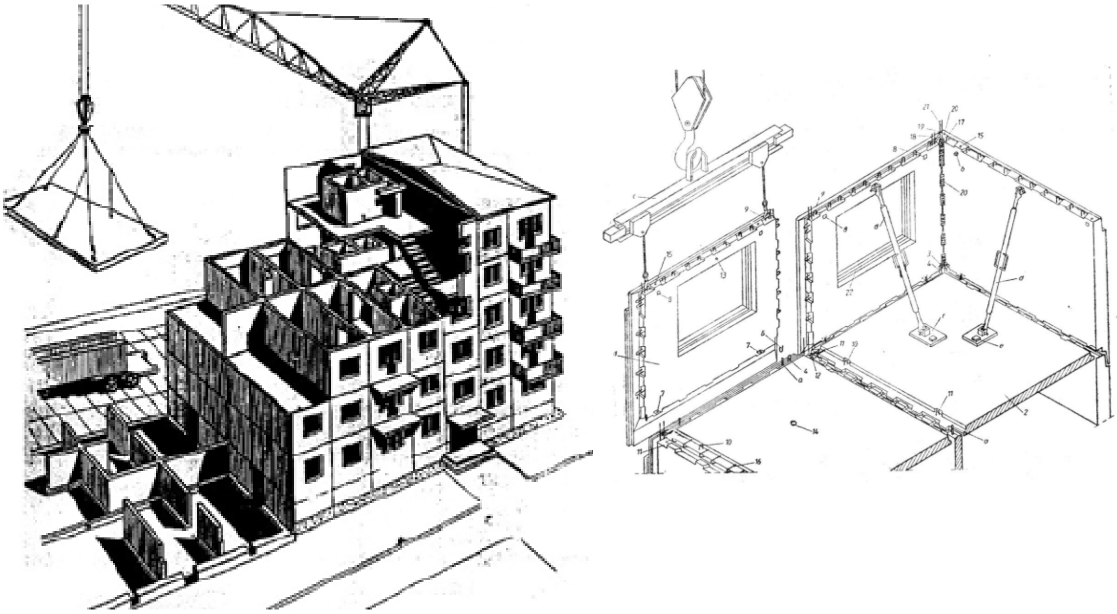


Figure 4. A large-panel concrete building under construction (Brzev & Guevara-Perez, 2011) and scheme of assembling of panels.

From the structural point of view, this system is extremely strong and resilient. Concrete panel buildings behaved excellently in the Vrancea earthquake in 1977, and in the subsequent earthquakes followed in 1986 and 1990. They are not likely to present any danger to occupants. As result of the strong tying of the panels for earthquake purposes, in the few examples of gas explosions, panel buildings also proved to be very stable. Figure 5 shows an extreme example, when gas explosion destroyed several panels from the façade of the building in two perpendicular directions. Despite of the severe damage, progressive collapse was not triggered and occupants could evacuate, even if the building had to be demolished later.

Figure 5. Ground floor external walls destroyed in a gas explosion in 2007, Zalău, Romania (Photos by Andrea Soós).

2.2 *Main problems of the flat buildings*

Many of the problems related to the panel apartments can be traced back to the basics of this building typology. As mentioned earlier, all walls of the system are supposed to bear load, and they are essential for the integrity of the building, resulting in fragmentation of the interior space.

While, buildings were not designed with a predefined service life period, as the codes of that time did not have such specifications, their intended life period was approximately 50 years. However, the majority of them have had no major maintenance operations as they are not in a monitored maintenance program which should have been established at their erection.

In addition to their eventual faulty construction, functionality problems (small rooms) and inadequate maintenance, low energy efficiency is also becoming a growing disadvantage. Coupling these technical problems with the social problems associated with the forced creation of new communities in the panel neighborhoods, results in a generally negative perception. This negative perception is common among inhabitants of panel buildings, fuelling a wish to move away (Egedy, 2000). Such tendencies are questioning the social sustainability of the neighborhoods, as the market worthiness of the properties is degraded.

As a summary, flat buildings in Romania have the following major problems:

- They need fast repair and consolidation;
- Most of the flat buildings erected before 1990 need thermal rehabilitation – they are in low energetic classes, and the heating costs are high;
- The plumbing and electrical system is old;
- The Homeowners Associations (HOA's) do not have the necessary resources to successfully solve the problems that arise.

3 OWNERSHIP MODELS

3.1 *Ownership in Romania and EE Countries*

The apartments built in 1950-1990 were owned by the state. The inhabitants were tenants who in the majority of cases moved from the countryside in order to work in the factories. Due to the political ideologies of the regime, the private property disappeared.

This situation changed after 1990, when the private property became protected and guaranteed by law. The authorities decided to sell the apartments to the tenants, initially at the price of 100.000 lei (the average price from 1989) equivalent of 32 monthly salaries. As the inflation was out of control, in 1993 this sum represented only 1-2 monthly salaries. The price of the apartments, though, did no change. Therefore, one apartment could be bought with only a few hundred dollars. As a result, in Romania around 96% of the apartments are now owner occupied.

In other countries the authorities treated the concept of private property differently. In Germany a large proportion of apartments are still owned by state-run housing companies or co-operatives. They regularly maintain the grounds, as the German laws require the flat owners to invest in their housing stock. On the other hand in Bulgaria, although there are significantly more owner occupied apartments, there is no organized system implemented for building administration, not even a place for the inhabitants to meet and discuss the problems of the building.

Even with the high ownership rate, Romania has a quite low property rights index (5.3), with most central European Courtiers being in the mid-range (Slovakia 6.2, Latvia 5.6, Poland 6.2, Hungary 6.4, Czech Republic 6.4), and Nordic Countries scoring very high (e.g. Finland 8.6, Sweden 8.5). The property rights index[3] measures the degree to which a country laws protect private property rights, and the degree to which its government enforces those laws. Higher scores mean that the property rights are better protected.

[3] http://internationalpropertyrightsindex.org/

3.2 *Condominium versus collective ownership models*

The ownership model, implemented in Romania after privatizing the state owned apartment stock after 1990, is a condominium type ownership. In this scheme, the apartment itself is a private property, while shared parts of the building are used under legal right associated with owning the apartment. They are divided co-property of the apartment owners; co-owned by them. Co-ownership, "*coproprietate*" in Romanian legal terminology, extends to all commonly used parts of apartment buildings, land, foundations, cellars, stairways, elevators, external walls, roofs, depositing areas, entrances etc. Owners are organized in home owner associations or HOA's, for the purpose of managing the co-owned parts of the property, but also to pay utility bills and other costs that are not divided by service providers to individual owner level.

The Homeowners Associations establishment, management and functioning is done according to the Law no. 230 from 06/07/2007. According to Chapter II, Art. 4. The HOAs "*have the responsibility to administrate and manage the common property, which asides from rights, imposes obligations for all of the owners.*" HOAs should define the common interests of the owners, find financial means to repair and upgrade the buildings, and have the legal and technical expertise to manage construction contracts. The law states that local authorities have to support the HOAs. However, in their current form, HOAs lack managerial skills and professional expertise for management (e.g. economic or legal issues).

An alternative model for owning buildings is the so called collective ownership model, frequent in Nordic countries. In such houses, the right to reside in a particular house or flat is tied to the ownership of shares in the housing company. In essence, the housing cooperative owns the building/buildings, and the shareholders own the housing company. The ownership of shares associated with an apartment automatically entitles one to live in that apartment.

In Finnish legal terms, the transfer of a home owned by a housing company is seen as the sale of shares in the housing company, not a real estate transaction. However, the perception of the occupant is very strongly that he/she owns the apartment. So much so, that "*owner-occupied*" is most frequently used term for this type of ownership.

Residents pay a monthly fee to the housing company to cover maintenance costs, heating costs and the water supply. Housing company decisions are defined by residents at open meetings. The main advantage of the scheme is that the housing company, as legal entity, is able to enter agreements for maintenance and renovation, or to sign loan agreements with banks for the financing of such renovation.

3.3 *Influence of ownership on maintenance*

Despite of the many shortcomings of the panel building typology and their negative perception, their replacement is not a viable option even on the medium to long term. Hence, workable maintenance and upgrading solutions have to be found and promoted. The following list of problems is presented with the aim of searching solutions.

One difficulty in HOA, as organized in Romania, is the lack of ability to agree on maintenance and renovation. Traditionally, it takes the full agreement of all owners to contact a bank loan to finance renovation of the building. In case of larger associations there is practically no chance to achieve unanimity, throwing the HOA in impossibility of deciding (Kecskés, 2006).

This has been the general situation until recently. But even with lowering of the required votes from 100% to majority, it will just make the group to decide e.g. to renovate, and then force a private individual to pay a bill. This approach has its limits, as the individual owner might not be in the situation to pay or to have a loan guaranty individually. So the leverage of the group over the individual is limited. It is not a surprise that current financing schemes for renovation leave only a minor part of the expenses to be paid by owners. E.g. 20% in Romania is paid by the owner while 50% or 30% is paid by the state or the local authority. In total 2/3 of the loan interest financing the renovation was paid by the state in the panel renovation program launched in 1995 in Hungary too (Kecskés, 2006).

In the collective ownership schemes, the situation is different. Once the decision is taken by the owners meeting, the contracting of the bank loan is not an individual burden, but it is done by the housing company. The guaranty to the bank is the collectively owned building, and the individual shareholder pays the interest corresponding to his shares in the housing company; or he pays off his share of the housing company loans. Apartments, more precisely shares, are freely sold on the market with outstanding renovation loans; the loans are simply transferred to the new shareholder.

Another problem, in most Central European countries, is that negative perception of an apartment block area leads to an outflow of financially able occupants. Paradoxically, living costs are much higher in panel buildings than in privately owned detached houses, since the occupants has no choice in affecting the utility prices. The reversing of this tendency should be the first priority of the local authority city planners, but utility suppliers are interested to keep higher incomes.

The neighborhood level degradation can also be traced back to several factors. One is certainly the inability of the city authority to provide proper maintenance services. But an equally strong factor is the property division of the land around buildings. Practically, only the land just under the buildings enters in the co-ownership of the occupants, all land around the buildings is public/city land. This arrangement leads to feeling of estrangement on the side of the occupants, and once the city is neglecting its obligation of maintenance, it is very rare that HOA's are making any effort to extend maintenance to these areas. In fact they would even enter in legal conflict with the city authority if they do so. The result is a feeling of abandoned public spaces.

Similar fate of the abandonment has the co-owned parts in the buildings e.g. access corridors, stairwells, elevators etc. The ownership arrangements lead to estrangement, and occupants make little effort to maintain or improve these spaces.

In the collective ownership scheme, the housing companies use usually external housing service, whose main task is to manage the property in accordance with the housing company's decisions. Also the building site is treated because the housing company either owns the land or has leased it from the city by a long-term contract.

A second strategy of the city authority in Romania could be to transfer land (e.g. internal courtyards) to the HOA's, by selling or long term lease. Hence the playground, parking space, trees etc. in a courtyard could become the responsibility of the HOA's to maintain, prompting people to look after what they perceive as their own.

There are numerous cases presented by the media highlighting the inefficiency of the HOAs management system in Romania[4,5]. One of the main flaws is that management tasks are carried out by untrained administration staff. As result of widespread amateurism, many HOAs were penalized by the city as they proved to have been writing unreal amounts of expenses on payment lists.

As a summary, at the market psychographic level one can observe the attitude, that:

- "*Home*" is a priority for people, but "*Home*" is ending at the apartment door (worst case), or at the entrance to the building (better case);
- Therefore, public area is out of focus and often looks neglected ("*Not mine!*");
- Global view of facades also neglected ("*Not mine!*").

4 RECENT TRENDS OF RETROFIT INTERVENTIONS

Since the Ministry of Regional Development and Tourism (MRDT) started the national program of thermal rehabilitation[6], many owners became more aware of the importance of energy efficient dwellings.

As the unanimity, needed for the renovation program, is hard to achieve in a large HOA, owners sometimes decide to resume to individual thermal renovations (see Fig. 8). This solution is not desirable due to the aspect of the buildings' façade and because it is not as efficient as it should be. For example the rehabilitated flat would have heat losses through the walls adjacent with the apartments that are not thermal renovated as the temperature within the building is prone to equalizing. The local public administration has a great responsibility regarding the in-

[4] www.adevarul.ro
[5] www.locatar.ro/Forum
[6] http://www.mdrt.ro/en/programe-de-reabilitare-termica

dividual renovations, but fails to make adequate regulations. In many cities there is no regulation that requires any kind of approval for the works involving the envelope of the building. As a result, one can find at the same block of flats various types of windows, various colors for the newly rehabilitated apartments or the old colors for the apartments that were not rehabilitated (see Fig. 8).

Figure 8. Individually rehabilitated flats (Photos by Zoltán Szabó).

Another trend regarding flat buildings is the over roofing of the flat buildings. The solution seems adequate to solve the lack of dwellings with spacious new apartments. Before a new floor could be added, all the owners have to approve it. As there have been many situations in which this unanimity was impossible, the new law 170/2012 eased the requirement by making overroofing legal with only 2/3 of the owners' approval.

Usually in context of the renovation, the investing company upgrades the plumbing of the building or rehabilitates the access routes of the increased traffic. A disadvantage of these types of interventions is that the increased number of occupants in the region is putting pressure on already overloaded infrastructure.

A third trend in renovation is to modify internal partitions of apartments. As the initial design for the functionality of the flats is outdated, many owners are modifying the partitioning in order to obtain larger and more comfortable rooms. In a large number of cases the ventilation ways are obstructed. The ventilation of the building may also be affected by the roofing works. This type of intervention is also very problematic when undertaken individually, from the point of view of overall safety of the building. As mentioned earlier most walls have been designed to participate in carrying the load, removing them is not acceptable from structural point of view.

Many of the shortcomings of the Ministry of Regional Development and Tourism (MDRT), which manages national program of renovation and increasing energy efficiency, can be traced back to the structure of ownership. In fact, the MDRT program is paying a substantial share of the cost of renovation, and also demand the HOA's to work together as a whole – but not accepting exceptions on the side of the owners. They must all participate.

Still the program is missing on the complexity of the problem related to panel building neighborhoods, being exclusively focused on thermal rehabilitation, i.e. putting external thermal insulation and changing the windows. Even in this respect, there is a need for a more systematic approach, if the improving of the aesthetics of the buildings is desired.

It is also a disadvantage, that immediate costs are virtually the only drivers of choice of renovation solutions. Not using life cycle costing and not being more safety conscientious leaves HOA's to choose the cheapest and fastest solution – usually some polyurethane foam wall insulation and plastic windows.

5 STEPS FORWARD: MODELS FOR BUILDING ADMINISTRATION

In the next chapter we present three visions of business strategies to participate/activate the retrofit market in Romania. We discuss the visions as potential possibilities and we analyze their weaknesses and strengths. The strategies are:

- Franchise System – With offering renovation services as a product and with target clients of Developer Companies, Construction Companies and Building Management Companies. This scheme could be implemented by a company or consortium with an extended portfolio of renovation products and solutions;
- Profit-Hunter facilitator Company System – Involves the creation of an association by a group of business companies in order to extend their operation in offering refurbishment services;
- Assisted self-organizing model – Based on the idea of facilitating HOA's own organizing and creation by direct investment of Management Companies (MC's). This scenario would require the cooperation of recently created MC companies with places where the practice is established (like in Finland) for the purpose of know-how transfer.

Only the first two models are sketched below in more detail.

5.1 *Franchise system*

5.1.1 *Executive summary*

ReNova LTD, is large corporation primarily for selling renovation solutions to the construction market. ReNova executes a business plan to partner with local companies in order to distribute its innovative, "turnkey" solutions for retrofitting and improving energy efficiency existing building stocks in emerging markets.

5.1.2 *Keys to success*

- Creating an effective and trusted support/selling base with local construction and development companies;
- Support with technological know-how the network, both at the bidding and execution phase. Solutions of ReNova are innovative and require supervision in application;
- Respect the interest of the local "dealer networks" and their ability to market the product to their customers;
- Cautiousness with partners in the network – today's partners may turn out tomorrow's competitors. Be one step ahead in innovation – always have a new upcoming product, better than the previous and applicable "exclusively" with technical support.

5.1.3 *Mission and objectives*

The mission of ReNova is to bring technological know-how to the market, providing technological support to local Development and Construction Companies. Dealing with the end users, the HOA's are left for local market players. Providing services to, and supporting the local companies in identifying market needs and viable service and product ranges for the future, is the key feedback loop needed to keep ReNova in competition.

- For short term: To start to build and steadily expand the dealer's network, starting with key local players in the renovation business;
- For long term: Constantly create new ways to facilitate the work of the network by technical supporting, evaluation software, studies supporting the marketing of products and services. Keeping the network connected to ReNova by periodically launched innovative products.

The objectives of ReNova are to:

- Start and expand the dealer network;
- Collect feedback from dealer network;
- Improve support services – these are directed to dealer network (construction companies and developers), not end user's e.g. HOA's.

5.1.4 *Organization summary*

ReNova is a focused on on-going renovation trends and the dynamics of companies working executing renovation works. The aim is to offer attractive terms to the more successful renovation companies and attract them to the franchise scheme offered by ReNova.

5.1.5 *Services*

Planned service package include:

- Technology - The product range of ReNova will be sold to the network together with technological know-how, planning and design support and training for Development and Construction Companies. ReNova gradually develops the online support system for the companies in the network.
- Collaboration within network – On the feed-back loop ReNova collects information on from companies concerning the opportunity of introducing new product ranges to market, or to develop entirely new product ranges based on market demand.
- Promotion of sustainable retrofitting - ReNova will launch and develop online site and planning support tools directed to HOA's and building owners. The aim is to educate the end user concerning the aspects of sustainability and eco-efficiently of the renovation choices. Another aim is to provide very basic tools/form templates/calculation sheet templates to support decision by end users.

5.1.6 *Market analysis*

The main customer focus of ReNova is on local emerging Construction Companies carrying out renovation work in Romania. Most of these companies are of small size, and they need support in the learning phase of adapting ReNova technology. What they contribute to the partnership is their local clientele, where they start promoting ReNova solutions instantly. Choosing dynamic companies for the network is essential.

ReNova will take decision on tolerating the use by the partner Companies of other/competitor's solutions in parallel with ReNova's on the case-by-case basis. Terms will be renegotiated on 2 yearly basis. As the ReNova brand is becoming more established on the market, stricter criteria can be applied.

Developer companies are the secondary focus of ReNova. They are less active in the renovation business, and usually have their own networks of designers/builders.

5.2 *Profit-hunter facilitator company*

5.2.1 *Executive summary*

RetroCon, is an organization created to execute this pilot business models – in order to support Romanian Real Estate Development companies and House Owner Associations (HOA's) in their management of changing to a sustainable model for their building stock. This support includes the management of new technological solutions, making thermal retrofitting of old buildings and improving the usage of energy, transforming old inefficient buildings into sustainable one, making in that way a step forward in thinking green and improving the quality of life of the occupants.

5.2.2 *Keys to success*

- Building a strong support base with some Romanian Real Estate Development companies and House Owner Associations;
- Creating an effective network between Managing Companies and House Owner Associations to facilitate cross-communication and contacts;
- Raising the viability of model transposed to Romanian market, for all transferable know-how and technology that is being applied on the established West European markets;
- Strong and straight forward communication with Owner Associations, to facilitate the change.

5.2.3 *Mission and objectives*

The mission of RetroCon is to bring know-how, technologies and applicable business models to Eastern European countries into public use; thereby providing economic development assistance to Romanian Real Estate Development companies and House Owner Associations to improve the efficiency of energy usage, providing service to the technology transfer staff of each institution by assisting in identifying, protecting, developing and transferring technology to the private sector and generating income. RetroCon perspective is in its ability to link market players from various private companies to transfer know-how that can then be marketed in Romania in the private sector.

- For short term: To start retrofitting buildings, whose first service time was long time ago elapsed;
- For long term: Redefine the objectives and status of Owner Associations, developing long-term relationships with the new defined Administrative Business community.

It is a problem of economy of scale, since this process is at the beginning and not much previous experience exists. Currently, there is a Government program funding in Romania, started in 2009, which gives support for thermal retrofitting of old buildings. This is far less than the number of buildings, which should to be included in a similar program. The objectives of RetroCon are to:

- Increase of corporate membership in RetroCon;
- Establish the contact with the Owner Associations Federation from Romania (FAPR[7]); with active organization RetroCon should achieve an increase of membership by 15% each year.
- Facilitate two new building retrofit agreements in the first year and increase the number of agreements each year;
- Create new linkages between industrial partners and developers and develop new collaborative relationships between main players;
- Develop a RetroCon webpage / database that will link players in this project.

5.2.4 *Organization summary*

RetroCon is a focused program that offers a powerful resource to Romanian Real Estate Development companies and House Owner Associations seeking new solutions and technologies to improve the energy efficiency. The program also seeks linkages between foreign and Romanian companies in developing new partnerships that will generate additional corporate interest.

5.2.5 *Services*

Planned service package include:

- Technology – Assist in identifying potential application of developed solutions and evaluation of these application areas to determine the commercial potential. A database should be created and maintained by RetroCon in order to respond quickly to requests for information from the Home Owner Associations and developers. It should be created a quick and accessible resource that will identify applications and industrial partners that match their interest areas;
- Industry Collaborations - RetroCon will actively seek collaboration opportunities between industrial partners and home owner associations / developers / FAPR;
- Retrofitting Technology Conferences - RetroCon will organize two conferences in Romania each year, focusing on the areas of Energy Efficiency, Sustainability and Retrofitting Technology;
- Newsletter and Promotional Publications of old building retrofitting - RetroCon will produce a quarterly promotional publications directed toward the home owner association which will focus on current development / case studies on retrofitting.

[7] www.fapr.ro

5.2.6 *Market analysis*

RetroCon will first focus on creating the information base necessary to satisfy industrial players that are currently prospecting for applying the existing retrofitting technologies. Branded companies are an advantage, but also include medium-to small-sized companies.

Two important groups of potential targeted customers were identified: development companies and HOA's. Both of them have limited resources and know-how to manage the owned building. It is critical that they find RetroCon an excellent tool in quickly identifying retrofitting technologies and know-how that will lead them to achieve their new goals.

RetroCon will provide a service that will correspond to the agreed set up in the Retro Consortium Council. There will be both a full and associate membership option in the Retrofit Technology Consortium Council. We anticipate that larger companies will select the full membership option because it will offer additional research services. An associate membership is tailored for the medium- to small-sized companies whose contacts will be less frequent.

5.2.7 *Service providers analysis*

The Home Owner Association (HOA) access to funds range from excellent in some cases, to completely chaotic and frustrating in most others areas.

RetroCon 's goal is to assure access to knowledge and funds through a streamlined process that leaves the targeted Home Owner Associations both satisfied with the results as well as the time invested in the searching process to solve their own problems.

5.2.8 *Competitive Edge*

RetroCon's competitive advantage is their members experience from the home market. RetroCon 's focus is to support the HOA in their successful pursuit of energy retrofitting technologies. The most critical component is the responsiveness of the program to HOA inquiries into a specific formulated problem.

The best scenario is the case study highlights provided by RetroCon before initial inquiries are made. RetroCon will strive to open doors for companies so that long-term relationships will develop and companies will become members of the Retrofit Technology Development Council.

The approach is decidedly sales-oriented in focus. This is a critical advantage when other competitors will start in competition with RetroCon. It is important that HOA will find RetroCon solutions viable and easy to access.

Yet the key to RetroCon 's success will be in how the program evolves in response to HOA demands. RetroCon's Retrofit Technology Development Council should have that evolution. The Council will provide companies with the access to fine-tune services to improve the program's ability to meet this particular market demands.

6 CONCLUSIONS

Based on the review of the Romanian market situation and the discussions reported here, the following general conclusions can be drawn:

- A great and growing need exists for renovation of the concrete panel building stock in Romania. Most of the buildings are built in the 70's and 80's and they are reaching the service life stage when retrofit is unavoidable. In this respect, even small stimulation can create good results on the market.
- Renovation market is quite new and rapidly evolving – competition is not yet fierce, but international companies are attracted by increasing number of EU and Government financing programs.
- Financing programs have particular rules; they are often overly bureaucratic and are sometimes distrusted by the Home Owner Associations.
- Home Owner Associations have no technical and legal knowledge to navigate the renovation process. It is imperative to support the HOA's with technical and legal information (private sector, associations, and local authorities). Lack of good technical information already results in substandard ad-hoc renovation solutions being applied with no responsibility.

– Existing weak legislation and lack of information on the side of HOA’s is already creating disastrous renovation examples in Romania.
– Three possible business models for private actors operating on the renovation market or actors interesting in accessing the market are proposed. Because the models were not tailored to a certain market player they are sketchy. They also represent different depths of involvement in developing the market – but in all cases important emphasis was put on educating/informing/strengthening the HOA’s, because the authors felt that they do represent a weak link in implementing a sustainable future focused retrofit strategy for the panel building stock.

So coming to the initial question: Are we too capitalist/individualist, and forget to focus on a comfortable life? Not easy to answer. But, certainly, one fundamental problem of administering panel buildings is related to HOA’s inability to take decisions as an entity; individual interest overriding/blocking the interest of the group. Authorities should further strengthen the stand of the HOA’s in relation to the individual owner’s interest, perceived or real. Ideally, panel building administration should be shifted from the “weak condominium ownership model” of today towards more “cooperative” ownership models, where the say of the group has priority over individual interest.

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An integrated approach - Retrofitting the blocks of flats made of prefabricated panels

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ABSTRACT: This paper presents up-TIM's technical proposal for the competition Solar Decathlon Europe that will be held in Versailles in 2014. SD is one of the biggest competitions for students, PhD students and young researchers in order to develop a solar house prototype and to respond to the sustainability challenges. Our team's proposal aims an integrated approach for the retrofitting the existing building stock made from prefabricated panels built between 1970 and 1990.

1 INTRODUCTION

1.1 *Solar Decathlon competition*

SD is one of the biggest competitions for students, PhD students and young researchers in order to develop a solar house prototype and to respond to the sustainability challenges. It was first held in the US and later imported to Europe. It challenges the collegiate teams to design, build and operate solar-powered houses that are cost-effective, energy-efficient and attractive. The main purposes of the competition are: to educate students and the public about the green-energy solutions and to demonstrate to the public the comfort and affordability of homes that combine energy-efficient construction and appliances with renewable energy systems.

SD Europe 2014 is the third European edition and will be held in Versailles in the summer of 2014. The previous editions, 2010 and 2012 were held in Madrid. The 2012 edition gathered over 10.000 visitors in only one week of exhibition. There were 8 editions from the beginning of the competition in 2002, which gathered 112 collegiate teams and 17.000 participants.

1.2 *Main purposes of the competition*

The focuses in the 2014 edition will be:

- density – sustainable collective housing solutions are needed in order to minimize environmental impacts on urban level;
- mobility – reducing energy consumption due to end-user transport;
- sobriety – produce clean energy and consume it wisely;
- innovation – innovation in architectural design, energy-efficiency solutions, using solar power, development;
- affordability – the key issue for applicable sustainable architectural and urban solutions;
- the project in its environment versus the prototype in competition.

There are ten categories that will receive points during the competition (hence the name decathlon):

- architecture;
- engineering and construction;

- energy efficiency;
- electrical energy balance;
- comfort conditions;
- house functioning;
- communication and social awareness;
- urban design, transportation and affordability;
- innovation;
- sustainability.

The competition had a qualification phase that was held in December 2012. The 20 team qualified and the 7 complementary teams will have to complete all the seven phases (deliverable 1 to 7), according to the rules of SD 2014 between January 2013 and November 2014.

2 TEAM UP-TIM – PRESENTATION

2.1 *Up-TIM and its place among the competitors for Versailles 2014*

Up-TIM is an interdisciplinary team composed from students and teachers from the Politehnica University and the West University of Timisoara, comprising various specialties: architecture, interior design, structural design and engineering, communication and public relations, systems engineering - building installation and specialists in clean energy production and photovoltaic panels.

Our team qualified in the third place on the complementary list. The first 20 team qualified will build the prototype, while the seven teams that are on the complementary list will compete for the deliverables 1 to 3 – namely the project. The first three teams will have the opportunity to build the prototype, so the competition will continue until November 2014 (deliverable number 7).

2.2 *Overview of up-TIM's technical proposal*

The main objective of the team is to promote a sustainable way of building in relation to existing resources and social context of Timisoara. All the issues related to sustainable development will be addressed in this project: ecological, social, economic and cultural.

Four main points were taken into consideration for the assessment of the technical proposals:

- technical innovation and design;
- fund raising and team support;
- curriculum integration and special considerations;
- organization and project planning.

From the technical innovation and design perspective, up-TIM's proposal takes into account the specificities of the "gray neighborhoods" in Timisoara, as this is one of the cities with the poorest conditions for the apartments, especially those built between 1975 and 1982 (the variants for T770 model). The team considers that weaknesses can be transformed in opportunities by having an integrated innovative approach, using low-tech and passive systems.

Fund raising and team support: The proposal is based on an integrated strategy involving all the stakeholders responsible for changing our city: the inhabitants of the city, universities, local authorities, development agencies, NGOs, private companies, media and professional organizations. The fund raising is planned and we expect to have the support of universities, local authorities, business clusters dedicated to alternative energies, private companies, not only from Timisoara, but also from the West Region, NGOs, civil society and media.

Curriculum integration and special considerations: This project is a major step towards forming such an interdisciplinary team in the universities of Timisoara (involving so many specialties). It also proves a proactive attitude of the university regarding the city life and its real problems.

Organization and project planning: The team is organized with the idea to carry some further projects and actions in the spirit of sustainable community development.

2.3 *Main objectives of the team*

The team's goal is to promote a sustainable way of building in relation to existing resources and social context. All the issues related to sustainable development will be addressed in this project: ecological, social, economic and cultural.

Our vision is to meet specific needs of the Romanian context and the local requirements and possibilities of Timisoara by identifying the opportunities and proposing the most viable and affordable solutions adapted to local context ("Technical innovation and design").

The entire solution is based on an integrated strategy involving all the stakeholders responsible for changing our cities: first of all the people – the inhabitants of the city, universities, local authorities, development agencies, NGOs, private companies, media and professional organizations. All will be partners in the project and also its beneficiaries on a long run ("Fund raising and team support" and "Organization and project planning").

One of the most important issues is the education of civil society in the spirit of sustainable development and to exercise a proactive attitude of all stakeholders related to their way of living, their neighborhoods and their cities ("Fund raising and team support" and "Curriculum integration and special considerations").

On a short run, we aim to develop an interdisciplinary team spirit in the universities, involving students from various faculties. On a long run the success of this project will prove to be the first step towards an integrative vision of the higher education and this is the best choice for the future for HE development ("Curriculum integration and special considerations").

3 UP-TIM'S TECHNICAL PROPOSAL

3.1 *Background*

It is normal for a nation to accept its own history. Romanian people perceive that the communist era marked the city with the so called "gray districts" made from blocks of flats. They are perceived as "gray districts" because they offer poor living standards, lack personality, green spaces and recreational areas. Around 60% of the urban population in Romania lives nowadays in an apartment situated in such a quarter. This type of building is a dominant presence in the Romanian society because of rapid urbanization between 1960 and 1980, when a large proportion of the rural population was moved to new towns developed around industrial plants. Although the appearance of these buildings was influenced by the theories of modernism, implementation in Eastern Europe was created with the idea of obtaining a large number of cheap housing, quickly and easily built using prefabricated panels.

3.1.1 *The importance of retrofitting older buildings for the 20-20-20 EU targets*

Retrofitting older buildings is one of the most important issues for the European commitment towards the targets of CO_2 and GHG emissions reduction and energy efficiency. According to Eurostat statistics, in 2009 European households were responsible for around 70% of the total final energy use in buildings and the space heating is the most energy intense end-use in EU houses. It is obvious that the policies addressed to the retrofitting of this part of the stock are crucial.

One of the most debated issues today is to find locally adapted measures that can be taken in order to assure the commitment for the 20-20-20 EU policy and to find alternative and innovative solutions for the cost-optimal energy performance of buildings adapted to the local market.

3.1.2 *Specificities of the apartment buildings in Romania among other EU countries*

The data presented below are taken from the BPIE study from 2011 "Europe's buildings under the microscope – A country-by-country review of the energy performance of buildings", from the National Institute of Statistics – results of population census and from urban and sociological studies.

The apartments of our country provide some of the poorest living conditions for the citizens. The apartments are small and, in many cases, over-crowded. The apartment floor space is around 17 to 20 sqm / capita (in other EU countries is between 31 and 36 sqm / capita).

Despite this fact, the satisfaction with the personal dwellings is quite high. The sociological studies performed in our country reveal that dwelling satisfaction increases steadily with each additional square meter, up to a point. A logical conclusion is that inhabitants will desire more space in the future, a trend that is already visible looking at residential constructions in Romania after 1990. Another important point is that Romania has 95% owner-occupied residential buildings, by far the highest percentage among all the European countries.

Currently in Romania are ongoing programs supported by various authorities that encourage thermal rehabilitation of existing blocks. Although these programs have a whole building approach, they are limited to achieve a better level of thermal insulation, without solving the problems of ventilation, air tightness and the relationship with the environment.

On the other hand, top-down approaches proved unsatisfactory results in Romania, as they have no continuity and the financial support is insufficient. The local construction market found its own solutions, but they do not lead to a win-win situation on a long run (as presented in the case of Timisoara).

3.1.3 *Local context - specificities of the built stock made from prefabricated panels in Timisoara – from weaknesses to opportunities*

Understanding specificities of the built stock made from prefabricated panels in Timisoara is the first step to find a solution suitable for the local context. We will present some points that we consider weaknesses, but properly managed, can be seen as opportunities for developing a concept.

In Timisoara, the collective dwellings made of large prefabricated concrete panels, most of them 5-storey high, represent 40% of the housing stock. In the city there are three main types of block of flats ground floor and four storey: model 770, 744 (built between 1970 and 1980) and 1340 (built between 1980 and 1990). The models used in Timisoara are the typology among those with the smallest spaces and that offer the lowest living standards. This means that the people will try in the near future to have more space (this is already visible in the tendency to enlarge the ground floors where possible). Another opportunity in this repetitive pattern is the fact that it allows a modular approach for the new interventions that can be easily personalized.

The fact that the typology is repetitive produces a sense of confusion, as the neighborhoods have no visual identity. The retrofitting and refurbishment of these blocks of flats can be seen as an opportunity to develop an identity to the neighborhood. Instead, where façade insulation works were performed, the result was that some of "the gray neighborhoods" (Figure 1) became "the yellow and orange districts".

Even it is perceived as a green city due to the parks in the central area, Timisoara lacks green spaces in some residential areas, namely these "gray neighborhoods". In fact there are stripes of green space between the buildings and the sidewalks that are frequently treated as private gardens by the older people living at the ground floor (the first moved from the rural areas). Usually the fact that these space are in decay, means there are no older people left in that block of apartments. In administrative terms, some of these areas belong to the blocks of flats (private property), while others are public space. This is a space of limit that deserves more attention.

The heating energy consumption in the buildings made of prefabricated panels is estimated between 180 and 240 kWh / sqm. The biggest problems for these buildings are: the thermal discomfort (due to the low thermal quality of the materials and the bad joints between the panels) and also the poor quality of indoor space and indoor air.

Timisoara is an interesting case-study of a bottom-up approach of small construction companies. There is a market demand for densification by adding a fifth floor to these blocks of flats especially in the neighborhoods adjacent to the student campus and faculties. The small companies built a fifth floor and in exchange they have insulated the facades and changed the old windows in order to improve the energy efficiency of the building. They sold the apartments and apparently this was a win-win situation for everybody. But is only for a short term, because on a long run it is not viable: it closed the possibility for further development and the materials used are the cheapest, so the quality is not as expected.

An idea has born: what if a tenant association could take this opportunity in its own hand and combine the idea of adding a fifth floor with the idea of an entirely new „skin"? Not only that they could really make a difference for their own comfort, but also with a good project they could change the urban space (adding some vegetation) and gain a plus of space and protection (the space of limit that is typical for all the Romanian houses, between the exterior and the interior). Therefore the solutions adapted to local market conditions most have the following qualities:

- to be affordable;
- to address properly the density level of the neighborhood and to encourage clean transportation (walking, use of bicycles, electric transportation systems);
- to improve the living conditions and comfort of the existing apartments - thermal comfort, appropriate air tightness level, adequate ventilation related to indoor air quality, improve energy efficiency;
- to improve the urban quality - as the external „skin" of these buildings form the „walls" for the public space of the neighborhood.

Figure 1. Map of Timisoara with the "gray neighborhoods".

3.1.4 *Intervention scenarios*

We considered four different scenarios:

- scenario 1: solar parks on the terraced roofs;
- scenario 2: attic apartments (the fifth floor) and solar parks on the roof;
- scenario 3: a continuation of the present program of thermal rehabilitation + scenario 2 developed with small steps, so that the investments are smaller and can be recovered faster;
- scenario 4: the interventions follow the computer industry model (the existing buildings become frames, over which can be implemented a light system that can be upgraded every 10 years, or even within certain limits by every owner).

By analyzing these scenarios, it became obvious that on a long run the fourth scenario is the most flexible and it offers an alternative that translates into this gray areas a piece of the present and future reality.

3.2 *Technical innovation and design*

As presented above, the weaknesses can be seen as opportunities for new ideas. An example of best practice in a city like Timisoara can really change the perception of its inhabitants about the possibilities of this building stock.

After analyzing the T770 model (the one having the poorest living conditions in terms of space and energy efficiency) we can say that only an integrated intervention can solve the problems of such a building. But it can be done step by step, by using low-tech means and passive systems best suited to the local context (a developing country with low average income per capita and no high-tech knowledge) (see Figure 2).

The solution is adapted to local conditions and it is based on an integrated strategy involving the use of construction materials effectively throughout the life of the building. The project improves the energy efficiency of the buildings "skin" using innovative interventions by creating a coating, a new external layer that provides an effective relationship with the environment as well as a local source of energy by using solar and photovoltaic panels. The project also aims to improve existing methods of construction in Romania by creating and integrating an energy self-sufficient module that can be used both on the terraces of existing blocks and for social housing or students apartments.

What a complete proposal should integrate are the issues presented in Table 1.

Table 1. Issues integrated in the proposal

Issues	Limit demands	Enhance solar energy
Building envelope:	-increase thermal insulation -assure air-tightness -change windows	-widen openings
Heating:	-upgrade old installations	-create buffer-zones -passive house -install solar panels -air-to-air / air-to-ground heat pump systems
Cooling and indoor air quality:	-use ventilation for cooling -use staircases for ventilation	-improve air quality
Electric system:	-class A	-PV on roof and façades -infrastructure for electric bicycles
Architecture: layer	-fifth floor (prefabricated)	-interior space extended with a new -accommodate passive system through furnishing
Ventilation:	-mechanical ventilation with heat recovery	
Structure:		-reinforce the modified structural panels -connect new structure with the old one

The calculation of the necessary energy for heating (presented in appendices) shows that comparing to the initial value (for the building envelope as it is) a reduction with 44% is possible with the usual system used today for thermal retrofitting and a reduction with about 86% is possible with the system that we proposed (see Figure 3). The calculation was made by taking into account measures taken at the envelope level, without considering further improvements generated by the external heat collecting buffer zones. For the passive systems, more sophisticated models will be used.

Further research is needed in order to understand and measure the gains for the other architectural and engineering parts.

We presented our proposal as an integrative model in order to demonstrate that such an intervention cannot be managed without taking into consideration the whole building and all the related problems (including the change in the urban environment).

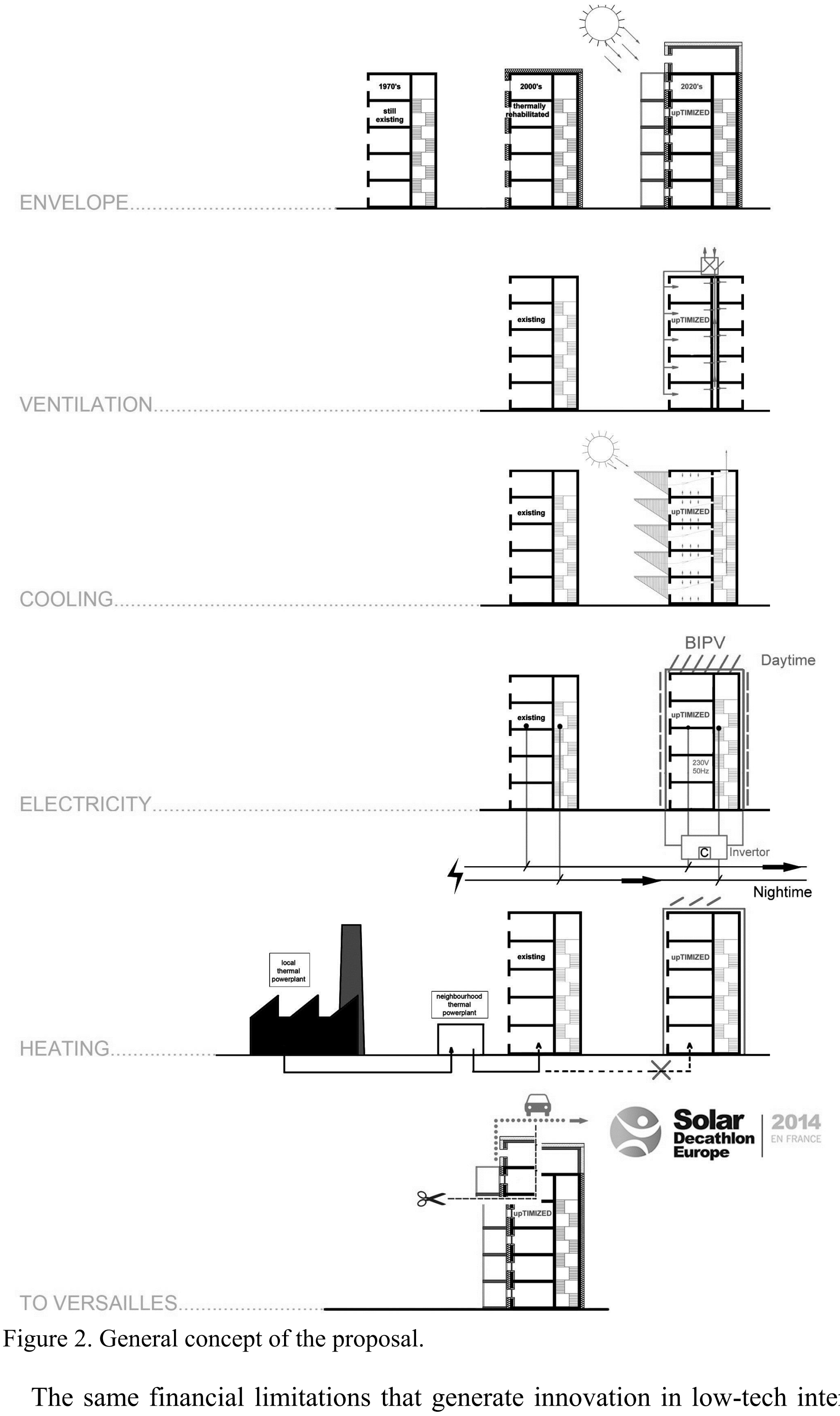

Figure 2. General concept of the proposal.

The same financial limitations that generate innovation in low-tech interventions operate in what we consider the first phase – the prototype that will be built. The team will build and test a module with a maximum 70 sqm built area in order to study and improve interaction between the new "skin" and the existing apartment.

It is important to mention that the prefabricated panels composing the T770 model were already tested in different variants in order to understand their structural behavior, during previous researches in our university. It is an opportunity to take further this research in a form of an interdisciplinary team.

Heating days per month										
	Jan	Feb	Mar	Apr	May	Sep	Oct	Nov	Dec	Total
Initial state	30	28	31	30	2	2	31	30	31	215
Thermally Rehabilitated	30	28	31	18	0	0	17	30	31	185
Optimised by upTIM	30	28	31	15	0	0	15	30	31	180

Average monthly temperatures for Timisoara for heating months								
Jan	Feb	Mar	Apr	May	Sep	Oct	Nov	Dec
-1.6	1.2	5.8	11.2	16.3	16.5	11	5.6	0.8

Heating demand/month for Initial state	kWh	Total kWh heating demand	Cost/kWh Heating (RON)	Total (RON)
January	59621.73	294354.69	0.15	**44153.203**
February	48433.45			
March	40502.29			
April	24290.33			
May	680.87			
September	644.06			
October	25670.47			
November	39747.82			
December	54763.66			

Thermal resistance for the initial state	
Basement slab	0.20
Flat roof	0.18
Exterior wall	0.87
Glazing	0.39

Initial state

Heating demand/month for Rehabilitated state	kWh	Total kWh heating demand	Cost/kWh Heating (RON)	Total (RON)
January	36061.09	164345.06	0.15	**24651.76**
February	29294.07			
March	24497.05			
April	8814.93			
May	0			
September	0			
October	8514.42			
November	24040.72			
December	33122.77			

Thermal resistance by thermal rehab.	
Basement slab	0.21
Flat roof	1.95
Exterior wall	1.85
Glazing	0.44

Thermal rehabilitation reduction of 44.32%

Heating demand/month for Optimised version	kWh	Total kWh heating demand	Cost/kWh Heating (RON)	Total (RON)
January	8929.68	40084.36	0.15	**6012.65**
February	7253.99			
March	6066.12			
April	1819.01			
May	0			
September	0			
October	1860.35			
November	5953.12			
December	8202.08			

Thermal resistance optimized by upTIM	
Basement slab	9.60
Flat roof	5.87
Exterior wall	4.47
Glazing	1.25

upTIM optimization reduction by 86.4%

Figure 3. Heating requirements calculations showing the energy savings.

3.3 *Fund raising and team support*

Our strategy takes into account the idea to assure the project's success not only on a short term but also on a long run, in order to achieve our main goals. Without understanding the value of partnership and working as a team for a better future, our effort will have no long-term effect. This means thinking further, working in interdisciplinary teams not only inside the universities, as students from different faculties, but also in partnership with all who are interested in changing our city and ultimately our lives. The most important objective of the project remains the one to educating people about sustainable living and sustainable community development.

The main stakeholders – partners in the project are briefly presented below. We also realized an analysis with what do we offer and what do they offer (see Table 2). The main idea is to have a win-win situation on medium and long run.

- Faculties and Departments from the University, Research Centers of the University;
- Local authorities (Municipality of Timisoara, Timis County Council) and Regional development agencies (West Regional Development Agency);
- Civil society and representatives of the tenants associations (FALT - Federation of Tenants Associations in Timisoara);
- Private partners: large, medium and small companies who are directly involved in the construction industry (companies with activity in renewable energy, suppliers of materials, design and execution, etc.);
- Private partners: large, medium and small companies which activate in related areas and are interested in supporting the project and traditional multinational and industrial partners of Politehnica University of Timisoara;
- NGOs interested in our project and topics related to the project (sustainable community development, green transportation and bicycle use, community empowerment, a "greener" city, sustainable living and consumption, Timisoara – the Cultural Capital of Europe Association);
- Professional organizations;
- Media partners (local and national television, radio, newspapers, internet network).

Up-TIM's fund raising plan will be organized around the idea of involving all the stakeholders interested in supporting our project as partners (Higher Education partners, authorities and development agencies, civil society and NGOs, private partners and media partners – as presented above), one of the main objectives being to make this project an example of best practice of public-private-HE partnership. "If the Universities do not collaborate with local and regional communities and do not involve the faculty, the teachers and the students as an integral part of the education process, they will lose 75 percent of the values of its efforts and will not fulfil their role in the society."

Table 2. Relationships with various partners

Partner	What do we offer	What do they offer
Faculties, departments:	- integrate their research programs into the project - create international relationships	- specialized knowledge - access to databases and contacts - students, MA, PhD, who want to work in interdisciplinary teams
Local authorities and Development Agencies:	- a contribution to the city's image - an example of best practice of SD - a platform for discussion about SD - a contribution to society's education - an answer to the densification issue	- establishing contacts with partners - organization of exhibitions, events - consulting - an alternative for tenants associations
Civil society and Tenants associations:	- support and empowerment - specialized knowledge and consulting	- a feedback from the local market - a connection with the tenants assoc.
Private partners involved in construction:	- a framework for promotion - an opportunity to demonstrate CSR - a connection with beneficiaries	- specialized knowledge - direct involvement in the final phases - sponsorship in mix cash and products
Private partners from related areas:	- a framework for advertising - an opportunity to demonstrate CSR	- specialized knowledge, consulting - sponsorship in mix cash and products
NGOs interested in the project:	- a contribution to the city's image - a contribution to society's education	- establishing contacts with partners - a network of people interested in changing the way we live, act, think
Professional org.:	- a framework for promoting their values	- professional knowledge
Media partners:	- a contribution to the city / region - a contribution to society's education about sustainable living and consumption	- informing the public about the project - support in organizing the events

3.3.1 *Fund raising planning*

Additional fund raising for the project is crucial for its success. Our team prepares various sponsoring packages, depending on the stakeholders / partner possibilities:

- single or mixed pack: know-how and equipment, instrumentation, industrial equipment for testing the prototype – for Faculties, departments and Research Centres inside the University and its industrial partners;
- single or mixed pack: cash and materials – for the producers and distributors of construction materials and equipment, large, medium and small companies who are directly involved in the construction industry and other companies who are interested in supporting the project;
- single or mixed pack: cash, know-how and prototype execution, transport, assembly and disassembly for large, medium and small companies who are directly involved in the construction industry;
- single or mixed pack: know-how and services from the companies who are interested in supporting the project and offer consulting in specialized areas (fund raising, law office, insurance company, publicity);
- mixed pack: consulting, support and cash from the authorities and the Regional Development Agency West;
- consulting, network support, donations and "free option pack" for individual or group members of the civil society and NGOs;
- single or mixed pack: know-how and cash from the professional organizations.

The planning of fund raises follows some necessary steps: in the first phase we will calculate an estimated budget, in the second phase we will contact as many sponsors as possible and we will rely on media and local authority support and in the third phase we will have the exact data about the financing possibilities. Then we will re-adjust the budget. We will get help on this part of fund raising and budget from a specialized company (among our partners).

3.3.2 *Tools for presentation and team support*

According to the main purpose and depending on the target public, we will use the following main tools for project presentation and team support:

- online website and a web social platform, addressing both the general public (presentation of the project, topics related, videos, network with the support group) and the specialists (with a part of discussion forum);
- contacts with stakeholders;
- media partnerships with local TV stations (UPT has its own TV station - Tele Universitatea Timisoara, but there are other local and regional TV stations), local radio stations, local and regional newspapers – some of all these are part of national networks;
- partnerships with other local projects and / or events: events related to the new project for the "Technological park for alternative energy and photovoltaic park - Timisoara" - financed with European funds, events related to the program "Timisoara - Cultural Capital of Europe 2020";
- attending the events whose main purpose is education the young generation, related with primary schools and high-schools - the week "School differently", related to the main students festival in Timisoara - Student-fest and cooperation with BEST - student's association, external workshops;
- for dissemination of the project information: printed materials for promoting the project (brochures), press release, internet dissemination, participating in national and international conferences related to the subject;
- for dissemination of the project abroad we will use the contacts with the Romanian Cultural Centers in Europe.

3.3.3 *Events organized and events to take part*

The events organized by the team have two main purposes: one is to maintain the main team cohesion (a united team) and the other is to develop relationships with all the stakeholders and all the people and organizations who share the same vision.

For the team unity we propose the following types of events: discussions in a university amphitheater (to get to meet students and to recruit a larger team for the second phase of the project), workshop at the beginning of 2013 with students and teachers for the final idea, training and consulting sessions for various needs of the project, summer practice, team building excursions.

In order to develop the relationships with the society we propose: a survey in Timisoara about the perception of the proposal (not necessarily event, but an important step), meetings between stakeholders involved in up-TIM project: students, tenants associations, representatives of local authorities, companies, NGOs, media partners.

We also selected some events to take part in order to present our project and to gain visibility (Architecture Annual 2012, 2013 - Timisoara, ROCAD 2013 - Bucuresti, StudentFest “Paradox” 2013 - Timisoara, participation at CAMEX 2013 - Timisoara (spring and autumn editions), itinerant exhibition in Romania with the project presentation 2013-2014). For international experience and visibility we intend to take part in the international fair RoEnergy 2013 - Timisoara, GIS 2013 - Bucuresti - series of conferences on architecture, MoldConstruct 2013 - Chisinau (Moldova), Infoinvent 2013 - Chisinau (Moldova) and similar fairs in others neighboring countries: Hungary, Serbia and Bulgaria.

3.3.4 *Communication with different target audience*

Our website, social network and the communication is based on managing different levels of information in order to have the proper message for each partner and various types of target audience. Depending on the target group which we address we will prepare three types of information packs:

- general information – generalities about how the project evolves, general data for the public, civil society, tenants associations, authorities and possible sponsors;
- detailed information, economical and technical data – a detailed description of the project for specialized companies, authorities, faculties;
- educational information – detailed description of the phases, of the stakeholders role and involvement, examples, information for educational purposes, open courses held by external experts, workshops.

3.4 *Curriculum integration and special considerations*

3.4.1 *The project as an extensive educational instrument for all the partners and for students*

The project is intended to become an open and transparent educational instrument not only for the students involved, but also for all the partners and the society, as mentioned before. It is based on the idea of learning that comes from the interactions between various stakeholders.

It will also be a transparent instrument of learning through sharing knowledge among students from different specialties: architecture, civil and structural engineering, systems engineering, public relations and communication, management, mechanical engineering. Each study, information, decision, study or analysis will be available for all the students involved in the project through an internal network in order to promote multidisciplinary and interdisciplinary approaches.

Students who will be part of the project will have several advantages: the first interdisciplinary team work at such a scale (so many disciplines involved) in our university, theoretical application and practical experimentation from the first phase to the last phase (from project to building), contact with social and economical environment. All the participating students will gain valuable experience and become marketable graduates and they will receive ECTS credits.

3.4.2 *The project as a continuation of research projects, studies, and PhD thesis and an opportunity for further projects and research topics*

From the academic point of view, the project promotes the collaboration between various faculties and the involvement of the local companies in the research field. Also we aim to continue several studies and PhD thesis which propose interventions on the building made from prefabricated concrete panels and solar and photovoltaic systems (civil engineering), green building design (architecture), sustainable building assessment of urban dwellings from Banat region. This project can be also seen as a continuation of an international research project developed by the Department of Steel Structure and Structural Mechanics – Inspire – Integrated strategies and policy instruments for retrofitting buildings to reduce primary energy use and GHG emissions.

As the existing building stock became the main topic in order to achieve the 20-20-20 targets and even for long-term scenarios (2035-2050), we consider that this is a huge potential for further interdisciplinary research projects, once the first step was made. In other words, we consider the qualification in the next stage a big step towards changing the way our faculties perceive research team, a step towards an interdisciplinary approach. It is a change of perspective and also a change of paradigm.

3.4.3 *Integration of the Solar Decathlon project into curriculum*

In various ways, this type of approach and sustainability issues are already part of the curriculum of the faculties involved and they will be further enhanced. What is already obvious even from this stage is that this type of reciprocal learning performed in this mixed team is extremely beneficial and it can be a first step to introduce common courses or projects for example at Faculty of Architecture and the Faculty of Civil Engineering (e.g. sustainability issues in architecture and civil engineering, integration of systems in the architectural design), or Architecture and Faculty of Communication Sciences (e.g. effective communication for community empowerment), or even common summer practical activities (building a pavilion with recyclable materials).

3.4.4 *Training and external courses for the students interested in integrative approaches*

Experts in various fields (from the faculties, our partners companies, NGOs and local authorities) will present thematic packages on different themes: integrative approaches, renewable energies and systems, effective communication, marketing and team support, accessing European funds, organization and management. This will help every student to understand his role for the team, how we interact and also specific issues related to the project (technical, economic, communication, organization).

3.5 *Organization and team support*

Up-TIM would like to consider the participation in the Solar Decathlon Europe 2014 as the first in a series of candidacies by teams from Timisoara. At the same time, the team thinks that the necessity of turning to a sustainable lifestyle still hasn’t reached the general public. That is why an association (NGO) will be created, that is intended to promote sustainability values and to increase public awareness concerning environmental issues throughout the Romanian society.

For the project completion, the team will be divided in three workgroups: a project development group (PD), responsible for developing and implementing the associations projects, a public relations group (PR) that deals with transmitting information regarding the associations projects to the general public and a fundraising group (FR) that attracts support for the associations projects. Its role is to establish strategies and to initiate projects within the interests of the association. The PR and FR serve all the association’s projects and work independently. As a first activity, the PD workgroup will be in charge of the project representing the submission to the Solar Decathlon 2014.

The advisory board (AB) will be constituted by representatives of the associated entities sustaining the project (universities and faculties, companies and NGOs) and offers consulting in the following fields: legal advice, financial planning, social analysis and market research, education and research). A key member of the advisory board will be the representative of The Lodgers' Associations Federation from Timisoara as primary beneficiaries of the project and owners of the apartments, whose role is to offer the essential end-user counseling. The board's involvement with the project starts at the very first beginning, while its members can differ from one phase to another. Any entity that supports the project by sponsorship or any other means except counseling will become a partner of the project on the short term and can later become a partner of the association, on a long term.

At the beginning of the second phase of the Solar Decathlon 2014, the association will promote its project through a series of presentations in all local universities (all the necessary specializations). It will launch an invitation destined for students to participate in a multidisciplinary workshop related to the project, with the purpose of completing the final team.

The selection process will have two stages:

-the pre-workshop selection: candidates will be asked to write a letter of intention stating the reasons for working on the project; the General assembly will analyze and deliberate a number of candidates that will be invited to the workshop;

-the workshop selection: a one-week training and team building exercise, where our university partners and other associates from all specialties involved in the project will hold lectures related to the project; candidates will be evaluated regarding their abilities and teamwork capacity during the brainstorming sessions representing the first solutions to the project; a multidisciplinary approach will be the main focus of the workshop.

At the end of the selection procedure, we aim at gathering 25 decathletes of different specialties to complete the final team.

4 CONCLUSIONS

Up-TIM team has great potential of performing an interdisciplinary research, as "Politehnica" University of Timisoara forms all types of specialists that are necessary in this project. Our team's participation in Solar Decathlon 2014 means to carry forward a tradition of innovation that Timisoara always had. And last, but not least, the project can be an example of best practice cooperation between all the stakeholders involved in the city development.

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