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A ROADMAP FOR A SUSTAINABLE INTEGRATED RETROFIT OF CONCRETE BUILDINGS

Proceedings of the SAFESUST2 - SURECON Workshop

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Editors

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SAFESUST 2

SURECON Workshop

A ROADMAP FOR A SUSTAINABLE INTEGRATED RETROFIT OF CONCRETE BUILDINGS

Joint Research Centre

Ispra (VA) - Italy

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European Commission
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WELCOME AND INTRODUCTION

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The Joint Research Centre is contributing to the formulation, implementation and promotion of European policies on strengthening the internal market for buildings and building products.

This includes the development and adoption of innovative materials, construction technologies and design methods for safe, resilient and resource-efficient buildings across their lifecycle.

This activity is developed within the Project SAFE&CLEAN-CONSTRUCT (*Safe and Cleaner Technologies for Construction and Buildings*).

In particular, the Workpackage SAFESUST (*Impact of Sustainability and Energy Efficiency Requirements on Building Design and Retrofit*) is aiming at developing a holistic design method, for assessing the global performance of buildings in terms of safety, energy efficiency and environmental impact.

This method, named *Sustainable Structural Design* (SSD) method, or simply SAFESUST method, considers both environmental and structural parameters in a life cycle perspective, and the results are expressed in purely economic terms, so that it can be potentially used by all categories of stakeholders.

In developing this approach, the necessary Roadmap is being drafted with the contribution of experts from different disciplines, and this is the aim of the SAFESUST workshop series.

A first SAFESUST workshop was held in Ispra in 2015 and was devoted to the definition of a "*Roadmap for the improvement of earthquake resistance and eco-efficiency of existing buildings and cities*".

That Workshop had the participation of experts from different areas of expertise, namely Architecture and City Planning, Energy, Materials and Structures, as well as Financial.

The Workshop was organized in technical sessions, with keynote lectures, technical presentations and discussions based on the syntheses produced by the rapporteurs, and was said to be a success.

A similar scheme is being proposed for this SAFESUST 2 - SURECON Workshop "*A Roadmap for the sustainable integrated retrofit of concrete buildings*".

In this workshop efforts will be paid to extend the roadmap for integrated retrofit of existing buildings to include actions other than earthquakes.

The collaboration with the University of Leeds, with which the Workshop is being co-organized, has been instrumental to the definition of important case studies, such as the multi-storey concrete panel buildings, which proved to have both insufficient thermal performances and insufficient robustness, and badly need a holistic approach for their renovation.

A ROADMAP FOR A SUSTAINABLE INTEGRATED RETROFIT OF CONCRETE BUILDINGS

Ornella Iuorio[1] and Paolo Negro[2]

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THE PROBLEM

The exponential grow of urban population is strongly responsible for depletion of natural resources and the increasing global warming. The construction sector plays a key role on the Triple bottom line of People – Planet – Profit. A proper management of the construction sector should aim to develop a built environment that is Safe for the People, Environmentally sustainable for the Planet and responsible for the Social Capital (Profit).

This approach should be envisaged for both the new construction development and the existing building stock. The existing building stock, in particular, accounts for almost 80% of what has already been built, and as such, represents an important part of the worldwide human and capital share. Assessment, improvement and valorisation of it, are essential steps for development of the full life cycle potential. Most of what is built today was built before the eighties, and is more than at least fifty years old, which means it has already overcome the common predicted design service life. Moreover, it has been built in a period when less attention was provided to safety against natural and man-made hazards, as well as, almost no attention was given to climate change.

Then the overall question, that in last decades has been discussed and brought forward in Europe and in most of the Countries is: How to increase the safety, energy efficiency and at least maintain the value of the existing building stock?

This is the central question that the **SAFESUST 2_ SURECON** conference is attempting to address.

SAFESUST is an acronym to mean **SAFEty** and **SUSTainability**, which identifies a research workpackage on Impact of Sustainability and energy efficiency requirements on building design and retrofit, conducted by the European Commission – Joint Research Centre, Directorate Space Security & Migration, as part of the project: Safe and Cleaner Technologies for Construction and Buildings.

SURECON is an acronym for **SUstainable integrated REtrofit of CONcrete** buildings, which aims to apply and develop the roadmap defined by SAFESUST to concrete buildings.

THE FOCUS

Why concrete buildings in particular? Concrete buildings constitute more than half of the share of multi-storey buildings in EU. A large part of the existing concrete buildings has been designed and constructed in the twentieth century, with a large percentage built after the World Wars, to house large homeless population. Concrete buildings were the icon of the modernist movement that had theoretical expression in the Bauhaus and Le Corbusier, among others. They have been loved and hated across decades. One of the extreme expression of concrete buildings after the Wars were the heavy prefabricated systems, which were largely adopted across Northern and Eastern European countries. The systems adopted low cost large structural components (floor slabs and wall panels) manufactured in factory and assembled on site and became a widely spread construction systems for multi-storey buildings since its first application that dates back to the end of 50's in Soviet Union. The prefabricated multi-storey concrete buildings have been a special focus of this workshop.

The retrofit of multi-storey concrete buildings has been under attention of a large number of research groups in the last decade. Their history is strongly connected to two major dramatic events that are still vivid in public memories. The Ronan Point collapse in 1968, when an internal gas explosion determined the collapse of half a tower block, and the more recent Grenfell tower event, when in 2017 a fire propagated through the refurbished façade of a 24 floors tower causing a large number of victims. While the first event initiated the research attention towards progressive collapse, the latest event has brought the public to interrogate about the quality and safety of any energy retrofit intervention. The 2017 Grenfell tower event, in particular, has indicated the criticality of any energy efficiency measure. In the occasion, the breaking of a fire in one of the fourth floor apartment, spread rapidly up the 24 floors building's exterior, bringing fire and smoke to all the residential floors. The tower had gone through an energy retrofit only few years before, when, the facades were over cladded with flammable materials, which burned for about 60 hours, and caused the death of 72 people. After the event, most of the towers in UK went through a verification, and many of them were found cladded with similar materials, which clearly indicated a systematic problem.

REQUIREMENTS

This workshop is a multi-disciplinary meeting aimed at discussing the need for a new way of conceiving building retrofit that integrates structural safety, environmental/thermal and economic performances in a sustainable perspective. The event focused on different fields of scientific study and research, bringing together experts of structural engineering, energy performance, economic values and life-time thinking with the purpose to define a Roadmap for the retrofit of Multi-storey Concrete Buildings across Europe. The two-days meeting were articulated in four plenary sessions devoted to Structures, Energy, Sustainability and Case Studies. Each session is introduced by a Keynote Lecture, aiming not only to introduce the topic from a specific corner, but more importantly, aiming to open questions and challenges to be discussed throughout the days. Each session key topics were re-elaborated at the end of the oral presentations by a Rapporteur.

PLAYERS and VISION

Transformation requires the coordinated participation of all the stakeholders, from civil and structural engineers, mechanical engineers, architects, planners, economist and the public. The challenge is finding a common language and a set of values that can be shared. During the two days, in the structure session innovative techniques for the retrofit and the assessment of existing buildings have been discussed. A big emphasis has been posed on the specificity of national and regional construction typologies and vulnerability. It was recognised the lack of awareness by the general public of the structural inability of buildings to cope with current structural requirements (particularly, in case of buildings located in vulnerable areas). The Energy session has been opened with the recognition of the need to decarbonise cities by investing in low-carbon measures in different places around the world. Measures for the improvement of energy efficiency have been explored, including passive strategies, integration of renewable energy sources and efficient energy management systems. However, big emphasis has been posed on the necessity to integrate energy retrofits to structural strategies. Criticalities of any simplified approach has been also considered since the risk of approaching energy issues considering few and simple parameters (as for instance thermal transmittance of envelope) can trivialize the problem and reduce the development of appropriate energy performing solutions. The sustainability session, among all, have reinforced the necessity to adopt a holistic integrated approach, which can allow to look at all the interrelated aspects of the building performance, including structural, energy, and aesthetic performance in a life time perspective. An integrated approach can, indeed, guide in the definition of retrofit strategies that can be weighted according to economic, social and environmental impacts. The case study session reflected on the application of integrated strategies to multi-storey concrete building around Europe. Emphasis was posed to analyse new methodologies that can facilitate the integration of expert knowledge.

Vision: Sustainable integrated retrofit of concrete buildings

Strategy	**Theme**	**Tactics**
Improving structural resilience under extreme and exceptional loads	Structural assessment Risk evaluation Retrofit	Involve all actors Set a common language Reduce expected losses
Improving energy efficiency while improving thermal comfort	Energy assessment Energy efficiency Thermal comfort	Involve all actors Set a common language Reduce all impacts on environment
Balancing solutions according to scenario analysis	Management of individual impacts	Define a global parameter and reduce global impact

WAY FORWARD

Codes, professional profiles and **economic incentives** have been identified as next steps to achieve the vision. Key facts are that sustainability, safety, and resilience cannot be pursued independently and therefore, the now withstanding sectorial code approach should be abandoned, giving place to an integrated approach. This new approach has to overcome the major barriers to the renovation thus replacing sectorial codes and traditional design methods for both the energy and structural retrofit, addressing at the same time sustainability and resilience. For such an approach to succeed, it is important to develop retrofitting strategies which would minimize typical barriers to renovation, such as limiting disruption of the construction site and avoiding inhabitants' relocation.

Creating a new professional profile, such as a Sustainability manager (possibly recognized by the EU) able to manage all the different competences, would be beneficial. The Sustainability manager would be a person with the ability to act beyond single discipline, and would need to be able to interact with all the professional figures, which are involved in the building retrofitting, as well as the subsequent maintenance and management.

Finally, to make any strategy in practice, economic incentives should be explored. There is an urgent need of incentives and initiatives to promote the retrofitting of buildings. For instance, by introducing a payback time for the structural retrofit, and by putting restraints to the possibility of selling buildings with low structural safety. Also, the advantages of an increased safety and sustainability of the retrofitted building should become tangible, not only in terms of quality of life, but also economically, through proper economic incentives for integrated retrofit works, and by introducing market barriers on sales of unsafe or unsustainable buildings or dwellings.

In conclusion, there is an impellent need to conceive retrofit interventions in an integrated way , putting the safety and wellbeing of the occupants at the centre of investments in order to develop coordinates approaches that can have more social and economic benefits.

STRUCTURES SESSION

STRUCTURES SESSION SUMMARY

Rapporteur: **Mario D'Aniello**

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Summary of Presented Papers

Several technical notes dealing with different topics were shown and fruitful discussions enriched the workshop during and after this session. The presented contributions are summarized as follows:

1. **Retrofit to enhance resilience and sustainability**:

   a. *"USING STEEL SOLUTIONS TO ENHANCE SEISMIC RESILIENCE OF REIFORCED CONCRETE BUILDINGS" by Dubina D., Dinu F., Ungureanu V.:*

   This contribution was presented by Prof. D. Dubina that showed an interesting and comprehensive study devoted to improve the resilience and robustness of reinforced concrete (RC) buildings by means of steel strengthening systems, covering both traditional types (e.g. conventional steel bracing) up to innovative types (e.g. dissipative braces and devices). In addition, several examples of seismic and energetic retrofit of existing RC panel buildings that are typical of eastern Europe. On the basis of experimental and numerical results, the Authors highlighted the suitability of metal systems that are viable solutions to guarantee adequate structural efficiency, especially in those cases where the concrete panels are weakened by means of wide openings.

   b. *"RETROFIT OF EXISTING RC BUILDINGS WITH DIAGRIDS ADOPTING A HOLISTIC-SUSTAINABLE DESIGN FRAMEWORK" by Labò S., Passoni C., Zanni J., Marini A., Belleri A., Riva P.:*

   In this paper another example of retrofit intervention of existing RC buildings was shown. S. Labò presented this interesting study that focuses on the use of exoskeleton made of diagrid external systems. Diagrid exoskeletons are a new holistic and sustainable technique for the deep renovation of existing RC buildings under a seismic, energy, and architectural point of view. Indeed, the exoskeleton can be conceived by addressing the Life Cycle Thinking principles, not also implementing eco-efficient materials but also guaranteeing reparability, adaptability, and demountability, selective dismantling and reusability of each component at the end of life. In order to achieve these goals, the cross section of the diagonal members can be designed by limiting the roof displacement to reduce the damage into the existing building in the case of a seismic event. This would reduce the waste production and the repair works in the aftermath of a seismic event, thereby reducing the costs and CO2 emissions connected with reconstruction and with debris disposal.

   c. *"DEGRADATION OF CONCRETE", by Black L.:*
   Prof L. Black presented a comprehensive overview of the main issues influencing the durability of concrete. He also highlighted the main criticisms encountered in the field of building constructions, as well as giving useful insights for the next trends of the research in the field of material engineering for application in civil engineering.

2. **Assessment/performance based**

   a. *"MEASURES FOR REDUCING VULNERABILITY OF BUILDING STRUCTURES DUE TO EXPLOSIONS" by Dinu F., Marginean I., Ghicioib E., Pasculescu V., De Iuliis E. and Khalil A.:*

   This article was presented by Prof Dinu, which shown a very interesting research activity carried out to investigate the progressive collapse of reinforced concrete buildings (both large panel and framed systems) when exposed to pressures generated by internal gas explosions or close in detonations. The examined structural archetypes are representative of building solutions of North and Eastern Europe and designed for gravity and lateral loads but without considering any accidental or seismic loads. Based on the results of the evaluation and considering the potential failure modes, retrofitting techniques are applied to upgrade the critical elements (increase load capacity, tying elements together) and/or to provide additional load-carrying mechanisms.

b. "TOWARDS PERFORMANCE-BASED ENGINEERING OF BUILDING STRUCTURES SUBJECTED TO EXTREME HAZARDS" by Parisi F.:

Prof. F. Parisi showed a numerical study devoted to evaluate the structural safety against extreme events through a probabilistic mathematical framework that applies to both threat-dependent and threat-independent approaches. The former is based on the identification and modelling of the abnormal load, whereas in the latter, the structural system is subjected to a prescribed local damage that typically consists of a notional removal of one or more vertical load-bearing components. This study shows the limits of current deterministic methods of structural assessment against abnormal loads in favour of a rational and effective Performance-Based Robustness Engineering. Indeed, this methodology allows decision makers to evaluate and manage large uncertainties in abnormal loads and nonlinear structural response.

c. "RISK ASSESSMENT PROCEDURE OF REINFORCED CONCRETE STRUCTURES DUE TO ACCIDENTAL EVENTS" by Szylak K.:

In line with the previous study, Dr K. Szylak presented a procedure for analyzing and assessing the risk associated with the occurrence of accidental actions or/and events and taking into account the fuzzy nature of uncertainties related to risk factors. Hazards and probabilities of their occurrence were calculated on the basis of failures statistics of buildings with reinforced concrete frames. Based on the structural analysis, possible local damages were identified and their impact on the state of the entire structure as well as their global consequences were determined. The risk acceptability criterion was determined in accordance with Eurocode reliability indexes.

3. Design rules for new structures

a. "DESIGN CRITERIA FOR BOLTED JOINTS UNDER COLUMN LOSS" by D'Aniello M. and Landolfo R.:

This contribution focused on the design rules of steel connection in the case of column loss scenario. The rules and requirements that were shown and discussed are conceived to enforce local ductile behaviour to accommodate large rotation without strength degradation of the connections. The proposed design criteria can be also easily implemented in all typed of bolted connections for both steel structures and steel-to-concrete systems.

Concluding remarks

On the basis of the brief overview of all technical notes as well as the discussion among the participants at the end of the session, the following remarks can be drafted:

- The use of steel systems to retrofit existing RC panel and frame buildings are effective to enhance robustness and resilience, allowing also to improve the sustainability within the entire life cycle.
- Probabilistic procedures to assess the structural robustness are the more appropriate to predict the structural performance accounting for the uncertainties in abnormal loads.
- Existing European codes do not provide adequate rules and requirements to enhance the structural robustness. On the contrary, European research findings cover the most of the lacks of current Eurocodes.
- Further efforts are necessary to improve and implement methodology and guidelines for the appropriate maintenance of existing constructions.

Keynote Lecture

USING STEEL SOLUTIONS TO ENHANCE SEISMIC RESILIENCE OF REINFORCED CONCRETE BUILDINGS

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&
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INTRODUCTION

Structural renovation of existing buildings, particularly those of masonry or reinforced concrete structures, is a difficult task for the construction sector, as structural, social and economic factors need often to be considered simultaneously. The problem is even more demanding in earthquake prone areas – e.g. the Balkan and Mediterranean countries – where existing buildings should withstand moderate to severe seismic actions.
Nowadays, in addition to prevention of structural collapse and save of human lives in case of strong earthquakes, seismic design procedures should support the application of advanced and/or reversible technical solutions for seismic upgrading, which in turn enable the reduction of the intervention cost disruption of activities. This means that the strengthening solution must provide *robustness* to the structure and recovery of building functionality in a short time – which is called *seismic resilience*.
In terms of structural mechanics, a robust structure is characterized by redundancy, which can be achieved by a proper conception and detailing, a good balance between stiffness, strength and ductility of components to provide alternative routes for loads transfer. Redundancy can therefore ensure that, in case of a localized failure, safe alternative load paths develop in the structure.
Concrete and masonry buildings which are not designed to resist any seismic loads do not typically possess the mechanical properties required by robustness. Also, if technical solutions to enhance resistance of such buildings may be available, there might not be able to provide ductility, which is essential for reducing the seismic design forces.
The paper introduces some general principles of Robust Performance Based Design and summarizes the seismic retrofit schemes usually applied in case of concrete buildings. Also, three case studies are presented to illustrate the application of steel retrofitting solutions for non-seismic designed buildings.

PRINCIPLES OF ROBUST PERFORMANCE BASED DESIGN

A large part of the existing buildings has been designed and constructed without adequate provisions for seismic resistance. Therefore, they are likely to suffer significant damage even for moderate earthquakes. To avoid collapse of these buildings in case of a severe earthquake, structures need to be strengthened, thus creating a more robust structure. If intervention eases the repairing of the structure and the recovery of its functionality, then it becomes more resilient.
Seismic resilience can be defined as the ability of a system to reduce the chances of a shock, to absorb a shock if it occurs and to recover quickly afterwards (Bruneau et al., 2003). More specifically, a resilient system shows:
- reduced failure probabilities;
- reduced consequences from failures, in terms of lives lost, damage, and negative economic and social consequences;
- reduced time to recovery.

Figure 1 presents the functionality vs time for different target functionalities and recovery paths. After disruptive event at t_0, it might be decided to reach a higher (1) or lower (2) level of functionality compared to the initial one. The dashed line 3 illustrates the case of a subsequent event that occurs during the recovery period. Line 4 corresponds to the case that no action is taken to restore, the functionality and the asset is left to degrade. For simplicity, a linear recovery path is often assumed, but other paths are possible, as indicated by lines 5 and 6.

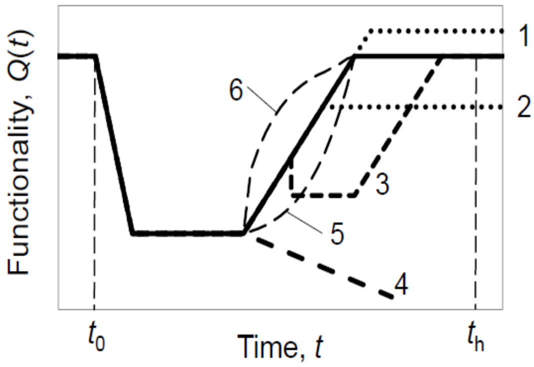


Figure 1. Functionality versus time for different target functionalities and recovery paths (Tsionis et al. 2017).

The intervention strategy may target different structural properties (strength, stiffness, ductility), see Figure 2. For example, by concentrating the plastic deformation in fuse replaceable elements, which are in-charge to provide the required ductility for seismic energy dissipation, the rest of the structure remains predominantly elastic during the earthquake.

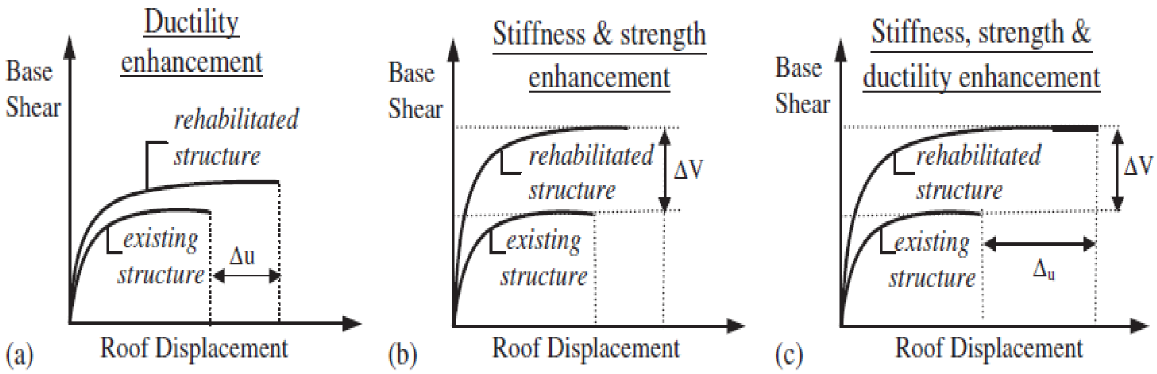


Figure 2. Intervention options: a) ductility enhancement; b) stiffness and strength enhancement; **c)** stiffness, strength and ductility enhancement.

In the case of seismic upgrading of existing building, it is recommended to apply reversible solutions as they allow the original solution to be replaced with a better one when technological developments or financing allow it. There are several reversible technical solutions, each characterized by a certain ability to improve the strength, stiffness or ductility of the system, see Table 1. Apart from the technical and structural criteria, the choice of the final solution must also consider the economic factors, see Table 2.

Table 1. Reversible intervention techniques.

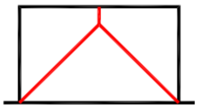
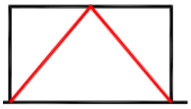
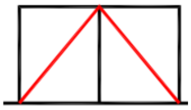
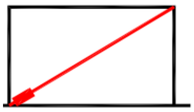
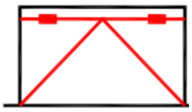
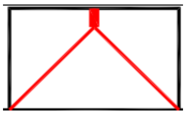
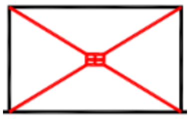
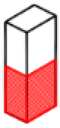
Device		Intervention type	Reversibility	Appearance
Eccentrically braced steel frames		Reduction of drift demands, energy dissipation	Very good, interaction with the existing structure only at connections	Good, may be hidden in walls. In open bays may impair appearance
Buckling restrained steel frames	 			
Pin INERD	 			
Viscous and magneto-rheological dampers				
Visco-elastic dampers				
Friction dampers				
Steel plate shear walls				
Fibre reinforced plastics	 	Improvement of strength and ductility	Very good, easy removal	Very good, concealed by plastering

Table 2. Criteria for selection of intervention strategies.

Technical aspects	**Reversibility of intervention**, Compatibility, Durability, Corrosion, UV resistance, Aging, Creep, Local conditions, Availability of material/device, Technical capability, Quality control
Structural aspects	**Structural performance** (Strength, Stiffness, Ductility, Fatigue), Response to fire, Sensitivity to changes of actions/resistances e.g. seismic action, temperature, fire, soil conditions, Accompanying measures, Technical support (Codification, Recommendations, Technical rules), Installation/Erection e.g. availability/necessity for lifting equipment
Economical aspects	**Costs**, Design, Material/Fabrication, Transportation, Erection / Installation / Maintenance, Preparatory works

In the following sections three case studies are presented to illustrate the application of steel retrofitting solutions for buildings designed only for gravity loads (non-seismic).

SEISMIC RETROFIT OF A REINFORCED CONCRETE FRAME MULTISTORY BUILDING USING BUCKLING RESTRAINED STEEL BRACES

This study presents the seismic retrofit solutions of a 4 span, 5 bay and 3 story reinforced concrete frame building, designed based on the provisions of the old codes in force in the 1940's (
Figure **3**).

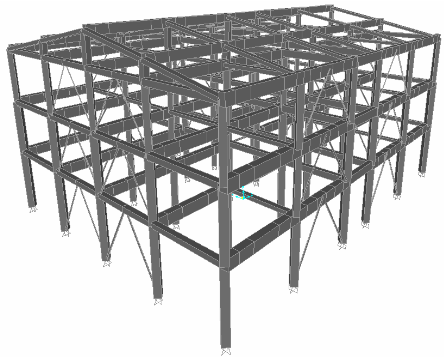


Figure 3. Reference non-seismic designed reinforced concrete frame building.

Five different solutions have been tested, i.e. (1) conventional concentric bracing systems; (1) conventional eccentric bracing systems (EB); (3) Buckling restrained braces (BRB); (4) Steel Plate Shear Walls (SPSW); (5) Light Gauge Steel Walls (LGSW) corrugated cold formed sheeting. In the following, only the BRB solution is presented in detail, including the tests realized in the Laboratory of Politehnica University Timisoara (PUT) to validate the technical solution and calibrate the numerical model (Dubina and Bordea, 2010; Dubina at al., 2011; Dogariu et al., 2012).
To evaluate the capacity of the BRB element, first a sub-assemblage test has been performed including two monotonic tests (one in tension and one in compression) and two cyclic tests (see Figure 4). For the cyclic tests, two loading protocols were applied, i.e. AISC (2005) and ECCS (1985). The main difference between the two cyclic loading protocols is related to the different number of cycles per loading amplitude. Thus, due to the larger number of cycles, specimens tested under ECCS loading protocol can be more prone to fail due to low cycle fatigue compared to AISC 2005. Figure 5 shows the backbone curve derived from cyclic tests and the monotonic curves (Figure 5). The experimental results have shown a good performance of the BRB, large deformation capacity and a very stable behavior under cyclic loading.

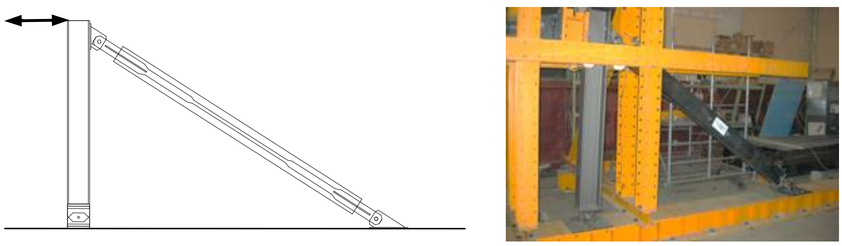


Figure 4. Sub-assembly test setup.

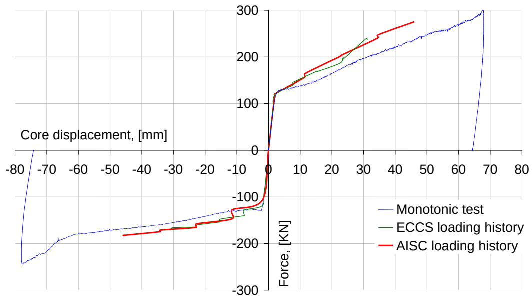


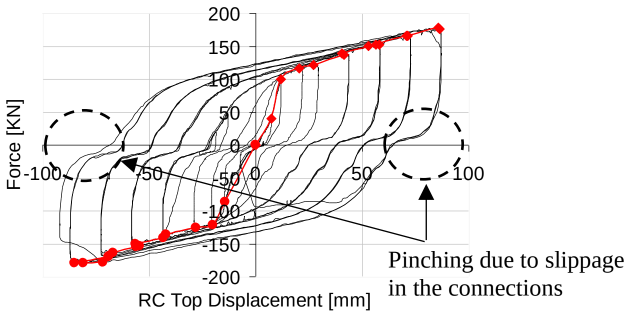
Figure 5. Monotonic tests vs. the envelopes from AISC and ECCS loading protocols, polyethylene film debonding material.

Following the tests on BRB elements, a RC frame was isolated from the case study building (Figure 3) and was strengthened with BRB. The test set-up, the loading system and the specimens installed in the testing rig are presented in Figure 6. Pinned connections between BRB and concrete frame elements have been employed. To prevent the slip of the connection between the braces and the RC elements, high strength preloaded ties have been used. The effectiveness of the connecting device has been preliminary checked by FEM simulation. Local pressure on the concrete was also checked, to keep the connection "elastic". The vertical and horizontal displacements of the connections were continuously recorded and plotted during the tests.

a) b)

Figure 6. Testing of a full-scale reinforced concrete frame in the PUT laboratory (a) and connection details for installation of BRB in the frame (b).

Figure 7 shows the hysteresis curve for the RC frame strengthened with BRB and the cracks developed in the concrete frame during test. The connection between braces and RC frame showed a very good behavior, with small slippage during the reversal of the loading (Figure 7.a).



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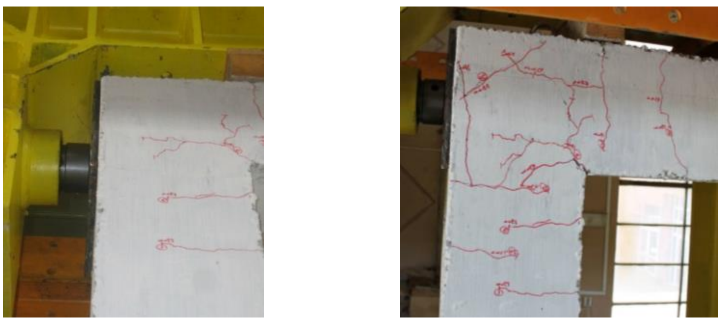


Yielding Peak force

b)

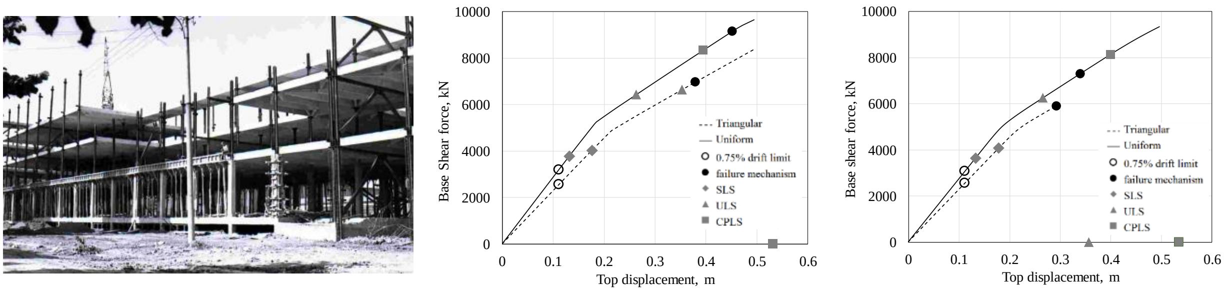
Figure 7. Results of the cyclic test on RC frame strengthened with BRB: a) hysteresis curve; b) cracks in concrete frame during test (CT-2007-00050-STEELRETRO Project, 2013).

STRUCTURAL UPGRADE OF REINFORCED CONCRETE BUILDING FRAMES USING REPLACEABLE HYSTERETIC STEEL-BASED FUSE ELEMENTS

The case study building is a four-story framed building, erected in 1970, with composite steel-concrete columns and special reinforced concrete precast slab panels (Figure 8.a). Building, originally designed for gravity and wind loads, has inadequate capacity for current code requirements (Dubina et al., (2017). The performance of the structure was assessed using the N2 method in accordance with EN 1998, Annex B (Eurocode 8, 2005) and SAP 2000 software (CSI). Two distributions of the lateral loads were applied, i.e. first a "uniform" pattern, based on lateral forces that are proportional to mass regardless of elevation (uniform response acceleration), and second a "modal" pattern, proportional to lateral forces consistent with the lateral force distribution in the direction under consideration (triangular distribution). The analysis was done independently on transversal and longitudinal directions. As seen in Figure 8.b, c, the lateral stiffness is low and the interstory drift limit is exceeded before the attainment of the expected target displacement for SLS. Also, on longitudinal direction, the development of plastic hinges in columns before the attainment of the target displacement for ULS indicated a high risk to life safety.

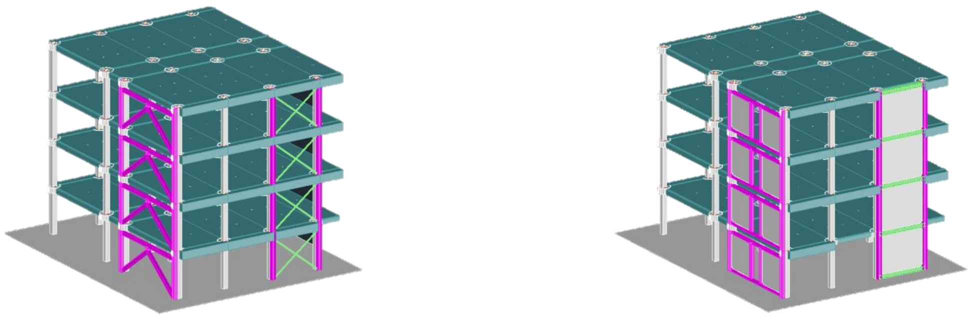
Therefore, two types of steel based solutions are proposed for seismic retrofit, i.e. concentrically (longitudinal) and eccentrically (transversal) bracing system (CB+EB) and steel plate shear walls system on both directions (SPSW) (Figure 9). The strengthening systems, both reversible, are designed and detailed to concentrate and dissipate most of the seismically induced energy, and, additionally, to allow an easy installation and replacement after moderate earthquakes.

For first solution, the existing columns from the braced spans are strengthened using H profiles made from S355 steel, and braces are connected to the H profiles at each floor level using bolted connections. The compressive forces that can develop are transferred, through columns, at the concrete perimeter beam. To avoid the interaction with the concrete floor slab, the vertical link is connected to a steel beam, which is connected to the retrofitted columns.



a) b) c)

Figure 8. Case study building: a) building during construction; b) force-displacement curves for existing structure, longitudinal direction; c) force-displacement curves for existing structure, transversal direction.

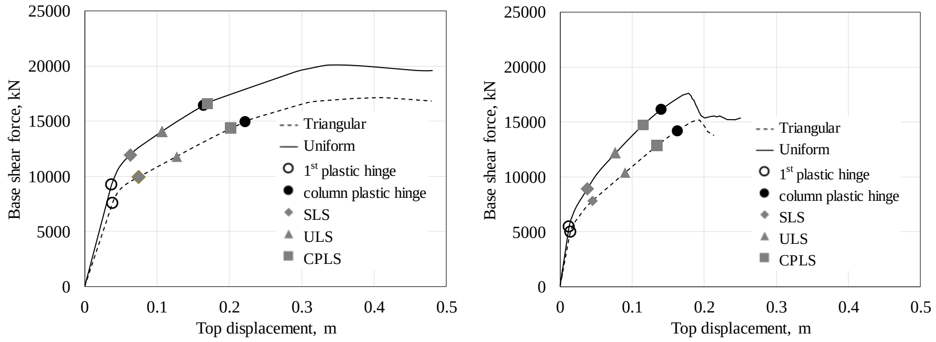


a) b)

Figure 9. Structural upgrade of the existing frame building (detail): a) strengthening with EB and CB; b) strengthening with SPSW.

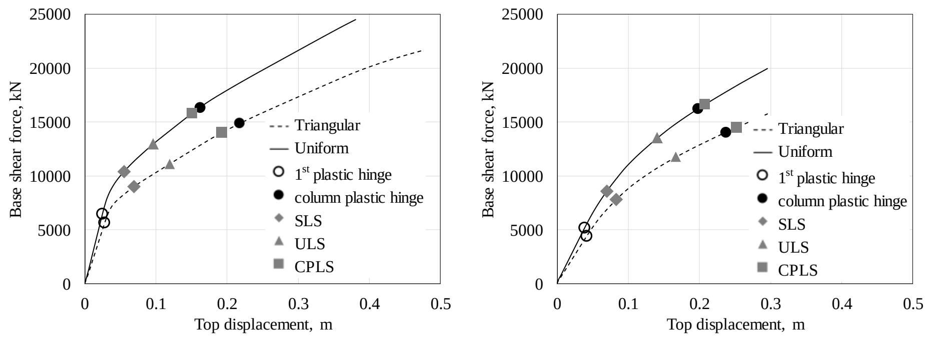
For the second solution, singular and coupled SPSW systems are applied. In the braced spans, the existing columns are strengthened using H profiles made from S355 steel. Additionally, longitudinal

beams are also introduced at each floor level. On the transversal direction, due to large span over height ration, two panels were used, separated by a link beam.
The response of the retrofitted structure has been evaluated using linear and nonlinear (pushover) analyses and SAP 2000 software (CSI). Two distributions of the lateral loads were applied, i.e. “uniform” pattern and “modal” pattern. The analysis was done independently on transversal and longitudinal directions.
Figure 10 and Figure 11. present the force-displacement curves for upgraded structure, for triangular and uniform distribution of lateral forces. Figure 12 and Figure 13 present the distribution of plastic deformations (plastic hinges) at several performance levels on longitudinal frames, while Figure 14 and Figure 15 show the same distribution but on transversal frames. Once plastic hinges develop in the un-retrofitted columns, it is assumed that the structure attains the ultimate capacity. The results are presented separately on longitudinal and transversal direction.



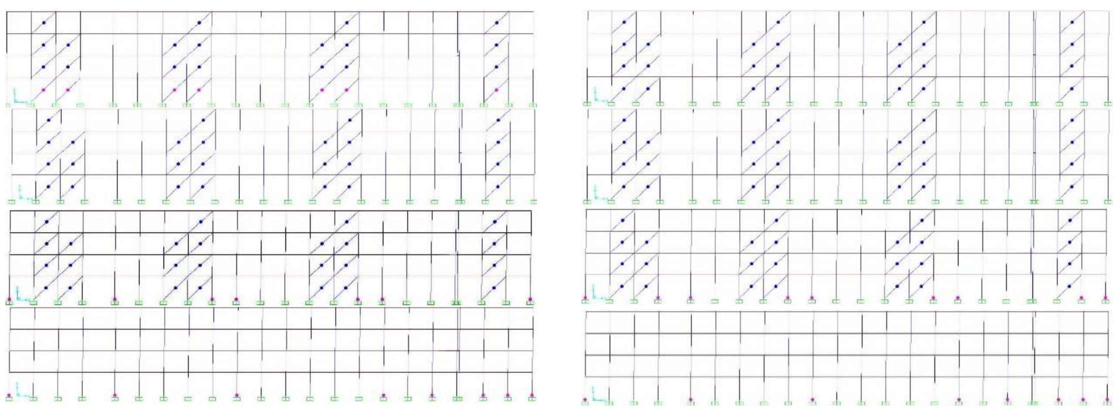
a) b)

Figure 10. Force-displacement curves for CBF+EBF upgraded structure, triangular and uniform distribution: a) longitudinal direction; b) transversal direction.



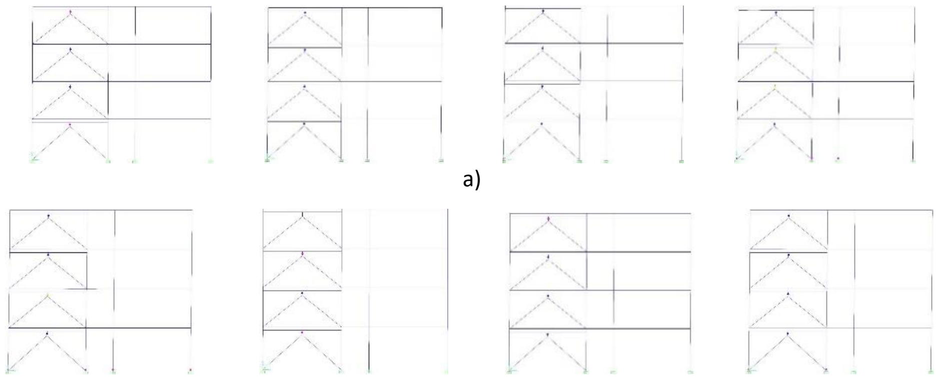
a) b)

Figure 11. Force-displacement curves for SPSW upgraded structure, triangular and uniform distribution: a) longitudinal direction; b) transversal direction.



a) b)

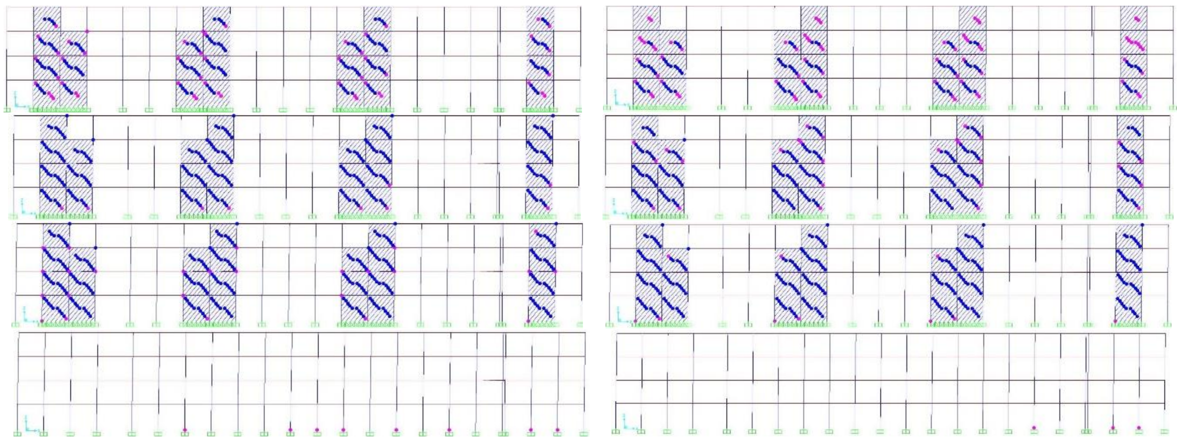
Figure 12. Plastic hinges at the three limit states and collapse for CBF+EBF structure, longitudinal direction: a) triangular distribution; b) uniform distribution.



a)

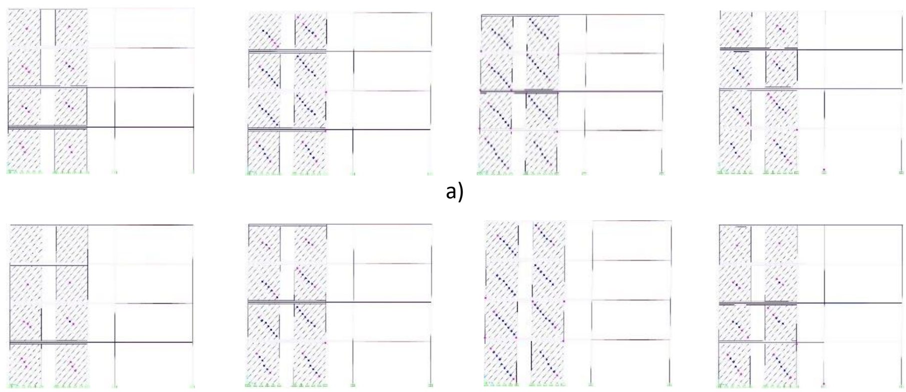
b)

Figure 13. Plastic hinges at the three limit states and collapse for CBF+EBF structure, transversal direction: a) triangular distribution; b) uniform distribution.



a) b)

Figure 14. Plastic hinges at the three limit states and collapse for SPSW structure, longitudinal direction: a) triangular distribution; b) uniform distribution.



a)

b)

Figure 15. Plastic hinges at the three limit states and collapse for SPSW structure, transversal direction: a) triangular distribution; b) uniform distribution.

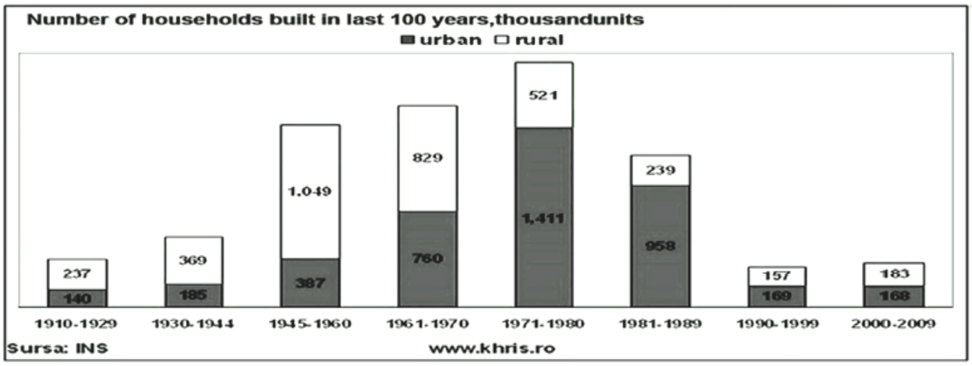
For both retrofitting solutions, first plastic hinges develop before the attainment of the expected target displacement at SLS. With one exception, i.e. SPSW upgraded structure, transversal direction, for all other cases, the expected target displacement for CPLS is attained before plastic hinges develop in un-retrofitted columns. This indicate the performance objectives of the upgraded structure are satisfied, and the risk of collapse is largely reduced. Even in case of SPSW upgraded structure, the structure shows a reserve of capacity after the attainment of the ULS displacement on transversal direction. The plastic mechanism is global in all cases, and the level of plastic deformation requirements is moderate.

The intervention would require also local retrofitting of some columns, for example by means of Fiber-reinforced polymers (FRP). Also, the diaphragm effect of the floor system needs to be improved, possible by adding steel braces at the level of each floor.

SEISMIC RETROFIT OF RESIDENTIAL COLLECTIVE BUILDINGS FROM LARGE PRECAST CONCRETE PANELS

General considerations

According to the data provided by the 2011 Census of Population and Housing, Romania had around 19.0 million inhabitants. Also, 8.5 million dwellings with a total of 22.7 million rooms were inventoried. 52.8% of the population was urban with most multi-apartment buildings concentrated in the urban areas. The number of apartment buildings was around 84000, with 2.5 million apartments. According to the *Census,* over 71% of the existing urban housings were multi-dwellings (e.g. collective buildings), covering an inhabitable area of 66% from the total inhabitable area, as shown in Figure 16 (Eracobuild Project, 2015).



Number of households built with large prefabricated concrete panels "BLOCK" type

TOTAL	de 1910	1910-1929	1930-1944	1945-1960	1961-1970	1971-1980	1981-1989
57431	93	123	239	634	4822	22355	25352
24533	742	976	2341	3397	6667	6059	3497
81.964	835	1.099	2.580	4.031	11.499	28.414	28.859

Households	Area (m)	
8.071.912	303.300.454	RURAL
4.234.173	159.234.576	URBAN
3.021.122	105.245.605	BLOCKS
71.35 %	66.09 %	

Figure 16. Statistics of households built in Romania during 1910 – 2009.

From the 57431 prefabricated panel buildings, most have been built between 1960 and 1990. During 1965-1989, 4 million dwellings were built; more than 150000 each year. The overwhelming majority, i.e. 41540 buildings, have 5 floors. A second group of important typologies are the 9, 10 and 11 floors summing 9180 buildings. All other configurations sum up 7440 buildings, 300 taller than 11 floors, 4920 buildings lower than 5 floors and 2220 buildings having 6, 7 or 8 floors. Practically, the two most widely used typologies in Romania are the 5 floors and the tall ones, of 9 to 11 floors, with very few interior partition configurations (Eracobuild Project, 2015).

It may be important to underline that the tall precast large panel buildings of 8-9 stories have been built since 1973, and only in the capital Bucharest! Figure 17 shows such a 9–story building in Bucharest. The typology of these buildings is characterized by a *„bar"* shape with closely space walls on both directions. Special attention was given to connections between precast elements to achieve the overall monolithic behaviour. This typology of buildings behaved rather well during March 4th, 1977 earthquake (7.4 Mw), when, in a few cases reduced damages only have been observed.

The post-earthquake surveys carried out on precast large panel buildings, particularly focusing tall ones, in Bucharest and Iasi after 1977 earthquake have shown:

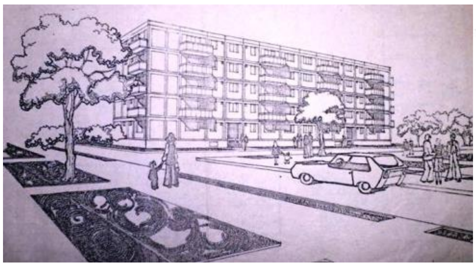
- Damages in Bucharest - cracks in joint areas (especially in the corner joints) between walls, and in the bearing joints between slab and wall; 45º cracks were observed in the panel lintels;
- Damages in Iasi – similar patterns as in Bucharest; nevertheless, the amount of damage being larger, a little, in this case, due to higher frequency content of the strong ground motions, as compared to Bucharest; quasi-resonance more important in Iasi.

The other strong earthquakes in the past 40 years (1986, 1990) did not change the perception on the seismic response of prefabricated buildings, of which seismic response capacity seems to be rather good! Even damages still have been observed, they have been repairable, and no collapses were recorded.

Figure 17. Typical 9-story precast large panel block of flats built in Bucharest since 1973.

Rehabilitation of collective buildings of large precast concrete panel located in a moderate seismic risk area

A systematic study has been conducted on the existing building stock for the City of Timisoara for the standardized collective building typology “T744R-IPCT”. For these residential collective buildings, built with large precast concrete panels and widely used in urban development within 1962-1975 period, practically no measures have been taken for seismic protection. At that time Timisoara was considered a low seismicity zone, while at present, the design ground acceleration is 0.20 g. The structure of these units is entirely made of precast concrete panels assembled on site. These panels were fabricated on specialized construction sites and transported to the building site. Unit T744R has a longitudinal internal wall made of precast concrete panels, and 6 transversal interior walls. Precast panels in these walls are single layered, using 14 cm thick B250 (C16/20) class reinforced concrete. The staircase is positioned at the middle of the building (see Figure 18).



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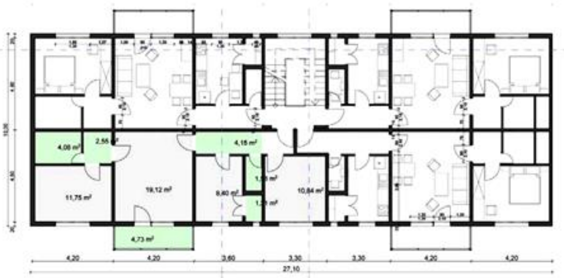

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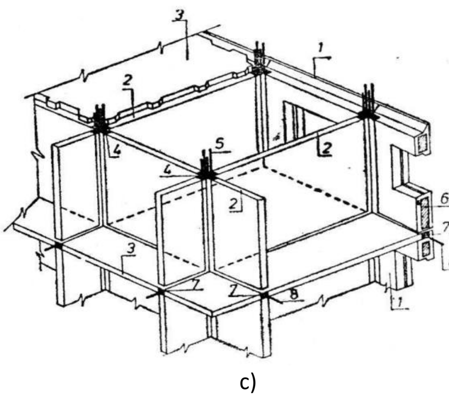

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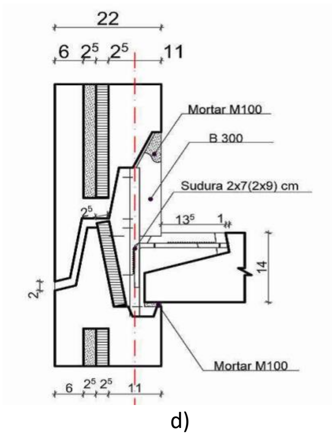


d)

Figure 18. T744R-IPCT: a) general layout; b) currently used floor partition; c) system scheme; d) external joint detail (Botici et al., 2011).

Since the buildings are in a seismic area, the structural rehabilitation must follow two objectives:

1. *Obtain the extension of existing flats* through coupling adjacent. This kind of intervention imposes the reorganization of interior areas and needs for that some major interventions on partition walls, which are also acting as structural diaphragms.
2. Insert steel frames into the panelized R.C. structure, to substitute the structural function of locally removed walls and, if possible, to enhance the strength, stiffness and, particularly, the *ductility of the whole system*.

However, structural rehabilitation alone is not enough. It also needed to improve interior finishing and building services, common spaces and facades, and, compulsory, the thermo-energetic performance. The present study deals with structural interventions, only.

The inhabitable areas in the units built before 1975-1982 are small (27 - 33m^2/apartment) and are built with rigid partitioning walls. From this point of view buildings may require special attention in the reorganization of the interior.

Reconfiguring through practicing large openings in the load bearing elements must be done in a coherent way for a whole building, so as not to affect the ability of the structure to resist loads. The final 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 (Figure 19.a). Two solutions can be applied: story steel frames connected vertically through the floors and vertical panels (Figure 19.b); vertically continuous column frames (Figure 19.c).

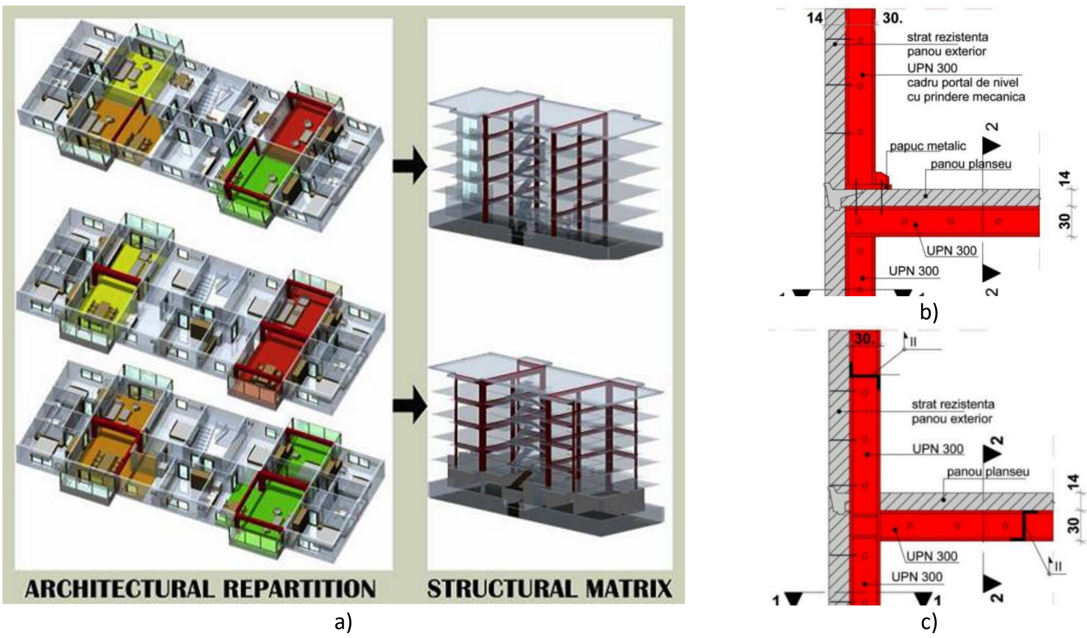
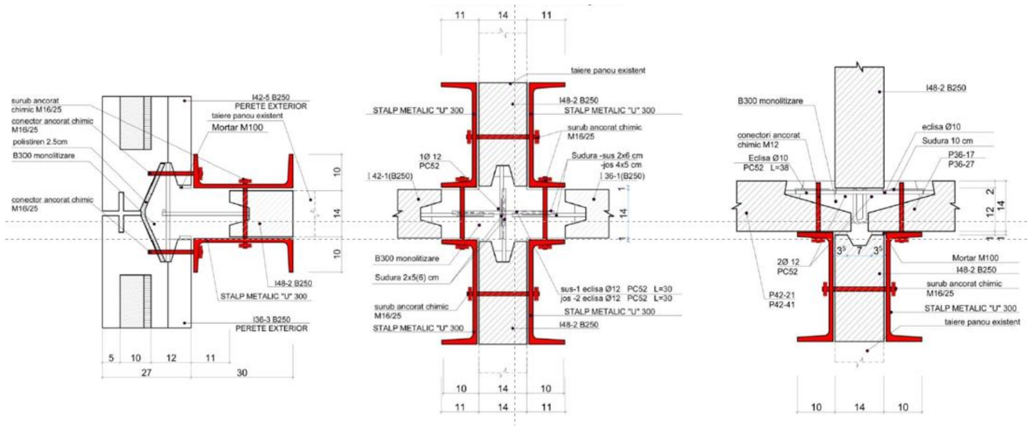


Figure 19. Scheme of proposed intervention: a) repartitioning of the floor and structural matrix; b) floor steel frame insertion; c) vertically continuous steel frame columns insertion (Botici et al., 2012).

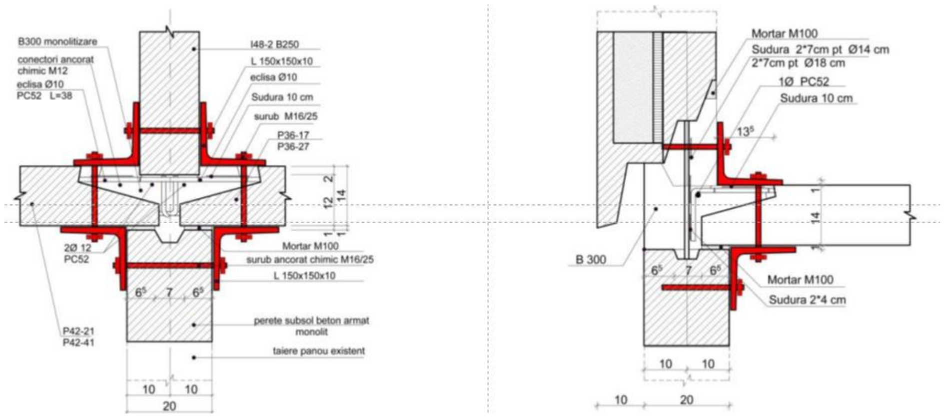
The steel intervention solution was aiming to obtain composite sections for both beams and columns of the frames inserted instead of walls (Figure 20). Since following the replacement of panels, higher shear and bending stresses might be expected, attention was paid to strengthen the vertical and horizontal joints (Figure 21).

On the purpose to observe and quantify the composite action obtained through these interventions, full scale tests (Figure 22) accompanied by numerical simulations with ABAQUS ATENA software (Figure 23) have been conducted on composite joints in the UPT Laboratory to find and evaluate the effectiveness of joints between steel frames and R.C. structure.



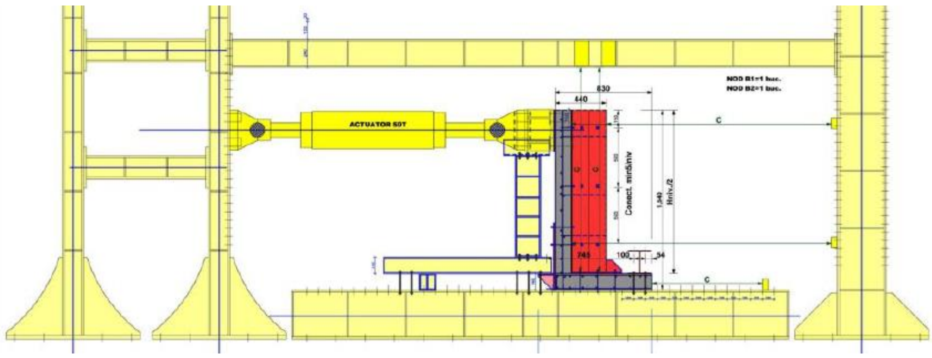
a) b)

Figure 20. a) Internal and external composite columns; b) composite beam.



a) b)

Figure 21. Strengthening solutions applied to reinforce vertical (a) and horizontal (b) joints between panels.



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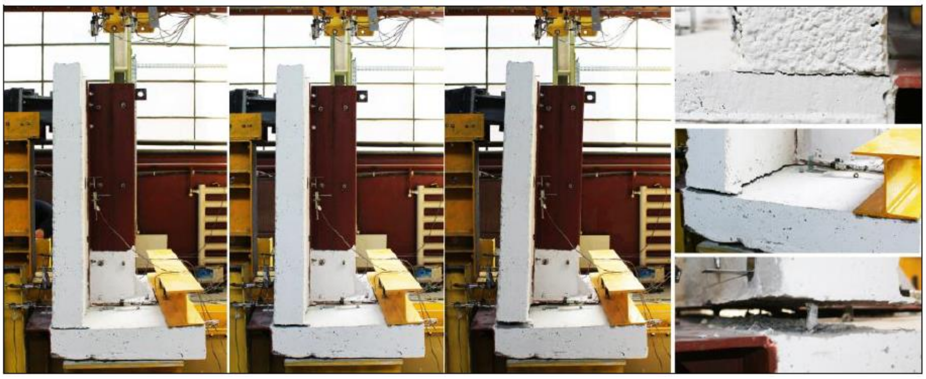

b)

Figure 22. Testing set-up for joint specimens (a) and a sample of test images (b).

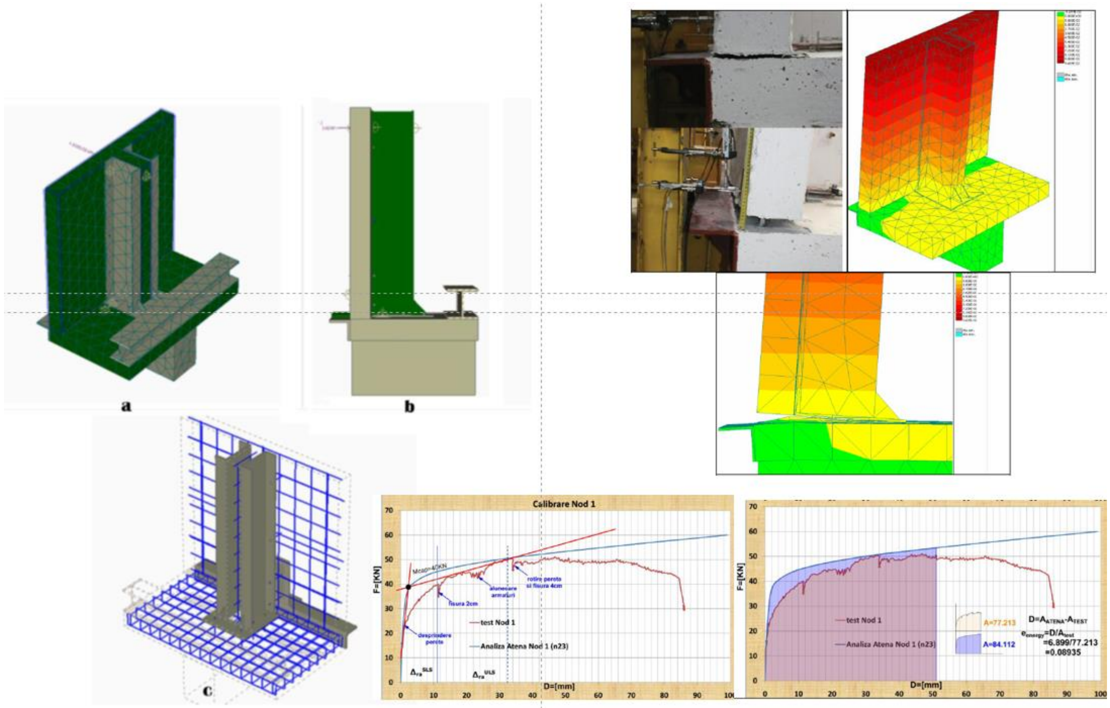

Figure 23. Collage of pictures with numerical models, stress distribution and comparison test vs. numerical Force-Displacement curves (Botici, 2014).

Based on these results, the frames composed by composite columns and beams, considered with rigid and full-strength beam-to-column joints have been numerically evaluated. The results obtained in this stage of research confirmed the potential of proposed solution (Botici, 2014). However, accounting for importance of this problem of refurbishment of collective buildings of precast concrete large panels, and the large area of application of prosed solution, still is necessary more research development; particularly a large-scale 3D model test on shaking table or pseudo-dynamic facility are necessary for validation.

CONCLUSIONS

The study introduces some general principles of Robust Performance Based Design and summarizes the seismic retrofit schemes usually applied in case of concrete buildings. The current seismic design codes of buildings focus primarily on minimum safety requirements, without allowing direct control of damage (repair costs, duration of activity interruption). This can lead to the design of buildings that resist earthquakes but cannot be repaired for functional or economic reasons after a strong earthquake. This philosophy also applies to the seismic modernization of old buildings!

Three case studies were presented to illustrate the application of steel retrofitting solutions for buildings designed only for gravity loads (non-seismic). Experimental tests and numerical simulations were carried out to verify the effectiveness of proposed intervention solutions.

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MEASURES FOR REDUCING VULNERABILITY OF BUILDING STRUCTURES DUE TO EXPLOSIONS

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ABSTRACT

Explosions bring a serious risk of damage or collapse when are produced inside buildings or in the close proximity. As the hazard intensity and possible effects are difficult to quantify, the structure should have the capacity to survive with inherent damages, thus preventing the progressive or disproportionate collapse. The measures for increasing progressive collapse resistance should be calibrated with reference to the type of structure analysed, and, in general, follow some common principles, e.g. hardening structural elements, providing additional load transfer routes or improving the continuity and tying. For existing buildings, strengthening may be necessary to provide or improve such abilities. In the paper, response against explosions of multi-story buildings is investigated and different intervention strategies are applied, considering both their efficiency and ease of application.

Keywords: gas explosion, accidental action, alternate load path, robustness.

INTRODUCTION

The development of design guidelines for multi-story buildings to resist propagation of collapse following a local damage started in 1968, with the partial collapse of the 22-story precast concrete building at Ronan Point, London, due to a gas explosion (NISTIR 7396, 2007). The failure of the building was considered disproportionate compared to the initial cause and later identified as "progressive collapse". Decades later, intentional attacks against Murrah Building in Oklahoma City (1995) and the World Trade Center (2001) led to an intensification of research and provisions for the avoidance of progressive collapse were incorporated in building codes (EN1991-1-7, 2006; UFC 4-023-03, 2016). The requirements introduced by these new standards are intended to produce more robust structures, and thus less susceptible to disproportionate failure due to various causes, in case of extreme loading conditions (e.g. gas explosions, detonation of high explosives). For existing buildings however, retrofitting may be necessary to provide or improve such abilities. In the paper, response against explosions of multi-story buildings is investigated and intervention strategies are applied where necessary.

RESULTS

The study investigates the progressive collapse potential of reinforced concrete buildings (large panel systems, framed systems) when exposed to pressures generated by internal gas explosions or close in detonations, see Fig.1. The structures are designed for gravity and lateral loads but without considering any accidental or seismic loads. Accidental loading conditions, as for example the explosions, involve different pressure loads obtained from relevant experimental tests, see Fig.2. Thus, for internal gas explosions, the pressure depends on size, shape and the strength of the enclosure (partition walls included), and the amount of venting or pressure release. On the other hand, the blast pressure decays exponentially with the distance from the charge, providing an adequate standoff will substantially reduce the exposure of the building and the damage to the structural elements. Based on the results of the evaluation and considering the potential failure modes, retrofitting techniques are applied to upgrade the critical elements (increase load capacity, tying elements together) and/or to provide additional load-carrying mechanisms.

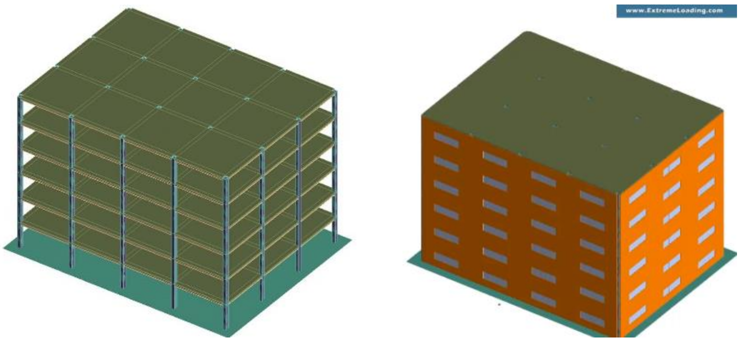

Figure 1. Structural skeleton of the reference building (left) and exterior cladding (right).

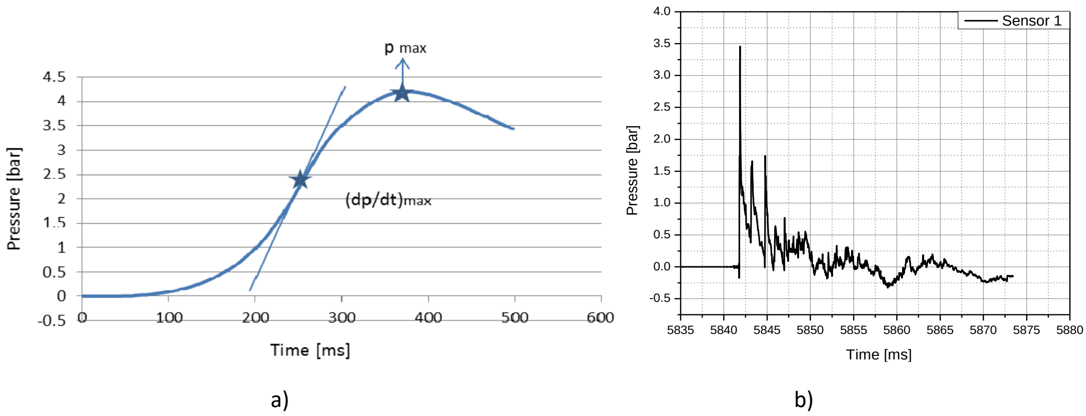

Figure 2. Calibration of numerical models: a) explosion pressure - time curve for a mixture of methane concentration of 6% air volume temperature of 20ºC (Prodan et al., 2014); b) pressure - time for 1815 g of high explosive (Dinu et al., 2017).

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PROCEDURE OF RISK ANALYSIS FOR RC FRAME STRUCTURES EXPOSED TO EXTREME EVENTS

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ABSTRACT

For buildings of the highest consequences class, i.e. objects whose failure causes a high risk to human life or very large economic, social and environmental consequences, it is recommended to carry out a systematic risk assessment and analysis. This analysis should take into account both predictable and unpredictable hazards that are often equated with accidental actions. Difficulty in identification of hazards and probabilities of their occurrence as well as in the sequence of exceptional events is the main reason that the detailed procedure for conducting the risk analysis for buildings structure caused by accidental actions has not yet been developed. Another issue that creates difficulties in the development of such a procedure is the determination of risk acceptance criteria that would allow for the design of safe structures in the accidental design situations.

The paper presents a procedure for analyzing and assessing the risk associated with the occurrence of accidental actions or/and events and taking into account the fuzzy nature of uncertainties related to risk factors. Hazards and probabilities of their occurrence have been calculated on the basis of failures statistics of buildings with reinforced concrete frame structures. Based on the structural analysis, possible local damages were identified and their impact on the state of the entire structure as well as their global consequences were determined. The risk acceptability criterion has been determined on the basis of the recommended in Eurocode minimum values of reliability index and reference period.

The developed procedure was used to the risk assessment of reinforced concrete frame structures but it can be applied also to different types of building structures.

INTRODUCTION

Statics of structural failures happened in Poland in 15 years, can give us information about main causes of structural damage and collapse. In group of this causes are accidental loads and accidental situations, which can be assigned to the one group - extreme events. Extreme events are very unlikely happening and difficult to predict, but generate the high costs of its consequences. Unfortunately, they are not included in designing process, but they are very often the reasons of building failures.

The highest number of structural failures in Poland are caused by the severe wind. The high number also have group connected with building process (design, construction and user errors) and snow (less pond) effect (Figure 1).

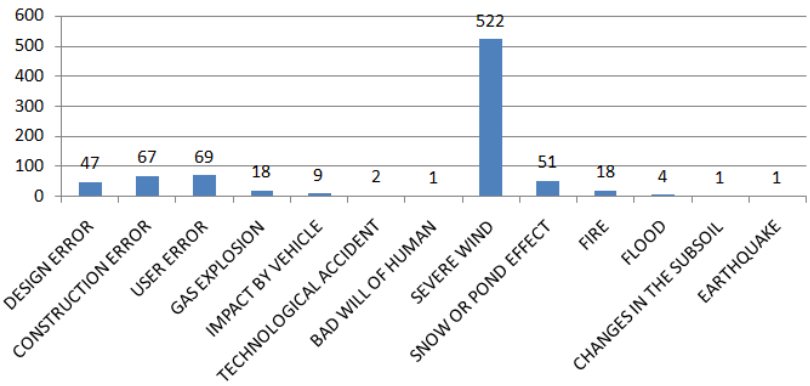
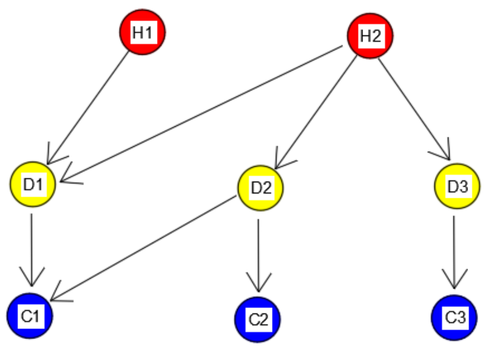


Figure 1. Main reasons of structural failures happened in Poland during the last 15 years (GUNB Poland; ITB Poland).

In Eurocode, structures are classified to three groups of low, medium or high consequences for injuries and loss of human life or very great economic, social and/or environmental consequences. For constructions from the third class of consequences - most of public building - a systematic risk analysis is recommended, which must include predictable and unpredictable hazard. It is way to include the extreme events in designing process (Eurocode 0).

LITERATURE REVIEW

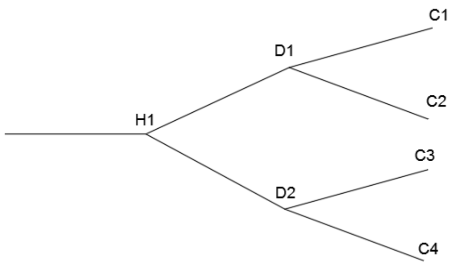
In civil engineering risk is a combination of the probability of an event occurrence and the magnitude of its consequences. There are two general methods of risk analysis: qualitative and quantitative [1].
In qualitative risk analysis all the hazards and possible scenario are identified after their occurrence. There are a lot of method to present hazard scenario: AHP, HAZOP, fault tree, event tree, causal networks (Eurocode 0).
In quantitative method probabilities of hazard occurrence and their consequences are estimated. Generally are two formulas to estimate the risk value. Nest are needed an acceptance criterion to compare the risk value.



(a)

Frequency/ Consequences	Remote	Occasional	Probable	Frequent
Low	Low	Low	Medium	High
Medium	Low	Medium	High	Unacceptable
High	Medium	High	Unacceptable	Unacceptable

(b)



(c)

Figure 2. Methods of qualitative risk analysis: a) AHP, b) HAZOP, fault tree (Harding and Carpenter, 2009; JCSS, 2008; Knoll and Vogel, 2009).

First formula from Eurocode (Eurocode 0; Wolinski, 2014) defines risk as product of probabilities of hazards occurrence and their consequences:

$$R = \sum_{i=1}^{n} p(H_i)\, C\,(H_i)$$

$p(H_i)$ - probability of hazard occurrence
$C(H_i)$ - consequences of hazard occurrence
Second formula from ISO (1998; 2009; 2018) define second part - the consequences as product of probability of local damage, probability of global effects and consequences (costs):

$$R = \sum_{i=1}^{N_H} p(H_i) \sum_{j}^{N_D} \sum_{k=1}^{N_S} p\big(D_j|H_i\big)\ p\big(S_k|D_j\big)\ C(S_k)$$

$p(H_i)$ - probability of hazard occurrence
$p\big(D_j|H_i\big)$ - conditional probability of the damage state of the structure given in the hazard
$p\big(S_k|D_j\big)$ - conditional probability of the adverse overall structural performance given in damage state
$C(S_k)$ - consequences

The structure can be subjected in N_H different hazards, that may damage the structure in N_D different ways and the performance of the damage can be discretised into N_S adverse state S_k wi the corresponding consequences $C(S_k)$.

To compare value of the risk are needed risk acceptance criteria, which can be expressed by value or monogram (Fig. 3). One of risk acceptance criterion is index of risk defined as total risk divided by acceptable risk. Acceptable risk is product of probability of failure and total costs of the structure.

$$i_R = \frac{R}{R_{ac}}; \quad R_{ac} = p_{fd}(RCX, T_0)\, C(S)$$

R - total risk for building value

R_{ac} - acceptable risk value

$p_{fd}(RCX, T_0)$ - probability of structure failure for RCX class of consequences and design period T_0

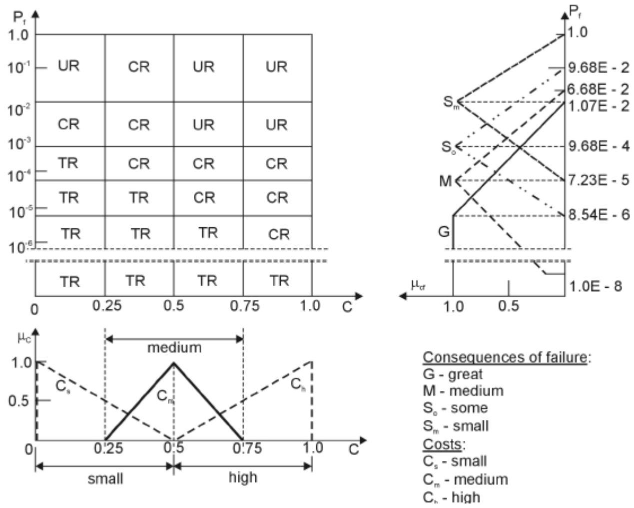


Figure 3. Risk acceptance criterion expressed by monogram (Woliński, 2003).

SUGGESTED PROCEDURE OF RISK ANALYSIS

Procedure of risk analysis

Suggested procedure of risk analysis is based on modified formula from ISO (1998; 2009; 2018):

$$R = \sum_{i=1}^{N_H} \tilde{p}(H_i) \sum_{j}^{N_D} \sum_{k=1}^{N_S} \tilde{p}(D_j|H_i)\ \tilde{p}(S_k|D_j)\ \tilde{C}(S_k)$$

All components of this pattern are described by means of fuzzy numbers with triangular membership functions (Fig. 4), because of their uncertainty.

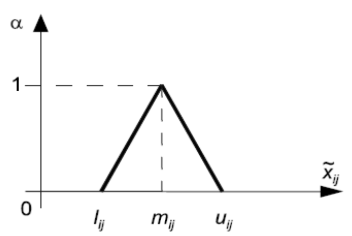


Figure 4. Fuzzy member with triangular membership function.

At the end risk value goes back to deterministic factor using the formula for specific gravity:

$$s_i = m_i + \frac{u_i^2 + 2\, m_i(l_i - u_i) - l_i^2}{3\,(u_i - l_i)}$$

s_i - medium value

l_i - the lowest value of fuzzy number
m_i - medium value of fuzzy number
u_i - the highest value of fuzzy number

The procedure of risk analysis includes next steps:

- identify the possible hazard for analyzed structure,
- identify the possible scenario after hazard occurrence (possible local damage, possible global effects and consequences)
- estimate probability of hazards occurrence, local damage, global effects and consequences value (costs),
- calculate risk value for hazards, group of hazards and total risk for a buildings using suggested formula,
- calculate value of the acceptable risk,
- compare acceptable risk value with risk value for hazards, group of hazards and total risk for a buildings,
- find the hazards or group of hazards, which have the highest influence on total risk value,
- find the solution to increase the total risk value.

Hazards

The possible hazards for buildings are classified to three group dependent on:

a) Building process:
- design error,
- construction error,
- user error.

b) Human activity:
- gas explosion,
- impact of vehicle,
- technological accident,
- bad will of human.

c) Environmental effects:
- severe wind,
- snow or pond effects,
- fire,
- flood,
- changes in subsoil,
- earthquake.

For all hazards three values of occurrence probability for maximum, medium and minimum number of being cause of structure failure for RC frame constructions in Poland are calculated (Figure 5).

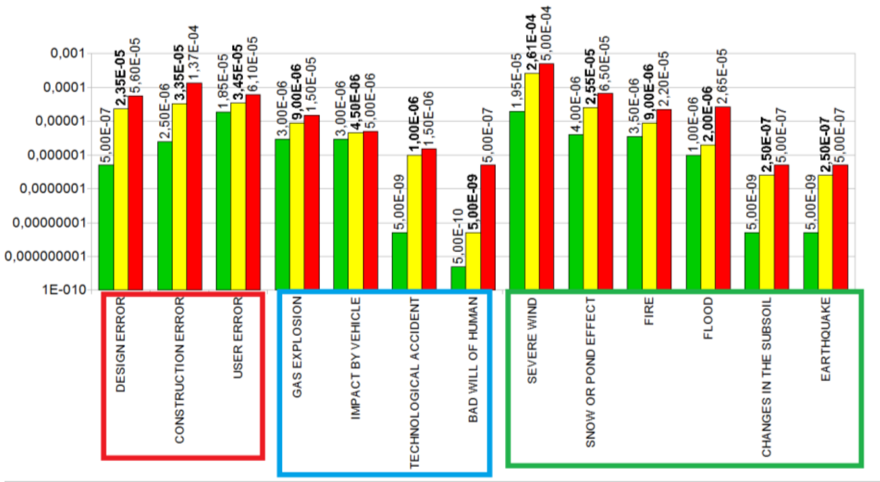


Figure 5. Probability of hazards occurrence for RC frame structure.

Consequences

In RC frame structure there are four possible types of local damage concerning: slab; beam; column and joints.

Local damage can generate the global effects, which are classified to the following groups (Figure 6):

- negligible damage,
- partial collapse,
- partial collapse with human injuries or deaths,
- collapse of the building.

Figure 6. Global effects of local damage.

Consequences are calculated as relative value dependent of the total costs of a structure (Figure 7). Costs of consequences include:

- damage costs (construction, elements, equipment),
- damage removing costs (reconstruction or demolition costs),
- injuries and deaths costs (treatment and insurance),
- other costs (environment pollution, rebuilding the infrastructure, etc.).

CONSEQUENCES	MINIMAL LEVEL OF COSTS				RELATIVE COSTS
	DAMAGE COSTS	DAMAGE REMOVING COSTS	HUMAN LOSS COSTS	OTHER COSTS	
EXTREME	EXTREME	EXTREME	EXTREME	HIGH	> 1,0
HIGH	HIGH	HIGH	HIGH	MEDIUM	0,75-10
MEDIUM	MEDIUM	MEDIUM	MEDIUM	LOW	0,5-0,75
LOW	LOW	LOW	LOW		0,25-0,5
VERY LOW	LOW	LOW			0-0,25

Figure 7. Consequences.

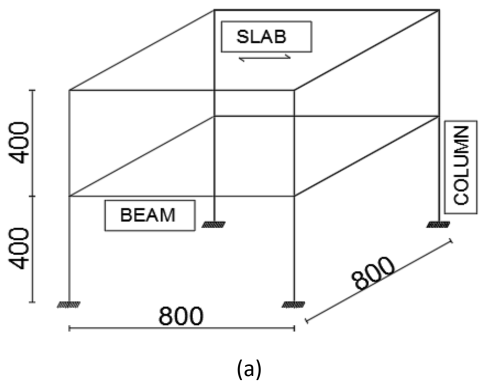
Risk acceptance criteria

Risk acceptable criterion is adopted acceptable risk from risk index formula. It is defined as product of probability of structure failure from consequences class RCX with design period equal T_0 and total costs of the structure:

$$R_{ac} = p_{fd}(RCX, T_0)\, C(S)$$

EXAMPLE

The shopping centre from class CC3 are analysed. Slab are precast. Beams and columns are reinforced concrete members. Model of construction with dimensions and cross sections of beam and column are showed in the Figure 8.



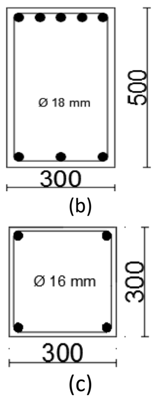


Figure 8. Analysed structure: a) model, b) cross section of beam, c) cross section of column.

At the beginning all hazards are identified. Next, all possible local damage and their possible global effects are assigned to the hazards. In the end possibilities and consequences values are estimated (Figure 9).

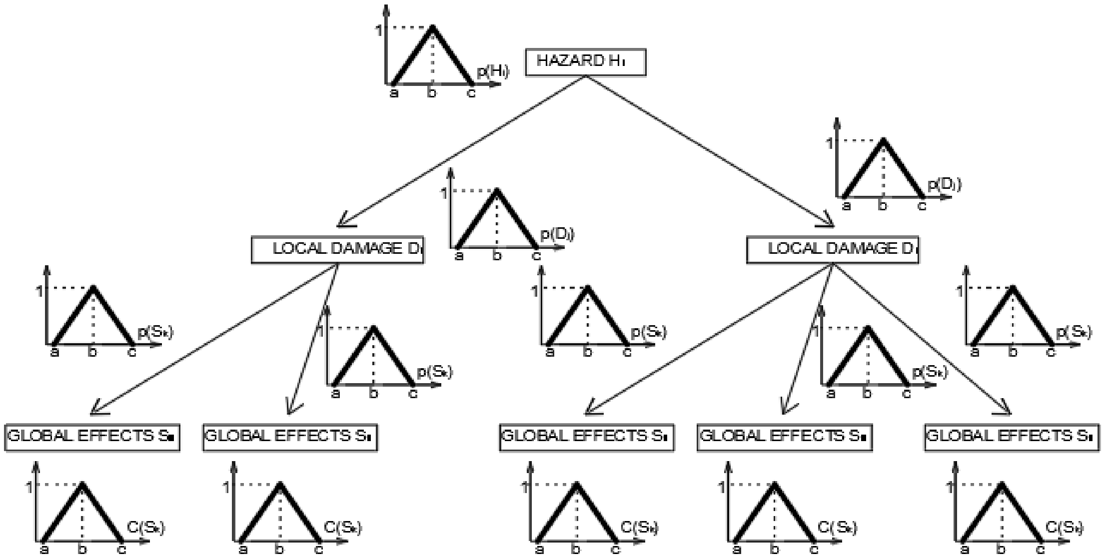


Figure 9. Scheme of fault tree.

Next step concerns calculation of the value of risk for specific hazards, group of hazards and the total risk. Red line shows the acceptable risk level. We will see, that all three hazards from the group of building process and hazard from snow effects have high risk value (Figure 10).

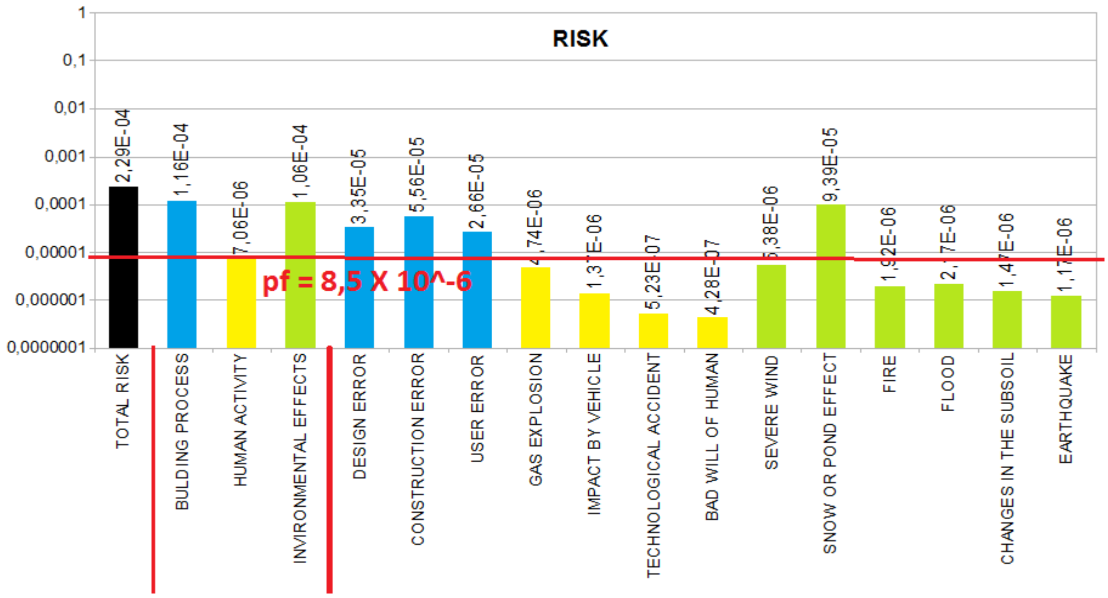


Figure 10. Risk and acceptable risk values

CONCLUSIONS

To sum up:

- for RC frame structures the highest risk value is obtained for hazard connected with building process error and snow;
- to design the construction resistant to progressive collapse the suggested procedure can be used;

- to quantify imprecise and/or subjective information necessary to estimate value of risk component, the fuzzy logic approach may be applied;
- it is possible to adapt the suggested procedure for other types of structure.

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DEGRADATION OF CONCRETE

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ABSTRACT

The continued presence of the Pantheon, with its 43m unreinforced concrete dome, is proof that concrete can deliver long-term performance. However, there are plenty of other examples to show that this is not always the case. Concrete is a permeable, metastable material which can react with aggressive species and degrade.

To the civil engineer, cement durability can be achieved by controlling the cement content and water/binder ratio. Meanwhile, to the materials scientist durability is defined by the porosity and phase assemblage. In reality, a thorough understanding of the material properties can inform engineering practice, while engineering practice can ensure practical relevance to scientific studies.

This presentation will consider the deterioration of concrete structures on the macroscale and show how an understanding of the microstructure and phase assemblage may help to shed light on engineering performance. It will focus on those deterioration mechanisms which are relevant to multi-storey structures, in particular carbonation and freeze-thaw damage. It will also, hopefully, demonstrate how recent and future changes in cement composition may result slight changes in the performance of aged concrete structures many years from now.

INTRODUCTION

With 4.1 billion tonnes of Portland cement produced in 2017 [USGS, 2017], this material underpins modern life like nothing else. Indeed, Portland cement is the second most heavily used manufactured material after drinking water [Sedgewick, 1991, cited in Brand 1994]. There has been exceptional growth in global cement production over the past 40 years, with the majority of that growth occurring in China and developing economies. Indeed, growth has been so exceptional that China produced more cement between 2011 and 2013 than the USA produced in the entire 20th Century (Gates, 2014).

During the inter-war years, and then in the boom years of the 1950s, concrete heralded a new future of urban living. The structural potential of concrete, coupled with the economies offered over, for example, structural steel, led to its continued use. However, the innovation of Le Corbusier's "Beton brute" was not to everyone's tastes, and brutalist concrete architecture soon synonymous with urban decay and the "concrete jungle". Numerous examples can be found of award-winning buildings soon falling out of public favour and being derided by the public, the critics and even royalty (HRH Prince Charles, 1984).

Concrete's fall from grace arose, in part at least, due to widespread problems with the durability of concrete structures. Poor design and workmanship would lead to the ingress of aggressive species, leading to the structures' deterioration, which was at first unsightly and ultimately unsafe. However, concrete can be an extremely durable material. For example, Los Angeles cathedral was designed with a 200 year expected service life. But, in order to achieve such durability, it helps to have an understanding of concrete as a material.

Furthermore, with growing environmental awareness, particularly with regards to climate change, the spotlight has been shone on the concrete industry. The production of one tonne of Portland cement leads to the direct or indirect emission of about 850 kg of carbon dioxide. This, coupled with the ubiquitous, global consumption of Portland cement means that cement production is responsible for 5-7% of global anthropogenic carbon dioxide emissions (Allwood and Cullen, 2011). The cement industry has been aware of this and has introduced a number of measures over the past 30 or so years to reduce their environmental footprint. A key aspect of this has been the increasing use of supplementary cementitious materials (SCMs). These SCMs, such as pulverised fuel ash (PFA) or ground granulated blast furnace slag (GGBS) help to reduce the amount of cement clinker in Portland cement, and thus reduce the cement's carbon footprint. However, these SCMs can subtly alter the performance of the concrete. For this reason, research into the performance of these blended cements continues apace.

WHAT IS CONCRETE?

In its simplest form, concrete is a heterogeneous composite material, comprising fine and coarse aggregate bound together with a hydraulic binder, i.e. Portland cement. However, many concretes also contain SCMs, and chemical admixtures such as superplasticizers.

Therefore, hardened Portland cement concrete can be considered also a heterogeneous mixture of hydrated cement paste, anhydrous clinker, aggregate and pores. Figure 1 shows a typical cross-section through a hardened cement paste, showing all of the above features apart from the aggregate.

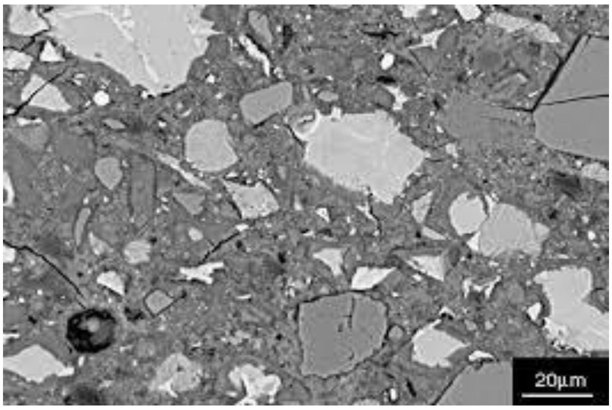

Figure 1. SEM backscattered electron micrograph from a 50:50 CEM I:slag blend, hydrated for 28 days, showing the presence of anhydrous material, hydrates and pores (Adu-Amankwah, 2016).

On an even finer scale, the hardened cement paste is also heterogeneous, comprising of a number of different hydrated cement phases, the most important of which are calcium silicate hydrate (C-S-H), portlandite (calcium hydroxide or CH using the standard cement chemistry notation), ettringite (AFt) and a range of calcium sulpho- and carboaluminates (AFm). Furthermore, the growing use of SCMs over the past 30-40 years has led to a gradual shift in the composition of the hardened cement paste in Portland cement. Increased use of SCMs leads to lower portlandite contents and C-S-H containing low levels of aluminium and a modified morphology. Furthermore, slag cements will also contain hydrotalcite-like phases (Whittaker et al., 2014).

Furthermore, the hardened cement paste is chemically metastable, and may react with aggressive species in its environment. In many cases, this is the basis of concrete deterioration. If we are to fully understand the long-term performance, we need to understand how the phase assemblage and microstructure defines engineering performance and explains concrete deterioration. The following sections present two examples (carbonation and freeze-thaw damage) as to how changes in composition and microstructure can affect concrete durability.

CONCRETE CARBONATION

Hardened cement paste is alkaline, with a pH of ~12.5. The hardened cement paste will therefore react with acidic species. One such reaction is known as carbonation. This may simply be considered as the reaction between cement paste and carbon dioxide, although in reality is the reaction between hardened cement paste and carbonic acid formed by the dissolution of carbon dioxide in the cement's pore water. This may be represented by the series of chemical reactions shown below.

$CO_2 + H_2O \rightarrow H_2CO_3$
$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3$
$H_2CO_3 + \text{C-S-H} \rightarrow CaCO_3 + \text{silica gel}$

These carbonation reaction lead to a reduction in the pH of the concrete pore solution, thus rendering any reinforcement liable to corrosion. Therefore, understanding the rate of carbonation is imperative if we are to understand the long-term performance on reinforced concrete structures.
Under ambient conditions, portlandite carbonates before C-S-H, and only once the portlandite has carbonated does C-S-H start to degrade. This can be illustrated by examining the FTIR spectra of cement paste exposed to ambient carbon dioxide levels. Figure shows a series of ATR-FTIR spectra obtained from a cement paste (CEM I + 30% replacement with PFA, w/b = 0.57) cured for 3 days before exposure to ambient air. The bands at ~1400 cm^{-1} are due to carbonate species, while the bands at 950-1200 cm^{-1} are due to silicate species.

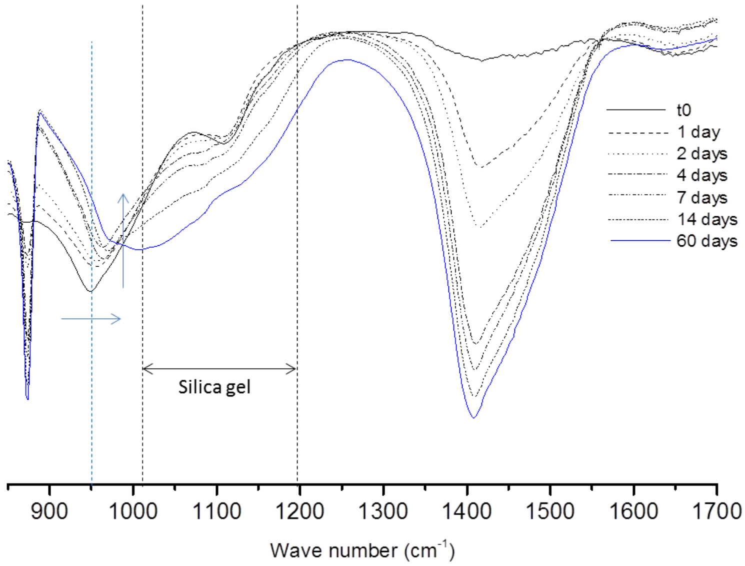

Figure 2. ATR-FTIR spectra obtained from a 30% PFA blend (w/b 0.57) cured for 3 days prior to exposure to ambient air (Herterich, 2017).

Upon exposure to air, the cement paste begins to react with the carbon dioxide, leading to the formation of calcium carbonate and growth in the carbonate stretching bands. This carbonation was particularly pronounced between 2 and 4 days. This coincided with the consumption of portlandite within the samples, i.e. the disappearance of hydroxide stretching bands at 3643 cm^{-1} (not shown). Furthermore, this was also coincident with changes in the silicate stretching bands. Initially, these were centred at ~950 cm^{-1} and were attributed to silicate chains within the C-S-H structure. Over time, there was a shift in this band to higher wavenumber, attributed to the formation of a more highly polymerised silicate species, namely silica gel. Thus, it can be inferred that once portlandite has been consumed, then the calcium required for formation of calcium carbonate is obtained from decalcification of the C-S-H, leading to its breakdown, with the formation of silica gel.
While this seems primarily of interest to materials scientists, it also has implications for civil engineers. Over the past 30-40 years, SCMs such as PFA have been used increasingly in concrete. This was driven by a desire to reduce the environmental burden of concrete, since SCMs, as industrial by-products have a much lower carbon footprint than Portland cement.
Furthermore, in addition to changes in cement's phase assemblage, it is important to understand how carbonation can induce microstructural changes in the concrete. The carbonation of portlandite to produce calcium carbonate is expansive, i.e. the volume of one mole of calcium carbonate is greater than the volume of one mole of portlandite. Meanwhile, the carbonation of C-S-H leads to a slight volume decrease. Figure below shows transmission electron microscope images obtained from a 30% GGBS blend (w/b 0.57) cured for 28 days before (left) and after (right) exposure to ambient air for 60 days.

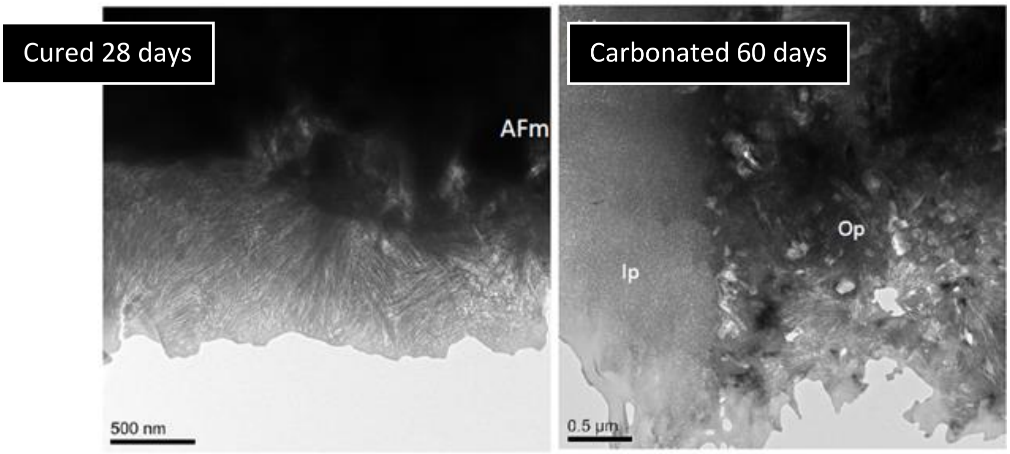

Figure 3. Transmission electron microscope images obtained from a 30% GGBS blend (w/b 0.57) cured for 28 days before (left) and after (right) exposure to air for 60 days (Herterich, 2017).

The microstructure of the non-carbonated sample (left) reveals the fine fibrillar morphology of C-S-H, plus occasional relicts of AFm. Carbonation led to a significant change in morphology. Some fibrillar C-S-H is still visible. This inner product (Ip) C-S-H had formed within the space previously occupied by the cement grains before they were consumed during cement hydration. The outer product (Op) C-S-H meanwhile, i.e. which formed within the water-filled space between cement grains in the fresh cement paste, had undergone considerable microstructural change due to decalcification. Coarsening of the microstructure could be seen, with the formation of small microcrystals of calcium carbonate. Thus, depending on the relative proportions of portlandite and C-S-H, which is defined by the composition of the binder, carbonation can either lead to a decrease or increase in porosity. While the proportions of inner and outer product, as defined in part by the water/binder ratio, can affect the microstructure of the carbonated concrete. Both of these effects have further implications for understanding concrete durability.

Figure illustrates how total and capillary porosity changes upon carbonation for a CEM I cement system (left) and a 65% slag blend (right), as a function of water/binder ratio.

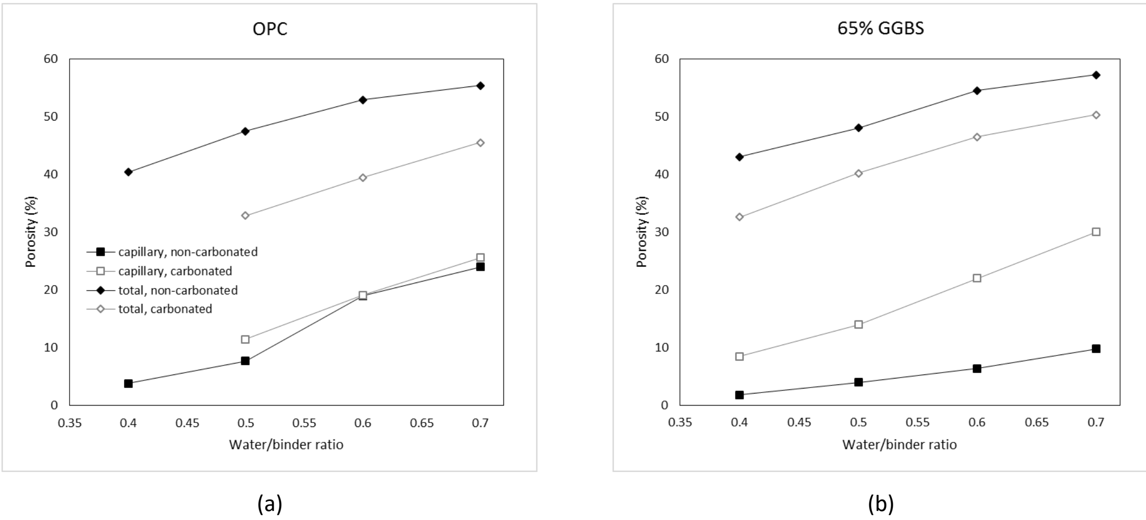

Figure 4. Porosity of non-carbonated and carbonated OPC (a) and 65% slag (b) pastes, cured at 38^{o}C for 10 weeks (Ngala & Page, 1997).

While there was a decrease in overall porosity for both systems, there were differences in the capillary porosity. This remained approximately the same upon carbonation of the CEM I system, but increased for the slag blend. While the non-carbonated blended cement showed a much lower capillary porosity than its CEM I equivalent prior to carbonation, this was not always the case afterwards. This may be understood in the context of the volume changes upon carbonation of the different phases and the reduced portlandite content in the blended cement. Since it is the capillary porosity which is responsible for transport of aggressive species through the concrete, this increase in capillary porosity upon carbonation can be detrimental for the long-term concrete performance.

FREEZE-THAW DAMAGE

Repeated exposure of concrete to freezing and thawing cycles can lead to deterioration. A number of mechanisms have been put forward to explain this, including the fact that water expands by 9% upon freezing, the exertion of osmotic pressure from pore solution to thawing water, and crystallisation pressure exerted by freezing ice fronts. Ultimately, this leads to the formation of microcracks and spalling of the concrete surface.

Blended cement concretes have been found to be particularly susceptible to freeze-thaw damage, particularly during accelerated ageing. Figure shows the surface spalling after freeze-thaw testing from three concrete specimens prepared so as to have the same mechanical performance, yet using three different binders. These binders were CEM I (C), 50% CEM I – 50% GGBS (CS) and 50% CEM I – 40% GGBS – 10% limestone (CS-L). After the standard 56 freeze-thaw cycles, there was some loss of surface material from all three specimens, but the CEM I system performed better than the two blended systems. The mass of spalled material and the loss of dynamic modulus is shown in Figure . The drop in RDM slight preceded loss of material. As was expected, the blended cements performed slightly worse than the CEM I system, with the limestone-bearing blend performing worst of all.

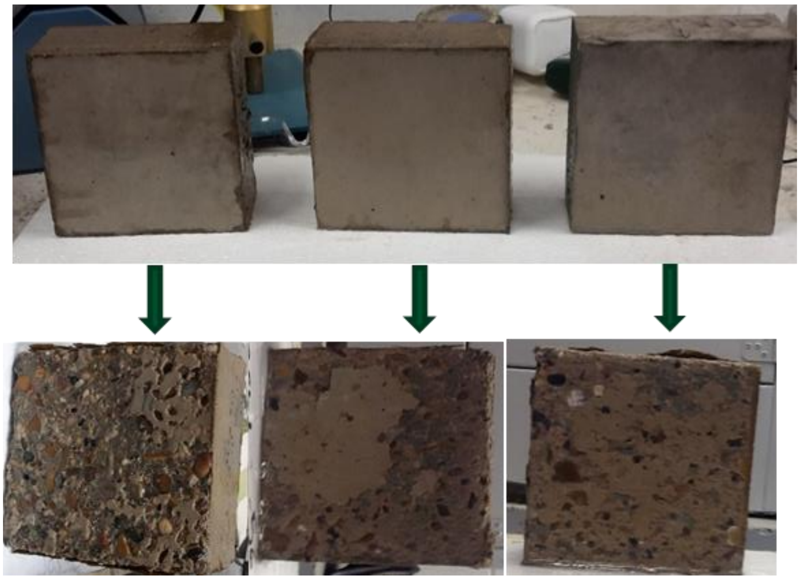

Figure 5. Specimens before and after 56 freeze-thaw cycles. Cement-slag-limestone blend (left), cement-slag blend (centre), cement (right). (Adu-Amankwah, 2016).

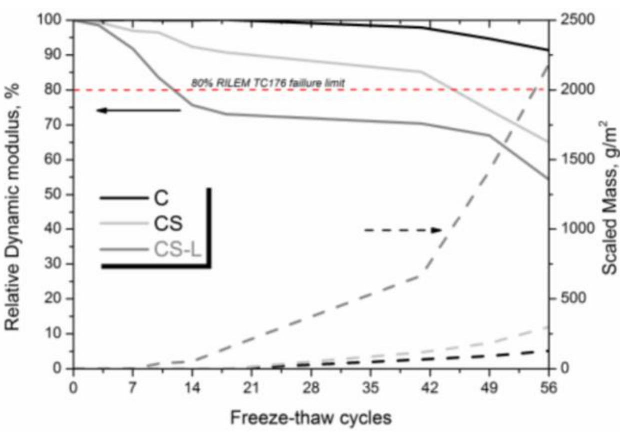

Figure 6. Change in relative dynamic modulus and scaled mass as a function of the number of freeze-thaw cycles (Adu-Amankwah et al., 2016).

Characterisation of equivalent paste samples by thermal analysis throughout the various stages of the accelerated freeze-thaw test can help to shed light on the reasons for the diminished performance. The differential thermal analysis traces shown in Figure reveal changes in the portlandite and calcite contents of the various samples. The accelerated test stipulates that specimens must be saturated. This is achieved by immersing samples in deionised water for 7 days. All of the specimens showed a reduction in portlandite content during this preconditioning step. However, both blended cements showed complete loss of portlandite (CH), while some remained in the CEM I system. This latter system also showed an increase in carbonate content, arising from carbonation of the portlandite. Subsequent electron microscopy on these samples (Figure) showed loss of material from the interfacial transition zone, particularly in the blended cements. Thus, the lower initial portlandite contents of the blended cement systems made the interfacial transition zones more susceptible to damage during freeze-thaw testing. This in turn affected the performance of the different binders under the accelerated testing.

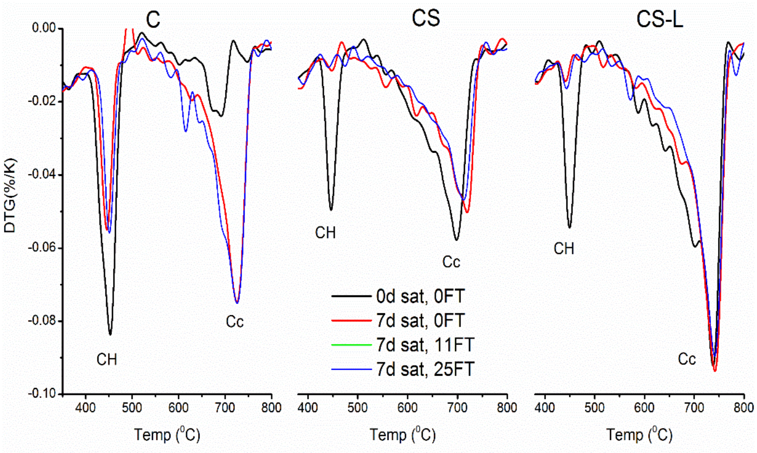

Figure 7. Differential Thermal Analysis traces obtained from the three specimens during various stages of the freeze-thaw testing. 0d sat: prior to any sample preparation, 7d sat: after conditioning in water for 7 days, 7d sat 11FT: after conditioning in water for 7 days followed by 11 freeze-thaw cycles, 7d sat 25FT: after conditioning in water for 7 days followed by 25 freeze-thaw cycles (Adu-Amankwah et al., 2016).

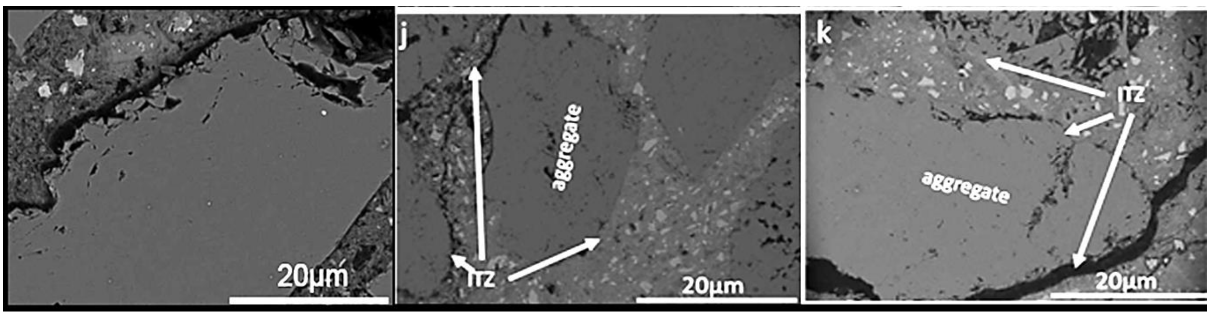

Figure 8. SEM backscattered electron micrographs obtained from specimens following 25 freeze-thaw cycles; CEM I (left), cement-slag (centre) and cement-slag-limestone (right). Voids surrounding the aggregates due to loss of the interfacial transition zone are highlighted (Adu-Amankwah et al., 2016).

CONCLUSIONS

Growing environmental awareness has led to changes in binder composition, with increased use of supplementary cementitious materials and other mineral additions. These changes have led to a reduction in cement's carbon footprint, a trend which is likely to continue in coming years. Thus, we cannot necessarily rely on historical data to predict future performance. While we may be able to predict some of the expected changes, for example in phase composition, some long-term behaviours are still uncertain. If we are to understand the long-term performance of newly

developed binders then we need to perform appropriate accelerated ageing tests. Many of these tests have been developed over the years for use with pure Portland cement systems.
Microstructural characterisation helps us to understand the fundamental properties of concrete and relate the changes in phase assemblage and microstructure induced by the use of supplementary cementitious materials to changes in short-, medium- and long-term performance.
Increased use of SCMs may reduce the porosity of concrete, but with the consumption of portlandite. This will affect the carbonation rate of concrete, sometimes for the better and sometimes for the worse. This has implications for the durability of reinforced concrete. However, understanding the interplay between microstructure and phase assemblage is an important part of predicting the long-term performance of low-carbon concretes.
Similarly, understanding the microstructural changes during freeze-thaw testing will allow us to develop more robust cementitious systems for use in aggressive environments. Furthermore, understanding how accelerated ageing tests designed for pure Portland cements may not always be entirely applicable to modern blended cements will help us to develop accelerated ageing tests which might be more appropriate for 21st century cementitious materials.
In summary, materials science may help the civil engineer to produce more durable, more efficient concrete, thus reducing the environmental and societal burden of poor concrete design and construction.

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TOWARDS PERFORMANCE-BASED ENGINEERING OF BUILDING STRUCTURES SUBJECTED TO EXTREME HAZARDS

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ABSTRACT

The sustainable development of resilient infrastructures and communities calls for a risk-informed design, assessment and retrofitting of building structures against extreme hazards. This is motivated by a number of global phenomena that influence hazard, vulnerability and exposure of property and people in several regions, causing a dynamic multi-risk environment. Actually, novel hazards have been identified or have become more frequent and intense in some countries as a result of, for instance, new industrial sites, climate change, terrorism threats and war scenarios. Besides, progressive ageing of existing infrastructure, urbanization leading to megacities, and worldwide connectivity of business activities and communities increase the level of exposure to extreme hazards and their consequences.

Extreme hazards, which are also called low-probability/high-consequence (LPHC) events, are a special class of potentially harmful events. On one hand, LPHC events have a probability of occurrence significantly lower than that of normal events considered in structural engineering, and on the other, are expected to produce huge losses (e.g. casualties, homeless, repair costs, business interruption). LPHC events include the following: (i) extreme natural events, such as large landslides, flash floods, windstorms, megathrust earthquakes; (ii) accidental (or technological) events, such as explosions, impacts, and fire; (iii) malicious actions; (iv) human errors in design, construction, usage or maintenance; and (v) deterioration phenomena, such as steel corrosion and concrete carbonation. In some cases, a LPHC event includes a sequence of natural and technological events, resulting in the so-called NaTech disasters. Consequences of extreme events can be measured at different scales in space and time, and their estimation has a strong impact on risk management of infrastructure systems, particularly because of both long-distance and long-term catastrophic effects of damage to critical and strategic assets.

If the scale of individual buildings is considered, LPHC events induce abnormal loads that often cause local damage to one or more vertical load-bearing components, leading to the progressive collapse of the whole structure or a large part of it. If there is a disproportion in size between the initial and final levels of damage, the progressive collapse phenomenon suffered by the structural system is termed disproportionate collapse and the ability of the structure to avoid this type of failure is defined as robustness. Abnormal loading is usually a dynamic or even impulsive load of short duration but with significant magnitude. These characteristics of loading can produce heavy damage to structural components, even if the latter have been designed or retrofitted to develop a ductile response to normal loads, such as gravity loads and far-field earthquake actions. Therefore, innovative fragility models for selected classes of load-bearing components and buildings need to be developed, in order to account for physical and probabilistic features of abnormal loads, structural capacity and extreme structural response.

In this lecture, structural safety against extreme events will be dealt with through a probabilistic mathematical framework that applies to both threat-dependent and threat-independent approaches. The former are based on the identification and modelling of the abnormal load, whereas in the latter, the structural system is subjected to a prescribed local damage that typically consists of a notional removal of one or more vertical load-bearing components. The aim of the presentation is to foster a shift from current deterministic methods of structural design and assessment against abnormal loads to a Performance-Based Robustness Engineering. This is a rational and transparent methodology that allows decision makers to evaluate and manage large uncertainties in abnormal loads and nonlinear structural response. The development of a

probabilistic methodology is also in line with Eurocode 1 – Part 1-7 that, particularly in the case of Class 3 structures, recommends a systematic risk assessment of the structure, considering both foreseeable and unforeseeable events.

The lecture will begin from limitations of load and resistance factor design (i.e. limit state design), delineating a matrix that outlines engineering services and stakeholders involved in management of structures subjected to extreme hazards. Key concepts of performance matrix, quantitative risk analysis, probabilistic performance objectives, and conditional probabilities of failure are discussed as a basis for the evaluation of progressive collapse risk for single and multiple hazards. In this respect, different types of aleatory and epistemic uncertainties together with the mean annual rate of occurrence of LPHC events will be identified, allowing the formulation of the main procedures for progressive collapse risk assessment.

Secondly, fragility analysis for conditional limit states associated with local and global damage states in a building structure will be discussed. The attention will focus on reinforced concrete (RC) framed buildings subjected to bomb explosion hazard, which will be selected as a case study for the numerical implementation of the theoretical methodology. In detail, the methodology and output of a fragility analysis on RC columns will be presented. Blast damage to building columns was measured in terms of residual axial load capacity and was assessed through Monte Carlo simulation coupled with deterministic pressure–impulse diagrams selected from the literature. A set of blast fragility surfaces will be proposed to assess the probability of failure at low, medium and high levels of blast damage to RC columns (Figure 1). Performance-based pressure–impulse diagrams for RC columns, each of them associated with a target probability level, will be also presented for their possible use in engineering practice.

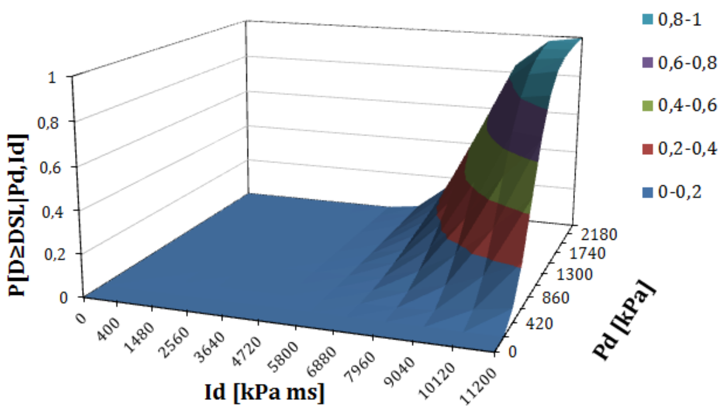

Figure 1. Blast fragility surface for heavy damage to RC column.

Finally, the presentation will move to the outcomes of fragility analyses performed on RC framed buildings, which were aimed at evaluating the conditional probability of progressive collapse according to the alternate load path method. Building prototypes representative of both gravity-load and seismically designed structures according to Eurocodes 2 and 8 are considered (Figure 2). Fibre-based finite element models were developed and integrated with numerical techniques to simulate sudden removal of one or more columns. This allowed the structural response to local damage and failure patterns to be assessed. Based upon statistics and probability distribution functions for material properties, geometry, and design loads of the building classes under study, a Monte Carlo simulation was performed to generate both two-dimensional and three-dimensional models. Structural performance was assessed by means of two alternative methods: incremental-mass nonlinear dynamic analysis and pushdown analysis. Both response analysis methods allowed the attainment of limit states to be captured, either at sectional or global levels of the structure.

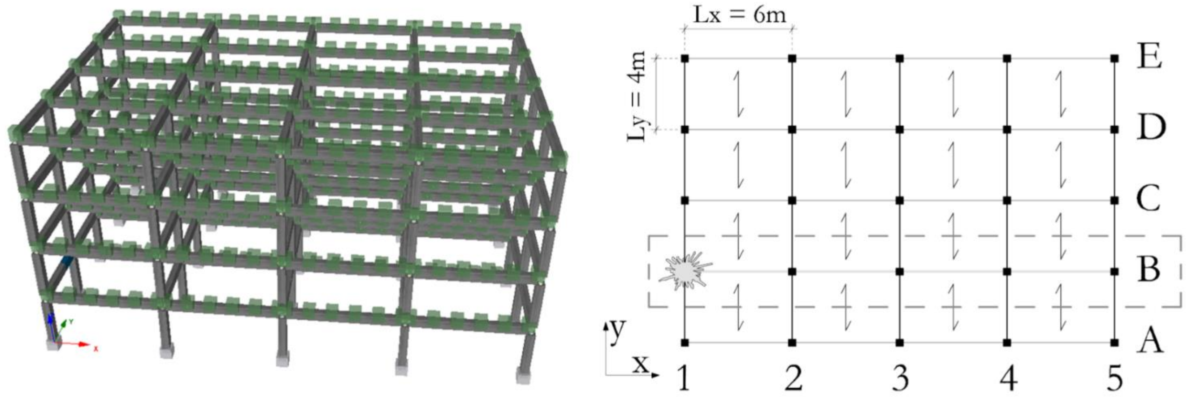

Figure 2. Building structure under study.

Threshold levels for steel and concrete strains, as well as vertical drifts, were used for the definition of multiple limit states associated with increasing levels of structural damage. Probability distribution functions were then fitted to fragility points in order to provide fragility functions at different damage states for their use in progressive collapse risk assessment. The comparison between analysis results allows the impact of alternative design solutions, modelling options and analysis procedures to be quantified (Figure 3).

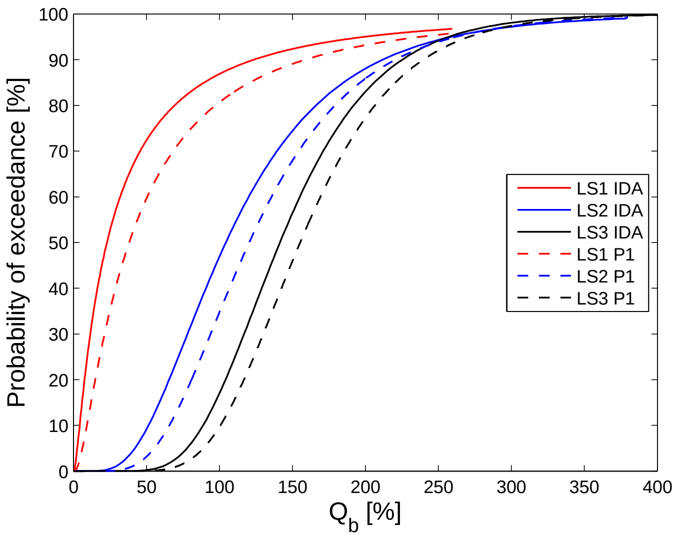

Figure 3. Comparison between fragility curves derived from incremental dynamic analysis and pushdown analysis on three-dimensional models of EC2-conforming buildings.

It is shown that structural robustness can benefit from seismic design, secondary beams in three-dimensional models, and explicit consideration of dynamic effects in the structural response analysis. Special emphasis is given on the differences between fragility functions derived from results of incremental dynamic analysis and pushdown analysis, presenting modification factors for parameters of the probability distributions.

Keywords: Extreme hazards, performance-based engineering, progressive collapse risk, robustness, fragility models, building structures.

RETROFIT OF EXISTING RC BUILDINGS WITH DIAGRIDS ADOPTING A HOLISTIC-SUSTAINABLE DESIGN FRAMEWORK

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ABSTRACT

The deep renovation of existing buildings is nowadays acknowledged as a priority in order to foster safety and eco-efficiency of the European construction sector. This renovation process should be inspired by some major principles as to ensure sustainability and feasibility of the interventions, also boosting the actual low renovation rate. The introduction of diagrid exoskeletons has been recently proposed as a new holistic and sustainable technique for the deep renovation of existing RC buildings under a seismic, energy, and architectural point of view. The exoskeleton can be conceived by addressing the Life Cycle Thinking principles, not also implementing eco-efficient materials but also guaranteeing reparability, adaptability, and demountability, selective dismantling and reusability of each component at the end of life. The solution is implemented exclusively from outside the building, thus avoiding inhabitants' relocation. Off-site prefabrication of components, as well as the use of standardized elements and connections reduce construction time and costs. A simple method for the preliminary design of diagrids, also considering sustainable principles aimed at reducing the damage along the life of retrofitted building, is here proposed.

Keywords: Diagrid exoskeletons; Renovation of existing RC buildings; Life Cycle Thinking; integrated retrofit.

INTRODUCTION

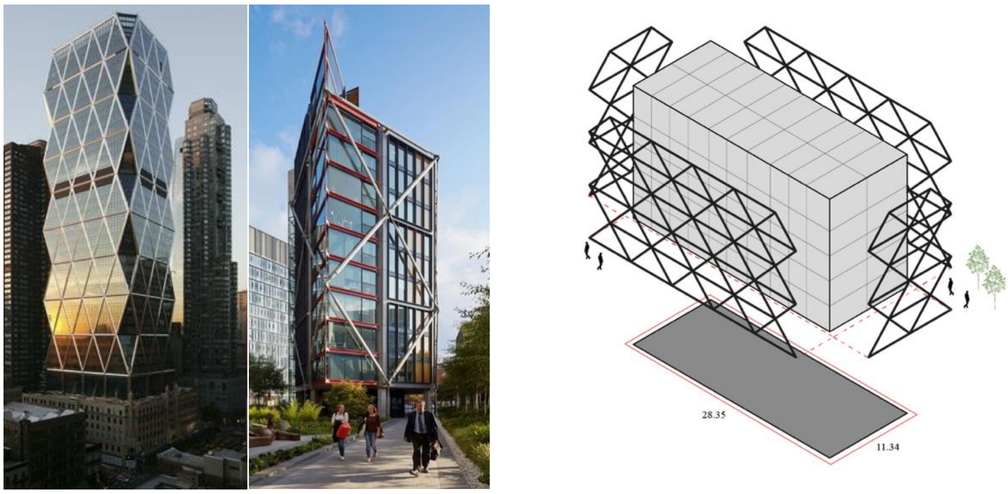
The existing building stock is obsolete and needs some deep renovation action in order to ensure safety and wellbeing of the inhabitants on one side, and the achievement of the European climate targets on the other side. About 40% of the existing heritage was built more than 50 years ago (BPIE, 2011), without any code or practice aimed at guaranteeing seismic resistance to the structure nor energy efficiency of the envelope and the technological plant system (Marini et al., 2014). As a consequence, those buildings are highly impacting both considering the day-by-day use for heating and cooling, but also considering the possible scenario in which natural events, such as earthquakes, would induce damage – or even the collapse – of the structures (Belleri and Marini, 2016).

For the renovation of the obsolete heritage, recent researches identified three main drivers: 1) to act from outside the building and minimize demolition of the finishing as to avoid inhabitants' relocation and to reduce the intervention cost (Takeuchi, 2009; Marini et al., 2016; 2017), which are two of the major barrier to the renovation, and responsible for a renovation rate of just 1% (BPIE 2011); 2) to adopt holistic technologies to tackle structural, energy, and architectural deficiencies of the building in a combined intervention (Takeuchi, 2009; Marini et al., 2016; 2017); 3) to embrace a Life Cycle perspective as to guarantee actual sustainability of the intervention (Marini et al., 2017; 2018, Passoni et al., 2018), which can be obtained by ensuring the minimum environmental and economic impacts of the retrofitted building along each phase of its life cycle (principles of reparability, adaptability, demountability, recyclability, etc.).

All these principles can be considered in the design of diagrid exoskeletons. This holistic technology consists in encasing existing RC buildings into a new multi-functional skin conceived as to solve all building deficiencies (Passoni et al., 2016; Labò et al., 2017). When assembled with standardized components and connections, such exoskeletons may be conceived as demountable, thus enabling the substitution of some components in the case of damaging events -such as earthquakes-, or to implement new advanced technologies and to enable maintenance works during the building service life, or to allow for selective dismantling at the end of life scenario.

DIAGRID EXOSKELETON FOR SEISMIC RETROFIT OF EXISTING RC BUILDINGS: PRINCIPLES AND DESIGN

Diagrids were initially conceived for the construction of tall buildings, devoid of RC inner cores (Moon et al., 2007; Mele et al., 2016). In these structures all the structural components are located along the building perimeter facades and are organized to form a diagonal structural grid. This subdivision of the structure into triangular modules gives architects the maximum freedom to design quite complex building shapes (Figure 1a). More recently, diagrid exoskeletons have been proposed to be adopted also in the renovation of existing buildings, particularly as a seismic mitigation measure (Figure 1b) (Passoni et al., 2016; Labò et al., 2017). In this case, diagrid exoskeletons would constitute a shell structure, properly connected to the existing building floor ring beams, which collects and transfers all the horizontal loads to the foundation system.



a) b)

Figure 1. Diagrid for the construction of new tall buildings (a); diagrids for the seismic retrofit of existing RC buildings (b).

A design method for the proportioning of diagrid exoskeletons as strengthening solution is proposed. This method is based on the optimization of the structural performances of the retrofitted building and on the adoption of Life Cycle Thinking principles (Labò et al., 2018). The main parameter for the preliminary design of the diagrid are: 1) the geometry of the diagrid module, which depends on the layout of the existing building and on the optimization of the diagonals' inclination angle (close to 35° for low-medium rise buildings) (Moon 2008); 2) the optimization of the diagrid stiffness, which must entail the reduction of the total and inter-story drift of the existing building, as to reduce the possible damage induced by an earthquake; 3) the optimization of the diagonal element cross section as to avoid the buckling of the elements.

Once the geometry of the modules is selected, the load pattern and the internal forces may be defined. The diagrid exoskeleton is subjected to its self-weight and to the seismic loads transferred by the existing building. In order to simplify the preliminary design process, the seismic actions are considered as linearly distributed along the building height. Bending moment and shear actions are decoupled (Montuori et al., 2014): bending moment is resisted by the diagrid façades which are orthogonal to the seismic action, while the shear force is counteracted by the diagrid façades parallel to the seismic action (Figure 2). The calculation of the axial force in each member of the diagrid is thus straightforward.

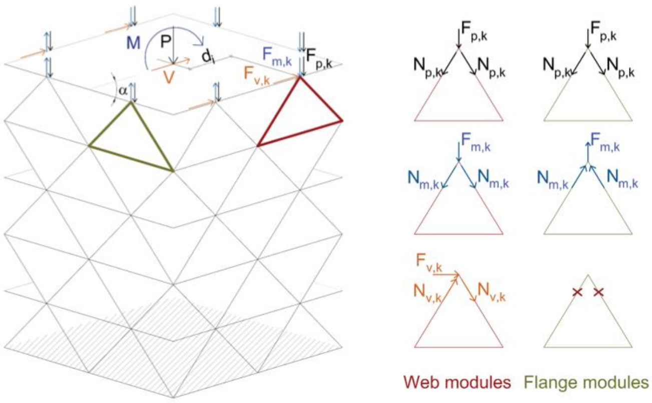


Figure 2. Diagrid module: effect of gravity load P (diagrid self-weight), overturning moment M and shear force V. Where $F_{p,k}$, $F_{m,k,}$ and $F_{v,k}$ are the forces in the k-th module due to vertical load, overturning moment and the shear force, respectively; and $N_{p,k}$, $N_{m,k}$ and $N_{v,k}$ are the correspondent internal actions (After Montuori et al., 2014).

The cross section of the diagonal members is calculated by enforcing two different criteria. First, adopting a Life Cycle perspective (Marini et al., 2018), a maximum roof displacement is imposed aimed at reducing the damage into the existing building in the case of a seismic event. This would reduce the waste production and the repair works after a seismic event, thereby reducing the costs and CO_2 emissions connected with reconstruction and with debris disposal. To evaluate the maximum displacement at the top, the retrofitted building is modeled as a cantilever beam. In addition, the minimum area required to avoid the buckling of diagrid elements is calculated on the basis of the axial forces estimated in the first step of the design with reference to the structural scheme in Figure 2.

The simplified analytical method can be addressed by the design professionals for the preliminary design of the diagrid module and for the initial selection of the element cross sections. More sophisticated numerical analyses are then required to validate the results of the preliminary estimation.

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DESIGN CRITERIA TO ENHANCE THE ROBUSTNESS OF FLUSH END-PLATE BEAM-TO-COLUMN CONNECTIONS

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ABSTRACT

Flush end-plate beam-to-column connections are often designed as pinned. However, this type of joint is generally semi-rigid and partial strength. In the case of column loss scenario, flush end-plate connections do not have sufficient strength to resist the catenary forces due to the tensile yielding of the connected beams, but they can arrest the progressive collapse by means their plastic ductility if properly detailed and designed. To this aim, a design criterion is discussed and its effectiveness is investigated and discussed by means of parametric finite element analyses.

Keywords: flush end-plate joints; column loss; robustness; catenary action; compressive arching.

PROPOSED DESIGN CRITERION

To enhance the performance (i.e. both the strength and ductility) of flush end-plate (FEP) connections under column loss, both end-plate thickness (i.e. end-plate flexural strength) and bolt diameter (i.e. bolt strength) should be selected in a given range so as to mobilise their corresponding strength but avoiding mode 3 that typically corresponds to reduced ductility of T-Stub connections. Hence, the thickness of end-plate can be selected between the minimum and maximum values inducing mode 2 for a given bolt diameter.
EN 1993-1-8 recommends a ductility criterion for bolted joints that relates the thickness of the end-plate to the bolt diameter as follows:

$$t_{EN1993:1-8} \leq 0.36 \cdot d \cdot \sqrt{\frac{f_{ub}}{f_y}} \qquad (1)$$

Where d is the bolt diameter, f_{ub} is the ultimate stress of the bolt material and f_y the yield strength of the material of the connected plate.
The thickness given by Eq. (1) is the threshold value between mode 1 and mode 2 depending on the yield line pattern (i.e. circular or non-circular), because Eq. (1) imposes that the resistance of each individual bolt ($F_{t,Rd}$) is greater than the resistance ($F_{p,Rd}$) of the connected plates (end-plate or column flange), having assumed γ_{M0} and γ_{M2} respectively equal to 1.0 and 1.25.
Considering the random variability of material strength and the strain hardening that can be developed by the connected plates in plastic range, the ultimate strength of joints can be also properly evaluated as follows:

$$F_{t,Rd} \geq \gamma \cdot F_{p,Rd} = \gamma_{ov} \cdot \gamma_{sh} \cdot F_{p,Rd} \qquad (2)$$

The random material overstrength factor γ_{ov} in Eq. (2) depends on the steel grade. The strain hardening factor γ_{sh} is assumed as the ratio between the ultimate stress f_u and the yield stress f_y of the plate material. For European mild carbon steel, the ratio f_u/f_y can be conservatively assumed equal to 1.5. Thus, rearranging the inequality in Eq. (2) and introducing the EN1993:1-8 design equations for the strength of the yield line mechanism into the end-plate and the bolt strength, the minimum thickness to activate mode 2 can be obtained as follows:

$$t_{min,Mode2} \geq \frac{0.40 \cdot d}{\sqrt{\gamma_{ov} \cdot \gamma_{sh}}} \cdot \sqrt{\frac{\gamma_{M0} \cdot f_{ub}}{\gamma_{M2} \cdot f_y}} = 0.26 \cdot d \cdot \sqrt{\frac{f_{ub}}{f_y}} \quad (\leq t_{min,EN1993:1-8}) \qquad (3)$$

The upper bound value of thickness can be determined in order to avoid mode 3, namely imposing the following inequality:

$$\beta = \frac{l_{eff} t^2 f_y / \gamma_{M0}}{m \sum F_{t,Rd}} \cdot \gamma_{ov} \cdot \gamma_{sh} \leq 2 \tag{4}$$

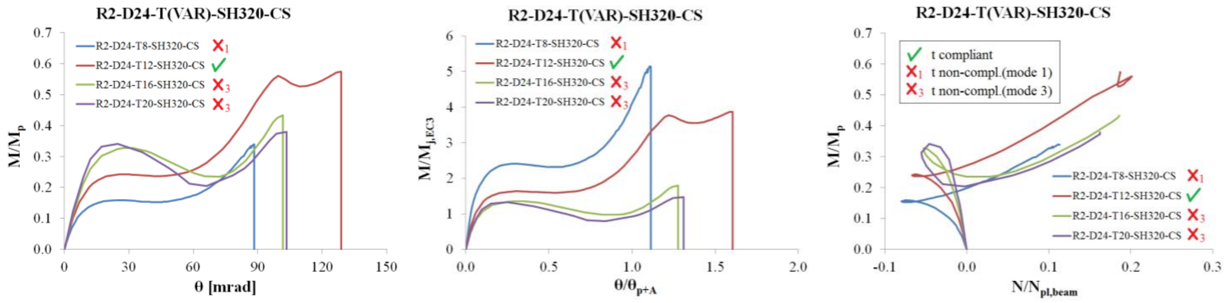
Where β is the ratio between the flexural strength of the connected plates and the axial strength of the bolts ($F_{t,Rd}$), being l_{eff} the effective length of the equivalent T-Stub, t the plate thickness and m is the distance between the bolt axis and the expected location of the plastic hinge into the plate. In this case the strain hardening parameter γ_{sh} should be assumed equal to 1.0, since the end-plate is elastic for failure mode 3.
The inequality in Eq. (4) can be also re-arranged considering that the threshold between mode 2 and mode 3 depends on the non-circular yield line pattern. In addition, adopting a factor equal to 0.9 to keep a margin from mode 3, $t_{max,Mode2}$ is given as follows:

$$t_{max,Mode2} \leq 0.9 \cdot \frac{1.43 \cdot d}{\sqrt{\gamma_{ov} \cdot \gamma_{sh}}} \cdot \sqrt{\frac{\gamma_{M0} \cdot f_{ub}}{\gamma_{M2} \cdot \alpha \cdot f_y}} = 1.15 \cdot d \cdot \sqrt{\frac{0.8 \cdot f_{ub}}{\alpha \cdot f_y}} \tag{5}$$

Where α is the coefficient to be used in calculation of effective length of the equivalent T-stub according to EN 1993:1-8.
The range of thickness [$t_{min,Mode2}$, $t_{max,Mode2}$] defined by Eq.(3) and Eq.(5) was proposed as a design criterion in Cassiano et al. (2017) to improve the robustness of FEP joints.

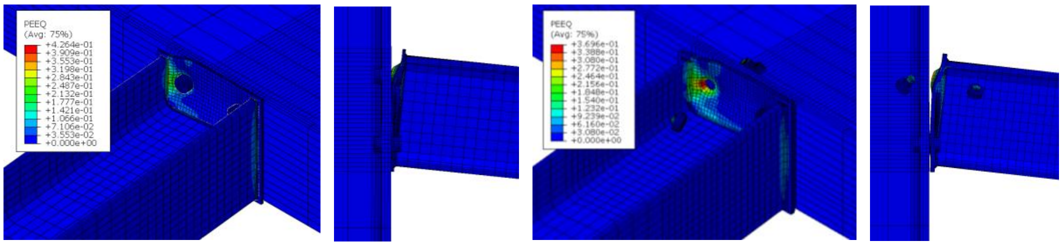
FINITE ELEMENT ANALYSES

Finite element analyses (FEAs) were carried out to investigate the effectiveness of the proposed design criterion. The numerical results showed that the increase of end-plate thickness corresponds to a significant increase of moment resistance and rotation capacity (i.e. ranging from 83 to 132 mrad). In particular, the connections with thicker end-plates (and corresponding thicker and stronger welds) mobilize an important membrane action into the bended portion of end-plate at each bolt row in tension. This mechanism is associated to large displacement capacity of the relevant bolt row (i.e. the equivalent T-stub in tension), thus explaining how rotation capacity increases with the thickness of end-plate. In addition, being the plastic engagement of the connection larger than in the previous case, the contribution of the beam elongation and the relevant axial force up to collapse increase with the end-plate thickness
As shown in Figure 1, the cases with thinner end-plate thickness show pure mode 1 up to failure, namely plastic deformation mostly concentrated into the end-plate and welds between end-plate and beam flange (see plastic equivalent strain *PEEQ* distribution in Figure 2.a), while the joint compliant to the proposed criterion (e.g. that with end-plate thickness equal to 12 mm) experiences mode 2 with plastic deformations into both bolts and end-plate (see plastic equivalent strain *PEEQ* distribution in Fig. 2b). Also in this case, selecting the end-plate thickness, in accordance with Eq. (3) and Eq. (5) (i.e. $t_{min,Mode2} = 10.5 \leq t \leq t_{max,Mode2} = 15.8$) leads to maximising the joint capacity. For end-plate thickness equal to 16 mm and 20 mm, the joint response is dominated by arching effect and rotation capacity is reduced because the connection collapse mechanism is shifted from mode 2 to mode 3.



a) b) c)

Figure 1. Influence of end-plate thickness: a) normalised connection moment vs. chord rotation; b) connection moment normalised to joint resistance vs. normalised rotation; c) normalised connection moment vs. normalised axial strength.



a) b)

Figure 2. Failure mode and equivalent plastic strain PEEQ for the R2-SH320-CS and M24 bolts: a) with 8 mm thick end-plate; b) with 12 mm thick end-plate.

CONCLUSIONS

The nonlinear response of FEP joints can exhibit two different resisting mechanisms: i) compressive arching-like and ii) catenary-like mode.

The proposed ductility criteria ($t_{min,Mode2} \leq t \leq t_{max,Mode2}$) defined by Eq.(3) and Eq.(5) is effective to enhance the connection response under column removal.

In order to guarantee activation of membrane action into the end-plate, the welds should be stronger than the connected plates. With this regard, it is recommended to use full penetration welds in place of fillet welds.

The bolt diameter and the number of bolt rows substantially influence the resistance of FEP joints under column loss. In order to improve the joint performance, it is necessary to use the larger bolt diameter and the greater number of bolt rows compatible with the constructional limitations.

Contrarily to the first order design, the inner bolt rows located close to the centroid of the connection noticeably increase the resistance and the rotation capacity under column loss. These bolt rows are very important to redistribute the internal forces developing into the connection, allowing to mobilize the catenary action under column loss.

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ENERGY SESSION

ENERGY SESSION SUMMARY

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LEARNING

It is well known that buildings cause a huge environmental impact and that strategies aimed at reducing energy consumptions are today required by the European Community, with the publication of the Directive 2018/844/UE that modifies the previous Directives 2010/31/UE on the Energy performance of buildings and 2012/27/UE on Energy Efficiency. These Directives have been adopted by each member state by means of the emission of laws and regulations both at national scale and a local scale (regions, districts, municipalities). One of the main goals of this Directive is that all buildings should be modified with proper interventions in order to obtain NZEB (Nearly Zero Energy Buildings).
All the contributions to the Energy session were in agreement with these abovementioned rules with the goal of reducing energy consumptions and consequently CO_2 emissions, proposing methods and solutions and at the same time highlighting critical aspects.

Starting from the keynote lecture by *Chris Jofeh* who focused on the importance of adopting digital technologies in processes aimed at improving buildings' energy performance, all the presentations were characterized by inter-disciplinary proposals, always considering together at least both energy and structural issues and in some cases evaluating the retrofitting approaches and proposals in terms of economic and sustainable solutions.

What emerges and poses in agreement the different contributions is that in Europe a great amount of multi-storey residential buildings were erected during the second half of the last century, mostly between 1960 and 1990, owing to industrialization and the consequent urbanization processes. These buildings, the envelope of which is mostly characterized by precast concrete panels, are indeed characterized by poor thermal and structural performances and often by improper distribution of spaces, as for example too small rooms and/or inadequate glazed areas, as reported by *V.Ungureanu et al*. This determines an insufficient indoor environmental quality and lack of safety for occupants, especially in seismic areas, without considering the economic and environmental impact due to the excessive energy consumption. For this reason the possible interventions should tackle all the problems and at the same time, be executed in the shortest possible time. So, coming back to the Keynote lecture, digital technology, in all the process phases should come in help and be largely adopted. Prefab solutions, as prefab panels with specific thermal properties or comprising multi-functional components in order to satisfy all the interconnected needs appear to be a sustainable solution for energy retrofitting (*Avesani et al*.), considering that building services should be renovated at the same time.

On a larger scale, buildings could be grouped into different typologies with the aim to adopt similar solutions for each of them. The first and common solution among all the presented proposals is intervening on both opaque and transparent building envelope, for reducing thermal transmittance according to the local climate conditions. If this strategy reduces thermal losses, it must not be forgotten that energy consumption is due not only to heating, but also to cooling, ventilation, lighting and domestic hot water production and the corresponding facilities should be renovated as well and not only at the envelope level. This is clearly expressed in contribution by *S. Pescari et al*., who presents solutions targeting the building services besides the envelope and that reports expected results after renovation regarding primary energy consumption and CO_2 emissions.

As previously mentioned, all the contributions to the session Energy are focused not only on "energy", but structural and safety problems are tackled as well, highlighting the necessity of an integrated approach, based on multi-criteria and/or optimization techniques. Energy issues are a (necessary and important) part of a more complex and comprehensive approach based on sustainability that, in its turn, includes other technical, economic, environmental and social branches. This topic was clearly discussed in the contribution by *M.C. Caruso* (Caruso et al.) where a "Sustainable structural Design Method" combining all the aspects is proposed. In this case different territorial scales of intervention are presented - National, Regional, Local. The interconnections between them and the importance of disposing of different annual energy consumption databases are topics of further discussion as well.

GAPS

There are two orders of gaps that can be individuated:

1 - The fact that, in the laudable and effective effort to integrate different disciplines, the risk of approaching energy issues considering few and simple parameters (as for instance thermal transmittance of envelope) can trivialize and reduce energy performing solutions availability.

2 - The difficulties to put into practice what analyzed and proposed, starting from funding disposal, connections with authorities (National, Regional, Local) and considering that the residential buildings are occupied and that inhabitants must be temporary moved.

As for the former point, what should be included in the energy proposals and deserves specific analyses is on the one side the integrated use of renewable energy sources and on the other one, when applicable, the adoption of passive strategies in dependence of the site characteristics and the urban configuration.

Another topic that requires to be included is the energy management at different levels: single dwelling, building and district. This implies energy monitoring actions and the adoption of automation systems, aimed at improving the global energy performances. It's worthy noticing that an effective energy management system allows to achieve huge energy savings.

As passive strategies are concerned, exterior wall finishes with specific optical properties as a function of solar irradiance, and glazed components equipped with shading systems should be considered as well.

Considering energy production from renewable sources, it could be obtained at different levels: district, building, dwelling. For these reasons it appears evident that each proposed retrofitting solution should derive from a careful examination of the surroundings where the building is located and that i.e. the presence of an energy network system (as district heating) could affect the refurbishment choices.

Furthermore it must not be forgotten that the final users are the dwellings occupants and that all possible interventions should focus on their quality of life, health and comfort (human centric approach).

Given that the buildings are for residence use, the acceptance by the inhabitants represents one of the first goals to be obtained, before any other issue. Some buildings characteristics, as presence or not of balconies or porches, windows sizes, shading systems typologies, rooms' areas, bathrooms dimensions and features, etc., are connected to social and cultural profiles, depending also on traditions and habit: they can significantly affect possible refurbishment choices as well.

Indeed, it must be considered that occupants behavior have a great impact on energy consumptions, so the best solutions are the well accepted ones. In other words, if occupants perceive their own home facilities as something unfamiliar and imposed by strangers, they will manage them obtaining worse results than those obtainable by an inefficient heating or cooling system. Moreover, the will not be glad for the retrofitted building. Advice from experts of indoor environmental quality should also be taken into account, and specifically visual comfort, thermal comfort, acoustic comfort, air quality, and sense of safety and security.

The latter point is much more tough to be tackled and specific procedures are not obvious or simple, given the differences among countries, local features, social background and the several stakeholders involved. In this sense, some attempts for individuating particular cases and solutions should be done.

FUTURE STEPS

As already underlined, when considering energy retrofitting, as disposed by EU Directives and national laws, a holistic sustainable approach should be adopted, including not only structural issues, but also LCA, economic, social and environmental impact. The outlined framework clearly shows how experiencing building retrofitting from a sustainable point of view leads to a natural cooperation among experts in the involved topics, specifically structures and energy, but other experts could be involved as well, as material technology.

What could be done and when?

In the short term:

Goals: Establishing a common approach for large panel concrete buildings retrofitting with sustainable actions

How: Starting not only from structural, energy saving and LCA assessment, a critical analysis and comparison among the “green protocols” already existing in different countries (as LEED, BREEAM, GBI, Green Star, ITACA, CASBEE…) could lead to a specifically adapted rating system for this building typology.

State of the art of existing research and projects about sustainability applied to retrofitting interventions.

In the medium term:

Goals: Preparing the ground for possible application and search for funding by proposing a project (EU project).

How: Individuation of “case studies” in some European countries and their connection at different territorial levels. Dissemination of information about retrofitting actions and advantages at different levels among potential stakeholders, favoring cooperation and avoiding misunderstanding. Given the diversity of interlocutors and their cultural and social background, different form of seminars and/or reports should be delivered.

In the long term:

Goals: Developing the proposed project. Creating a new professional profile -Sustainability manager- (possibly recognized by the EU) able to manage all the different competences. The -Sustainability manager- is a different figure than the Energy manager, interacting with all the professional figures (as for instance the energy manager) involved in the building retrofitting and subsequent maintenance and management.

How: By experimenting sustainable interventions in the individuated case studies. Proposing learning activities.

Keynote Lecture

AUTOMATED OVERCLADDING FOR IMPROVED ENERGY EFFICIENCY – A UK PERSPECTIVE

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ABSTRACT

Across the world, millions of buildings require a major change in their energy performance to reduce their energy consumption and associated greenhouse gas emissions. To achieve this, it will often be necessary to improve the thermal performance of the buildings' envelopes of large areas of cities.
Using traditional construction methods will be slow, expensive and prone to poor workmanship. However, digital technologies offer the potential to achieve step changes at the scale required to make substantial reductions in energy consumption, as follows:

1. Buildings are accurately digitally surveyed by automated surveying equipment.
2. The data is automatically processed into 3D models, with overcladding schemes parametrically generated from these models.
3. Components are digitally fabricated, assembled on automated production lines, automatically shipped to site (e.g. driven by autonomous trucks) and are installed by autonomous robotic equipment.

We describe these processes, and levels of digital fabrication and automation in other industries and compare them with façade manufacture and installation in the building industry. We explore the current and potential roles of automated manufacturing.
We discuss how current technology would need to develop in order to allow an automated city-wide retrofit scheme to occur, and what could realistically be expected in the near future.

RENOVATION SOLUTIONS FOR BUILDINGS WITH LARGE PRECAST REINFORCED CONCRETE PANELS – CASE STUDY

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INTRODUCTION

Like many other Member States, Romania has an important heritage of old buildings, mostly built during 1960 – 1990 and characterized by several shortcomings: high energy consumption, high GHG emissions, thermal discomfort, poor architecture and very often, poor structural safety.

In Romania, out of the total dwelling units located in urban areas, 72% are apartments located in residential blocks inhabited by about 35% of the country's population. The most spread construction type of apartment buildings is the one with large precast reinforced concrete panels. The total primary energy consumption of these buildings varies between 150 and 400 kWh/m^2/yr, therefore renovation solution for increasing the energy performance of such buildings is essential in the current context.

The interior partitioning and the living areas of buildings with large precast reinforced concrete walls are not ideal and many of them do not meet the actual necessities of the residents, forcing them to search for local solutions in order to increase the indoor comfort. Local solutions are often destructive such as creating new openings, increasing the existing openings or even removing walls. Although the buildings were designed with proper seismic behaviour the above mentioned interventions raise thoughtful problems in terms of seismic behaviour; for this reason structural retrofitting interventions are crucial as well.

Currently, in Romania, the global renovation of buildings with large precast reinforced concrete panels is limited to thermal rehabilitation, and possibly local and episodic structural retrofitting interventions if any structural elements no longer relate to the situation for which they were designed.

Further on a case study is presented – energy efficient renovation solutions for a collective residential building with large precast reinforced concrete panels located in Timisoara, Romania.

CASE STUDY

In Timisoara, one of the largest Romanian cities, three main reinforced concrete large panel systems typologies are commonly encountered: T744, T770 and T1340.

T744 was the first typology implemented starting with 1962 and up to 1977. This system was designed considering only the vertical loads leading to relatively large panels and low reinforcement areas. The second typology, T770 was designed as a response to the 1977 earthquake, taking into consideration the seismic loads. The third typology, T1340, is considered to be a combination between T744 and T770. In addition to these three reinforced concrete large panel systems typologies, several other typologies have been used but with a lower incidence.

Current situation

The analysed building (Figure 1) is a 5 storey collective residential unit located in Timisoara and designed according to T744 typology. No interior modifications or interventions on structural elements were identified. The building comprises 20 apartments, four on each floor, an unheated technical basement and flat roof.

The building is still connected to the local district heating system, but some of the apartments are disconnected being equipped with gas condensing boilers.

Figure 1. Analysed building

The geometrical parameters of the building are listed in Table 1 and Table 2.

Table 1. Envelope elements area.

Envelope element	Orientation	Area [m^2]	Total area [m^2]
Exterior walls	N	62.48	650.92
	S	62.48	
	E	274.23	
	V	251.73	
Windows and exterior doors	N	20.50	239.18
	S	20.50	
	E	87.84	
	V	110.34	
Flat roof	Horizontal	254.28	254.28
Floor over unheated basement	Horizontal	254.28	254.28

Table 2. Building geometry parameters.

Total envelope area [m^2]	Heated area [m^2]	Heated volume [m^3]	Compactness ratio [m^{-1}]
1398.66	1271.42	3436.98	0.407

Thermal and energetic parameters of the building are listed in Table 3 and Table 4.

Table 3. U- values.

Element	U –values [W/m^{2}K]
Exterior walls	2.222
Windows and exterior doors	2.631
Flat roof	1.612
Floor over unheated basement	3.367

Table 4. Annual energy balance and CO_2 emissions before renovation.

Energy consumer	Energy consumption [kWh/m^2/yr]	Total energy consumption [kWh/m^2/yr]	Primary energy consumption [kWh/m^2/yr]	CO_2 emissions [kg/ m^2/yr]
Heating	281.40	367.80	359.83	82.44
DHW	75.40			
Lighting	11.00			

Renovation solutions

The renovation solutions aim, primarily, at reducing the energy consumption of the building, but also bring substantial improvements in terms of indoor comfort and architecture.

The proposed solutions were grouped as follows: solutions targeting the building envelope and solutions targeting the building services.

Table 5. Solutions targeting the building envelope.

Element	Technical renovation solution	U –values [W/m^{2}K]
Exterior walls	Ventilated façade with 150 mm waterproof glasswool and ceramic tiles as finish coat	0.219
Flat roof	200 mm polyurethane foam protected with polyurea;	0.154
Floor above unheated basement	100 mm polyurethane foam applied on the underside of the slab and also partially on the basement exterior walls;	0.290
Windows and doors	Triple glazing, Low-E, Argon, PVC framed windows and exterior doors equipped with exterior wooden shutters; g = 0.60.	0.800

Table 6. Solutions targeting the building services.

Component	Renovation/modernization solution
Heating	Maintaining existing connections to district heating; Reconnecting disconnected apartments to district heating; Horizontal distribution of heat transfer medium in apartments; Resizing the heating system (radiators, pipelines); Thermal insulation of pipes located in the basement; Individual heating consumption metering;
Cooling	Equipping all apartments with individual air condition units;
Ventilation	Equipping all apartments with individual ventilation systems with heat recovery;
Domestic hot water	Maintaining connection to district hot water system; Thermal insulation of pipes located in the basement; Individual hot water consumption metering;
Lightning	Replacing all light bulbs (apartments and common areas) with energy efficient light bulbs;
Renewable energy system	Integrating a PV System on the building's flat roof to cover energy demands for apartments + common areas ventilation and lightning;

Expected results

The primary energy conversion factors were considered as follows: 2.62 for non-renewable electricity and 0.92 for district heating. The CO_2 emissions conversion factors were considered as follows: 0.22 for district heating and 0.299 for non-renewable electricity.

Table 7. Annual energy balance and CO_2 emissions after renovation.

Energy consumer	Energy consumption [kWh/m^2/yr]		Total energy consumption [kWh/m^2/yr]	Primary energy consumption [kWh/m^2/yr]	$C0_2$ emissions [kg/ m^2/yr]
	Non- renewable energy	Renewable energy			
Heating	13.40	22.60 (recov.)	77.60	105.87	17.51
Cooling	5.60	1.00			
Ventilation	0	1.00			
Domestic hot water	58.60	0			
Lighting	0	2.00			

CONCLUSIONS

In Romania, buildings with large precast reinforced concrete panels dating before 1990 have several issues of which the most important are the high energy consumption, high CO_2 emissions, residents' discomfort, poor architecture and of course, possibly local seismic-related problems.

For the presented case study, the proposed renovation solutions lead to high energy performance along with major improvements in user comfort and also architectural requalification.

Currently, renovation interventions on buildings with large precast reinforced concrete panels aim mainly at increasing their energy performances. However, special attention should be paid to structural elements which no longer meet the requirements for which they were designed, as their behaviour under accidental loads could be improper.

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TECHNOLOGY OVERVIEW OF PREFAB FACADE SYSTEMS FOR MULTI-OBJECTIVES BUILDING RENOVATION

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INTRODUCTION

In Europe, around 75% of the existing building stock dates back to before the 1990s (Building Performance Institute Europe, 2017) and is characterized by remarkable energy demand levels, spanning from 200 to 300 kWh/m2y for the residential and the non-residential sector[1], respectively. Within this energy demand, around 70% is ascribed to households at European level. This allows to easily infer that renovating the existing residential building stock is a major priority to be addressed in order to meet current European decarbonisation targets (Marina Economidou, 2011).
Buildings are assets with an expected service life up to 50 or more years. Hence, 75-90% of those standing today are likely to be still in use in 2050. Considering the current demolition rates (0.1% per year), and low rate of construction of new high energy efficient buildings (1% per year), the European energy efficiency challenge in buildings can be mainly addressed through investments in renovation of the existing building stock. However, as the renovation rate of the existing stock is still limited (1-1.5% per year), a significant acceleration is needed (Ad-hoc Industrial Advisory Group, 2010). Recently, retrofit actions have been focusing on single aspects of building performance. This can be ascribed to the combined effect of several root causes, such as: capital investment costs, technological constraints, complexity in planning construction time schedules and decision-making procedures. Hence, deep renovation is a challenge that is rarely tackled applying a standardised approach, provided that each building has its own story, in terms of technical and morphological features. Nevertheless, addressing the building renovation process has provided successful results in several cases, where a comprehensive approach based on systemic technology packages to face the multiple and interconnected retrofit needs has been adopted.
Comprehensive retrofit actions should be treated as multidisciplinary and multi-objective research questions, to address an extensive set of needs and requirements, such as: (i) energy efficiency; (ii) exploitation of renewable energy sources; (iii) structural and seismic robustness; (iv) indoor comfort; (v) space functionality; (vi) aesthetics and (vii) lean manufacturing and installation process. More in detail, European and national regulatory energy targets require to consider both the envelope and the energy system in the deep renovation, besides the need to exploit renewable energy sources and reduce the overall usage of non-renewable sources. Furthermore, the structural topic is increasing in importance given the obsolescence risk of the existing building load bearing structure. This especially applies to buildings constructed in the last century, as well as historical ones, which are generally characterised by limited seismic resistance. Such aspect is particularly relevant for southern European countries, which bear higher seismic risk. In addition, precision and reliability of construction results are crucial as well as guaranteeing minimum impact on building occupants.
In this context, designing envelope retrofit solutions leads to an increased level of complexity. On one hand, costs tend to rise and becoming articulate and difficult to predict, requiring the adoption of life-cycle costing evaluation methods to support soundness of the solutions adopted from both the technical and economic point of view. On the other hand, technical complexity is more comfortably addressed through the implementation of digital design processes, such as the use of Building Information Modelling coupled with advanced performance simulation tools.
For all the above, the use of a prefabricated multifunctional timber-frame façade represents a convenient solution to allow effective and multi-criteria renovation of existing buildings (e.g.

[1] As seen in http://qualicheck-platform.eu/wp-content/uploads/2015/12/QUALICHeCK-Webinar-02-2015-12-17-1-MSantamouris-pub.pdf, retrieved on November 13th 2018

envelope, energy system, structural function), guaranteeing quick installation of pre-optimized technological systems and very limited impact on building occupants.

OVERVIEW OF FAÇADE RENOVATION TECHNOLOGY AND SYSTEMS: PREFABRICATION AND MULTIFUNCTIONALITY

The basic technology concept proposed in this article is a modular prefabricated sub-structure anchored to the existing building load bearing structure, hosting all functional components needed for the retrofit (e.g. windows, energy generation and distribution systems, mechanical ventilation machines, …). This multi-functional new façade is then applied on the outside of the existing building envelope, using an adaptation layer to cope with construction tolerances and an anchoring system connecting the new and the existing facades. The main constitutive elements are described hereunder, from the outside to the inside of the building (Figure 1).

- Functional Component: each element that can be integrated accomplishing one or more functions, such as new window systems, insulation layers, energy services module, and other building services' elements. Such component is covered or integrated in a finishing system to fulfil architectural integration requirements.
- Connections System: connections, both between functional components and among adjacent modules, must be designed in order to assure fast, durable and effective connection under different aspects, such as mechanical resistance, thermal performance, air and water tightness. They support the distribution of cables and wires, pipes and ducts.
- Sub-structure: frame structure that holds each component together and transmits loads to the existing wall. It must be modular and flexible in dimensions, designed to integrate functional components in a fast and effective way, also allowing easy maintenance and possible re-cladding. Preferably, it should combine lightweight and load bearing features.
- Adaptation layer: this layer is needed to provide adequate adherence between the new facade and the existing wall. This is usually designed based on precise geometric measurements of the existing building.
- Anchoring System: all the bonding between the existing wall and the new façade. It must provide good mechanical resistance while minimizing the thermal bridge.

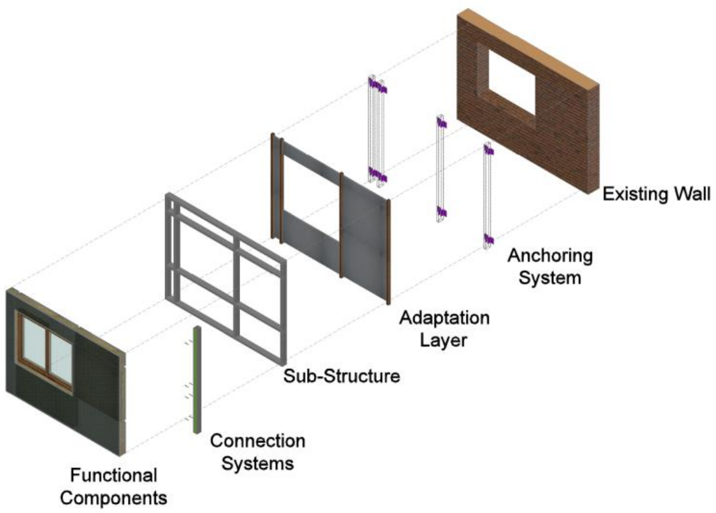

Figure 1. Ontological scheme of a timber-frame prefabricated façade for the retrofit of existing buildings (Credits: Eurac Research).

This idea was firstly launched in 2006 by the International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems (ECBCS) with the Annex 50[2], as a research task on the retrofit of existing building with prefabricated multifunctional elements. The studied façade modules integrate mainly insulation layers, high performance windows, air ducts, decentralized mechanical ventilation systems, hydronic pipelines and electric cabling into a wooden façade structure. Both timber and metal-based façades have been studied, but the solution based on timber seems to have prevailed as this has also been implemented in real demo cases in Austria and Switzerland (Zimmermann, 2012).

Here below, a list of best-practice projects in the field of prefabricated façade modules for building renovation is presented, with the aim of highlighting main achievements and developments in terms of increased level of prefabrication, building quality and functionality.

TES Energy Façade project (2008-2009), and its follow-up *smartTES* (2010-2013)[3], were developed by a consortium of researchers and companies from Finland, Germany and Norway, during 2008-2010. TES Energy Facade has defined basic principles for the energy modernisation of the building envelope using prefabricated large-sized timber frame elements. The strategic vision laying behind the use of prefabricated retrofit building elements is a frictionless digital workflow spanning from survey, planning, off site production and mounting on site based on a precise initial 3D measurement (Lattke et al., 2009) (Lattke and Cronhjort, 2014).

E2ReBuild - Industrialised energy efficient retrofitting of residential buildings in cold climates[4] has worked on demonstrating the most cost-effective and advanced energy-efficient industrialised retrofit strategies in real case studies. Hence, also prefabricated timber-frame façade has been implemented in several demo cases[5] (Claeson-Jonsson, 2014).

H2020 SINFONIA project - Low Carbon Cities for Better Living[6] has worked on the development of an extensive set of energy saving measures at different scales, such as smart transportation systems, energy management strategies and envelope retrofit solutions. In this frame, prefabricated façade modules have been designed and applied in several construction sites (via Passeggiata dei Castani in Bolzano/Bozen), based on a timber frame self-bearing structure, integrating both adaptation and insulation layer. In this case, external architectural finishing has been installed onsite, as well as solving air and water tightness of joints.

iNSPIRe – Systemic Energy Renovation of Buildings[7] developed an off-site fabricated modular facade system for efficient energy renovation of residential buildings, with the aim of minimizing construction works on site for the deep renovation of façade, roof and energy systems. The designed façade has been successfully deployed in two different case studies. The main technical features of the system can be summarized as follows: (i) large panel size, to cover one storey of the building; (ii) timber framed insulated cassettes; (iii) external cladding, chills and reveals as well as steel weather profiles; (iv) integrated windows. The iNSPIRe façade also integrated multifunctional system components, such as micro heat pumps, heat recovery units and related ducts (Dermentzis et al., 2014; Ochs et al., 2015). Some hydraulic and aeraulic components have been integrated in a dedicated system shaft, prefabricated as well, and integrated within the façade allowing to bridge apartments over different levels.

4RinEu - Robust and Reliable technology concepts and business models for triggering deep Renovation of Residential buildings in EU[8] dedicates part of its activities to the topic of timber façade for retrofitting (Figure 2). With this regard, focus is put on capacity building within the technical

[2] www.iea-ebc.org/projects/project?AnnexID=50
[3] www.holz.ar.tum.de/forschung/tesenergyfacade/
[4] https://cordis.europa.eu/project/rcn/100470_it.html
[5] https://smartcities-infosystem.eu/sites-projects/projects/e2rebuild
[6] www.sinfonia-smartcities.eu
[7] http://inspirefp7.eu
[8] http://4rineu.eu

community about the renovation solution to boost replicability of the proposed building system. Options for integration of building services and sets of integration options are given to enable planners to adapt the solution to the needs of specific existing buildings. During 4RinEU emphasis is put on adapting the façade solution to different geo clusters in Europe. To provide investors (mostly the owners) and designers with decision criteria for defining suitable deep renovation measures, economic and environmental issues are being addressed with a life cycle approach, demonstrated especially for prefabricated multifunctional timber façade elements.

Figure 2. 4RinEu Prefabricated multifunctional façade mockup tested in the lab (credits: Gumpp&Maier Gmbh).

DISCUSSION

From the above-mentioned experiences of deep renovation with multifunctional prefabricated timber-frame façade elements, the following considerations on criticalities and trends based on project data can be drawn.

TECHNOLOGY

- The existing building audit is a priority when a retrofit action with such technology is envisaged. Building audit must be multi-disciplinary, covering geometry as well as structural, energy and functional aspects.
- The facade installation, and generally the overall duration of the construction site, runs much faster than traditional retrofit actions. On the other side, the design phase is much longer and more complex, highlighting the need to involve all building retrofit stakeholders since the preliminary phases. The choice of the companies involved in the workflow is fundamental to assure an effective and efficient design flow as well as fluid coordination on construction site.
- Investment cost intensity is an issue of such kind of technology, and as such functional mock-up and testing phases have been playing a crucial role in all projects, providing preliminary and reliable validation steps before starting construction activities.
- The way tenders and technical specifications are defined and verified is crucial in effectively driving the design, the installation and the commissioning. In this sense, the adoption of the so-called performance-based procurement would be beneficial (Vullo, Passera, Lollini, Prada, & Gasparella, 2018).

ECONOMICS and SUSTAINABILITY

- Manufacturing and assembling costs can be optimized along the whole value chain. Reaching a critical mass on the demand side can increase the margins obtained from the industrialisation of the manufacturing, assembling and installation. In fact, win-win partnerships can further reduce investment costs. In addition, the adoption of a design for assembly approach can provide room for significant improvements in production lines, aiming at efficiency standards as in the automotive sector.

- Economic and sustainability must enter the decision process in a quantitative way. A strong paradigm shift is needed towards a Life Cycle (LC) and circular economy perspective. In particular, the increase of building life time, its economic value, and the use of metrics like the net present value besides the payback time must be taken into account since the very beginning of the design process. Dedicated design and evaluation tools are needed on the market to include economic evaluation of prefabricated façade systems for retrofit over a real service life timeframe, to foster the adoption of such façade technology.
- As a consequence of the previous point, investors (or new joint technical and economical entities) have to be involved since the very beginning. On the one side, the higher investment cost can be more easily covered. On the other, new financial mechanisms could be envisaged thanks to the reliability and robustness of the implemented façade technology.

COMPLEXITY

- The complexity of design and construction site management shows the need to promote a participative design approach involving all stakeholders (including tenants) from the earliest stages, as well as to reduce the number of involved companies in the installation phase as much as possible. In addition, all the process should be planned and managed with a lean approach. On this topic, specific education should be provided to a generation of new skilled workers and companies, building capacity across the relevant community.
- The use of multifunctional prefabricated façade systems confers to façade manufacturing companies a strong connotation as system integrators. As a result, the integration of new responsibilities and expertise, as well as the creation of strong partnerships with suppliers, is needed to close gaps in the whole value chain. An example is the case of integration of aeraulic or hydraulic components within façade modules, where system commissioning and maintenance requires specific expertise that might not be available within the company or its traditional suppliers.

The set of presented case studies highlights that there has been a constant progression towards the integration of multiple functions in prefabricated façade modules. This bears a consistent degree of complexity, which could be more efficiently handled through an extensive adoption of digital tools to support both the design and fabrication phases.

OUTLOOK

Based on the analysis presented in this paper, the use of multifunctional prefabricated timber-frame façade in the residential building deep renovation is a technically and economically viable solution in many situations. As future perspective, a paradigm shift in both design and process management is needed, thinking the renovation differently by including the whole life cycle in any analysis and comparison. The spreading of the circular economy principles represents a good chance in this sense. Nevertheless, dedicated design and evaluation technical and economic tools supporting designers, owners and investors are needed, in addition to spreading awareness on both the approach and technologies already available on the market. From a technological point of view, a mix of technical solutions can be studied depending on the building and the façade features and needs, optimizing the whole renovation cost. Finally, there is high potential of exploiting such facade technologies with suitable optimised and viable technology solutions to couple in a synergic way structural and seismic rehabilitation too. This can be an effective driver for investors besides the energy, aesthetic and functional renovation or the increase of quality and quantity of living area, and is in line with the current European and national policies and regulations.

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COMBINED ENERGY UPGRADING OF BUILDINGS AT LOCAL/REGIONAL/NATIONAL SCALE

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EXTENDED ABSTRACT

Sustainable development is one of the most relevant topics of the last decades, which involves each branch of human activities. Among the others, the construction sector provides high contributions to the three dimensions of sustainability: the *social* dimension, because people spend most of their time in buildings and a healthy environment has to be guaranteed; the *economic* dimension, because the construction of buildings sector accounted for 3.7 % of the total number of enterprises in the EU in 2015 (European Commission 2018a); the *environmental* dimension, because buildings are responsible for approximately the 40% of the total energy consumption and the 36% of the total greenhouse gases in Europe (European Commission 2018b). Among the three dimensions, in the last years more attention has been given to the environmental issue. The growing interest in achieving the environmental efficiency of buildings, requested by the global agreements regarding the reduction of climate change, has prevailed, somehow, on an important aspect of the buildings performance, which is the structural safety, a critical topic considering the statistics on construction age of European building stock (Economidou, 2011). For this reason, a combined approach for evaluating the performances of buildings, including the environmental and the safety performances, is necessary. According to this, Romano et al (2014) have developed the Sustainable Structural Design (SSD) method, which aims to equip the buildings with a single parameter, called "Global Assessment Parameter" (R_{SSD}). The R_{SSD} parameter includes energy consumption, equivalent CO_2 emissions and the structural costs, and is provided in economic terms. The methodology, outlined in Figure, is based on three main pillars, each of them corresponding to a procedure evaluation step: I) the Energy Performance Assessment, where the parameter related to the life-cycle energy incurred in all phases of the building life is evaluated; II) the Life-Cycle Assessment, where the environmental impacts of products and processes generated during their entire life cycle of the building are evaluated; and III) the Structural Performance Assessment, where the total cost for structural performance assessment, C_{TOT}, is evaluated from the economic losses and the initial construction costs. The fourth step represents the conversion of the three identified pillars in economic terms, to address "Global Assessment Parameter".

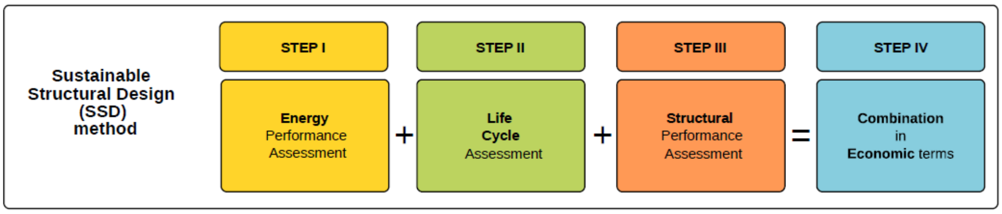

Figure 1. Framework of the Sustainable Structural Design (SSD) Methodology

An important development of the SSD methodology is its application at territorial level. If the methodology was applied to small or big areas, it could represent a solid method for supporting the administrations in addressing the policy projects on the territory. Indeed, if the building stock is classified into groups of buildings having similar characteristics and the global assessment parameter is evaluated for each building group, the territory can be divided into areas having same R_{SSD} range, and, according to this classification, areas with highest values of R_{SSD} will result as the ones where a structural and energy intervention is more necessary.

In order to reach the described aims, the development of the SSD methodology at territorial level is briefly summarized in Figure 2. As shown in the figure, Step I represents the energy performance assessment step, in which, the energy performance parameter can be obtained following two different procedures: Procedure A, for evaluations at national level; and Procedure B, for evaluation at regional and urban levels. Procedure B can be divided into two sub-procedures: B1, where the energy consumption is provided by the European energy databases; B2, where the energy consumption is provided by the Energy Performance Certificates. Step II and Step III represent, respectively, the life-cycle assessment (LCA) and the structural assessment steps. The LCA performance parameter and the structural assessment parameter are individually evaluated by using the same procedure for national, regional and urban levels. Moreover, Step III consists in an initial phase of building data gathering and stock classification, followed by the loss assessment and the initial costs evaluation. The conversion of the single parameters in economic terms is performed at the end of each step, so that Step IV simply consists in the sum of them.

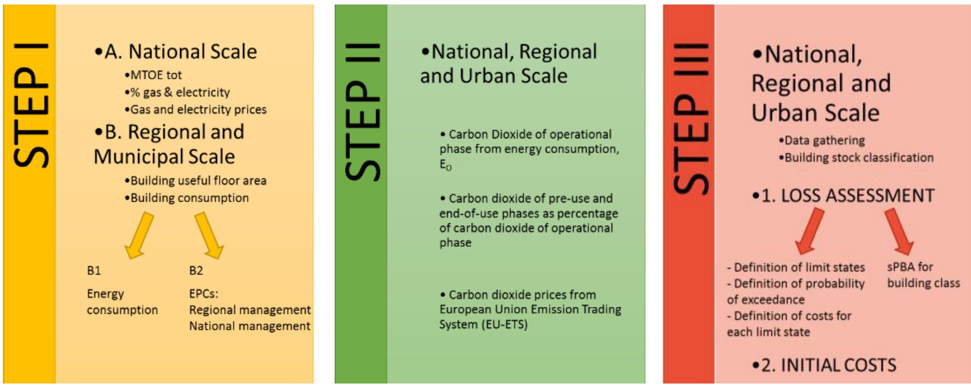

Figure 2. Framework of the development of the SSD methodology at national/regional/urban level

Step I - Energy performance

Procedure A - National Level

The assessment of the energy performance parameter (R_E^{Energy}) at territorial scale can be evaluated as:

$$R_E^{Energy} = \sum_{(i=1)}^{N} \sum_{(j=1)}^{M} \left(\%_i \cdot (kWh_{TOT,i}/\ year)_{MS} \cdot (€/kWh)_i\right)_j \quad (1)$$

being i the i-th energy component (gas, electricity); j the j-th building occupancy class (as households, offices, schools,…); N the number of energy component considered; M the number of building occupancy class considered; $\%_i$ the percentage of the i-th energy component on the total, for the considered Member State (MS); $(kWh_{TOT,i}/(year))_{MS}$ the annual total energy consumption of the i-th energy component, referred to the considered MS, provided by the main European databases (Eurostat, IEA - International Energy Agency, BPIE - Buildings Performance Institute Europe, ODYSSEE); $(€/kWh)_i$ the price of the i-th component.

Procedure B - Regional/Urban level

The option B for the energy performance assessment regards the buildings at regional and urban levels. In option B1, the same data source of option A is used; in option B2, Energy Performance Certificates (EPCs) data source is used. The yearly energy performance parameter at regional/urban level can be obtained with Equation 2 according to approach B1 and Equation 3 according to approach B2:

$$R_E^{Energy} = \sum_{(i=1)}^{N} \sum_{(j=1)}^{M} \left(\%_i \cdot (kWh_{TOT,i}/(m^2 \cdot year))_{MS} \cdot m^2_{(region/city)} \cdot (€/kWh)_i\right)_j \quad (2)$$

$$R_E^{Energy} = \sum_{(i=1)}^{N} \sum_{(j=1)}^{M} \left(\%_i \cdot EP_{gl} \cdot m^2_{(region/city)} \cdot (€/kWh)_i\right)_j \quad (3)$$

where i, j, N, M, $\%_i$ and $(€/kWh)_i$ assume the same significance of Equation 1. Moreover, $(kWh_{TOT,i}/(m^2 \cdot year))_{MS}$ is the annual total energy consumption per square meter of the i-th energy component, referred to the considered MS; EP_{gl} is the annual total energy consumption/m^2 of the i-th energy component, referred to the considered region/city and provided by the energy performance certificates (Directive 2010/31/EU); $m^2_{(region/city)}$ is the usable area of building groups in the considered region or city.

For both the options, information about the buildings floor area is required. For this reason, a comparison about buildings floor area data provided by different databases (Eurostat, IEA, BPIE, ODYSSEE and IVL -Swedish Environmental Research Institute) has been performed, revealing that the usable floor area data do not match well for all the Member States.

Step II – Life-Cycle Assessment

The second step of the SSD methodology aims at evaluating the total CO_2 emissions of the buildings at territorial level. The environmental impact of global change, R_E^{CO2}, can be evaluated as:

$$R_E^{CO2} = Q^{CO2} \cdot P^{CO2} \tag{4}$$

Being P^{CO2} the carbon dioxide price, provided by the EU ETS system, and Q^{CO2} the equivalent amount of carbon dioxide generated by all the life cycle phases of the buildings and evaluated, with a simplified approach, from the CO_2 emission of the operational phase (CO_2^O) of buildings with the following equation:

$$CO_2^{LC} = CO_2^E + CO_2^O + CO_2^D = a \cdot CO_2^O + CO_2^O + b \cdot CO_2^O \tag{5}$$

where the coefficients *a* and *b* are set equal to 0.15 and 0.03, respectively, starting from the results provided by Scheuer et al. (2003), Adalberth et al. (2001) and Loli et al. (2016).

Step III - Safety performance

Safety performance of buildings can be assessed by evaluating the expected losses generated by events that can occur during the building's lifespan. The evaluation of the building safety performance at territorial scale implies the economic loss estimation of a large number of buildings. In this study, expected losses generated by earthquakes are computed.

Before developing the steps for structural performance assessment of buildings, two initial phases have to be developed: a) data gathering about the building stock; and b) building stock grouping into classes having similar characteristics. Several techniques for data gathering are available, as the Italian ongoing field survey of all the existing buildings, called "CARTIS Project" (Presidenza del Consiglio dei Ministri (2014)), which is collecting all the relevant building characteristics at Municipality level. Once the building stock information is gathered, the building groups having similar characteristics, that means they will likely show similar damages, have to be labelled. To this aim, the building stock taxonomy defined by the SYNER-G Project (Hancilar et al., 2013) is ideal for the SSD methodology.

Expected earthquake losses evaluation is performed by following five steps: *definition of limit states, definition of probability of exceedance, estimation of repair/replacement costs, estimation of expected losses for each limit state and estimation of total losses*. In the first step, four limit states (LS) are introduced for describing the building seismic performances: LS1 - slight damage; LS2 - damage at non-structural elements; LS3 - heavy damage; LS4 - near collapse. Then, the probability that an event causing the over-mentioned damages for each limit state occurs during the building reference period has to be assessed, and it can be derived by national technical codes. The evaluation of repair/replacement costs after an earthquake is an ongoing research topic. Several approaches have been developed so far; among the others, the assessment based on surveys on existing post-earthquake costs data. According to this approach, data gathering after L'Aquila earthquake (Italy, 2009), published in the "Libro Bianco" (Bertani et al. (2015)) is mentioned. The book presents the costs related to the rehabilitation of RC and Masonry buildings, classified according to the usability classes, defined by the "AeDES" usability form (Presidenza del Consiglio dei Ministri (2009)), from class "A" (the building is functional and usable) to class "F" the building is not usable because of external risks). The usability classes can be then correlated to the limit states. The "Libro Bianco" reports the repair/reinforcement costs related to the AeDES Usability Classes and some of the building features.

The expected losses for each limit state can be estimated by using the following expression:

$$L_i = C_i \cdot (P_i - P_{(i+1)}) \tag{6}$$

being L_i the expected earthquake economic losses related to the *i*-th limit state; C_i the repair/replacement costs of the considered building related to the *i*-th limit state; P_i and P_{i+1} the probabilities of exceeding, respectively, the *i*-th and the *i+1*-th limit state.
Finally, the total earthquake expected losses, related to the whole lifespan of the building, can be evaluated as the sum of the expected losses for each limit state:

$$L = \Sigma_{i=1} [C_i \cdot (P_i - P_{(i+1)})] \tag{7}$$

The building initial costs (I) can be evaluated by means of the market information provided by each Member State. Finally, the total cost for structural performance assessment, C_{TOT} is evaluated as:

$$C_{TOT} = I + L \tag{8}$$

Global assessment parameter

As for building level, the global assessment parameter, R_{SSD} can be evaluated as:

$$R_{SSD} = R_E^{Energy} + R_E^{CO2} + C_{TOT} \tag{9}$$

In conclusion, the study has demonstrated that SSD methodology is applicable at territorial level. Indeed, a framework to extend SSD at national/regional/urban level has been presented by developing the four steps of the method itself. SSD methodology, if applied to small and big areas, could be a solid methodology for supporting the administrations in addressing the policy projects on the territory. Nevertheless, the study herein presented has highlighted some critical aspects related to the methodological development. Firstly, no sound data on national and regional usable floor area of buildings are available, resulting in a difficult evaluation of energy consumption. A study on prices of all the energy components should be conducted in order to provide a more complete value of energy performance parameters. Moreover, a field survey on buildings at regional/urban level is necessary in order to treat groups of buildings having similar characteristics as single building; the field survey should be finalized with the grouping of buildings having same label and according to Syner-G taxonomy. Another aspect to be considered is the necessity of collecting techno-economic studies regarding repair/replacement costs from worldwide-occurred earthquakes.

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STRUCTURAL AND THERMAL INTERVENTIONS FOR REHABILITATION OF PRECAST LARGE CONCRETE PANELS FOR RESIDENTIAL BUILDINGS

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INTRODUCTION

Most Eastern European countries inherits a large building stock from the earlier periods. During the 1960-1989's, vast urban areas were built-up with collective buildings from prefabricated concrete panels. For example, in Romania, during the industrialization period (1958 to 1978) a large wave of population migrated towards the cities and the number of cities grew from 187 to 237 (1965-1985). In order to accommodate the large number of inhabitants, new homes had to be built in a short period of time. The use of highly industrialized building technologies with simple assembling on site was the solution adopted. In order to reduce costs, national design institutes delivered standardized projects for the entire country. This pattern of construction can be observed in most Eastern European countries, fueled by the needs of the centralized state economy.

The housing building program was implemented over the entire country, had a large scale and generated numerous studies and approaches to improve the standardized typology projects during the years. However, the buildings were conceived with small inhabitable areas and reduced number of rooms in each apartment, especially in first stages.

The studies and researches at that time (BIT 24/1967; BIT 8/1968; BIT 4/1969; BIT 11/1970; BIT 4/1971) generated major differences regarding the typologies of precast reinforced concrete buildings. The differences refer to urban criteria (density, number of storeys, related facilities, etc.); architectural criteria (interior partitions, volumes, facades, etc.); energy consumption, finishing materials, structural and seismic performance, etc.

In various stages of development of the collective buildings the housing comfort grew from the point of view of inhabitable area, useful area and the number of rooms in the apartments. From 1975 to 1982 a significant increase of the average living area of apartments was made, arriving to 33 square meters from an initial value of 27 square meters. It can be seen that the inhabitable areas of the dwelling units are fairly low and, in addition, are built using a rigid partitioning system dictated by the prefabrication needs. From this point of view, these buildings require a special attention in the reorganization of the interior spaces, with special difficulties in the units built before 1975.

Studies conducted for these types of buildings in Timisoara revealed that large prefabricated concrete panel buildings constitute some of the most important urban tissues in the city and that the construction of the buildings can be staged in three different periods that used, mostly, three different project types (Tadi, 2007; Radoslav et al., 2010; Botici et al., 2011).

The current major problems of these buildings can be categorized into (see Figure 1):

- problems regarding thermal comfort, ventilation, energy consumption;
- problems caused by the small inhabitable area and rigid internal partitions;
- problems concerning the public space, accessibility, lack of parking areas, elevators, space for social interaction etc.

In the framework of the European energy policy, Law 372/2007 enforced the Directive 2002/91/UE requiring significant reductions of primary energy demand and greenhouse gas emissions in the building sector. The Directive, revised in 2010, specify that the enhancement of energy performance for residential buildings must be done such that the specific annual energy consumption for heating to fall below 100kWh/m^{2}year.

The required thermal rehabilitation, in order to achieve the stricter energy consumption goals, was quite expensive. In order to offset some of the costs, owners of the flats in well-interlinked areas sold the attic of the building to investors, in exchange of costs for thermal rehabilitation of the building. The investors soon built new apartments and over-roofing became a large-scale phenomenon.

Figure 1. Problems regarding the built environment.

The laws regarding over-roofing did not anticipate the different impacts of these new interventions in the built areas. Over-roofing was primarily regulated as a punctual intervention on a single building. As a result, new problems created especially in terms of densification and aesthetic of building assemblies.

RETROFITTING INTERVENTIONS THROUGH INTERIOR PARTITIONING

From an urban and architectural point of view the study of possible intervention scenarios in relation with the layout of the neighborhoods can revitalize the city image. As example, considering a possible intervention on the standard project T744R-IPCT, built generally between 1962 and 1975 by reconfiguring the areas separated by vertical surfaces. This building is a low rise four story type, nearly 14 meters height. One unit generally accommodates four apartments on each storey, having the staircase located in the middle span. The apartments have two rooms, one kitchen and one bathroom, with a living area of less than 60 m^2 (see Figure 2).

The structural walls are vertical reinforced concrete diaphragms, while non-structural walls are used for internal partition. The necessity of making large openings in diaphragms is highlighted from the architectural point of view that allows for the re-design of the interior rigid partitions and also provides multiple options in terms of interior furnishing. Reconfiguring through practicing large openings in the structural diaphragms must be done in a coherent way, to maintain the ability of the structure to withstand vertical and horizontal loads.

Figure 2. Current flour plan - project type 744.

The study consisted in the analysis of different types of apartment repartitioning, in order to obtain a more or less cost-effective, structural and functional solutions that could be integrated into a reliable 3D building matrix (see Figure 3).

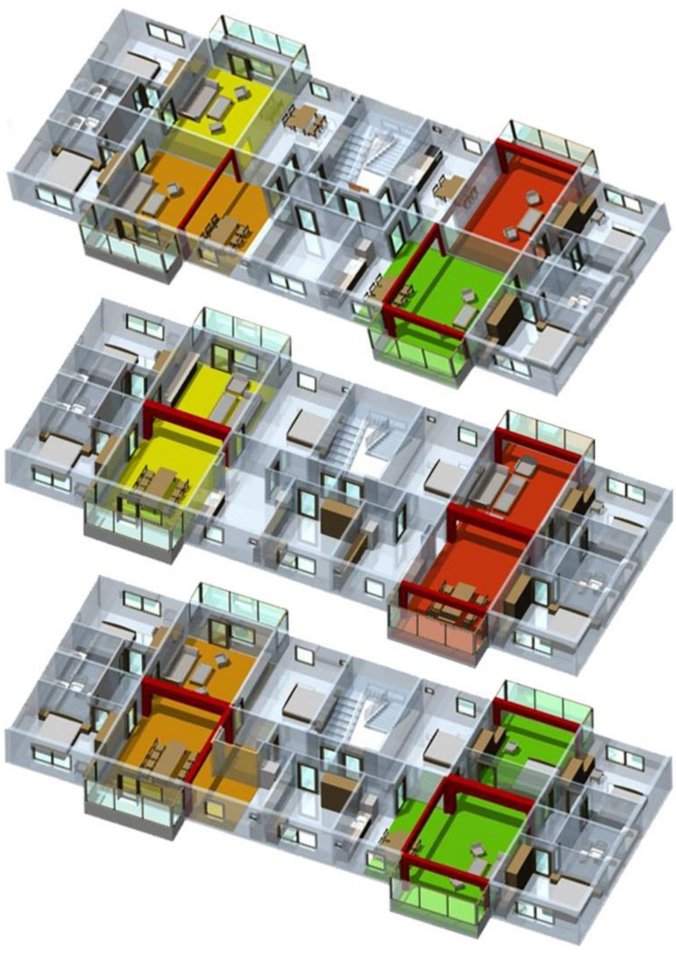


Figure 3. New types of apartments and interior space partitions.

The structural system is made of precast panels assembled on site. The original building has there longitudinal and eight transversal concrete diaphragms composed of standardized precast concrete panels. The interior panels are single layered elements of 14 cm thickness, in B250 (equivalent to C16/20) concrete class. The exterior panels are composed of three specific layers, with different functions: the load bearing layer (12 cm), the thermal insulating layer (6 cm) and protection layer (6 cm), respectively.

The main objective of the case study is to design, analyze and develop an experimental evaluation for steel structural solutions, which can be easily standardized and manufactured at an acceptable cost. The structural solutions must be able to facilitate the reconfiguration of the existing apartment's interior space by enlargement of the living area and connecting it efficiently to the small balconies. Another possibility is the design of larger apartments by coupling and partitioning the interior space of existing ones. The solutions proposed, could be used in case of designing new openings in the ground floor exterior walls in order to develop new social functions for ground floor area, or to attach external lifts to the existing staircase.

Due to the fact that the interconnection of the panels was emphasized in several papers (Demeter, 2005) and stated to be one of the vulnerable points of the existing structure, the solution was to create large openings in the precast panels without affecting the joints, and to consolidate them with steel frames (Botici et al., 2012). The structural solutions can be made either locally, inside one or more apartments or for all stories using continuous steel frames, as presented in Figure 4.

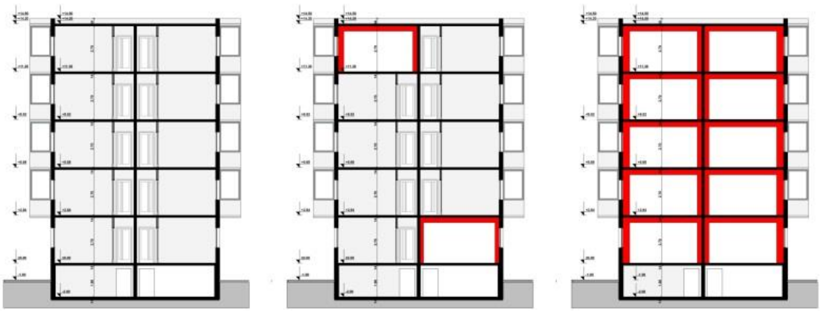


Figure 4. Possible steel frame configuration.

In order to understand the structural behavior, 3D analyses using shell finite elements were performed on original configuration and by considering different intervention scenarios, in order to obtain a structural matrix and observe its limitation depending on the seismic zone. The analyses were performed by ETABS using shell finite elements. The structural scenarios computed included the initial structure (denoted as case „A" – Figure 2) and 3 scenarios, in which large openings were created in panels and consolidated with steel frames (denoted as case „B", „C" and „D" – Figure 3). The analysis results show no significant increase of lateral displacements for the diaphragms with large openings (case B) in comparison to the initial case A and also small modifications of the stresses in the diaphragms. This is mainly due to the high rigidity of the slabs, which act as a horizontal diaphragm.

In order to have an experimental evidence of the impact for the proposed interventions, and the positive results obtained from numerical simulations, an experimental program was conducted in the CEMSIG Research Centre of the Politehnica University of Timisoara. The experimental tests consisted in testing the steel reinforcing frames installed in the new openings, concentrated on the steel-frame to original concrete panels. The main purpose of testing was to check the load bearing capacity of the joints, and, to establish the maximum levels of the bending moment they ensure the continuity of transmitting the forces in the newly created structural assembly.

The scale of the specimens was maintained 1:1 as in the real situation. For the specimens the active concrete zone considered was of 75 cm on both sides for the vertical diaphragm and 83 cm for the slab. The testing set-up considered horizontal forces simulating the seismic force: specimen 1 and 4 were pushed; while the specimen 2 and 3 were pulled as showed in Figure 6.

The typology of the base connection of the metallic steel frame to the concrete slabs considered longa passing-bolts, with or without consolidation steel plate placed at the exterior face of the concrete diaphragm (see Figure 5). Two types of steel profiles have been considered to strengthen the panel cut, namely UPN 300 for specimens 3 and 4, and angles type of 150x150x10 mm and 150x75x10 mm for specimens 1 and 2.

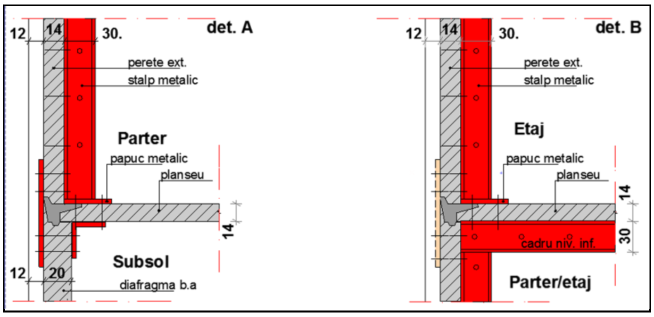


Figure 5. Steel frame joint types.

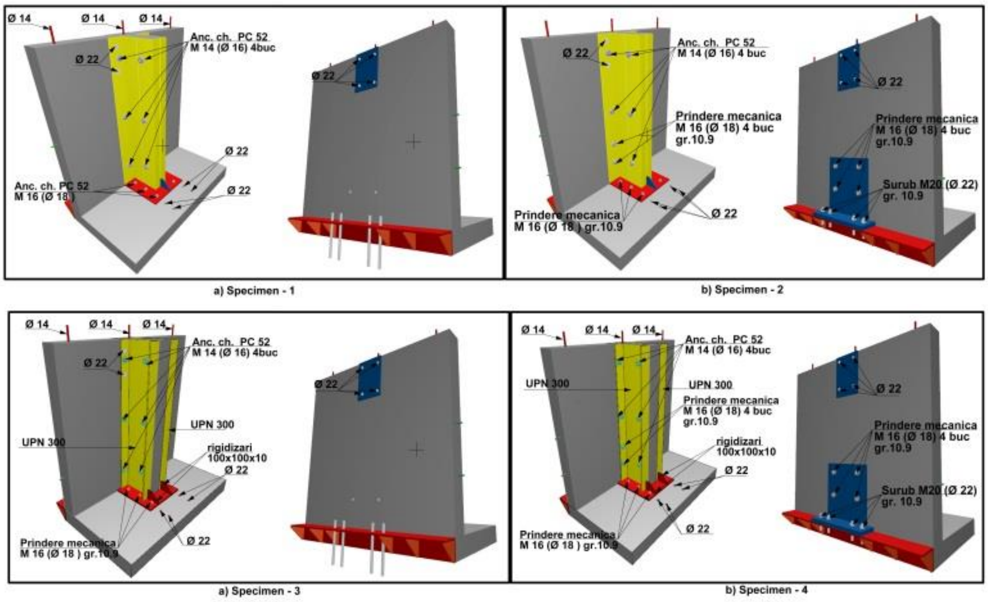


Figure 6. Specimen assembly.

The following parameters were recorded during the experiments: force of the actuator; displacement at the top; lifting of the base of the specimen; the slip to the reaction beam; torsion; slip between elements etc. Figure 7 presents the specimen no. 3 during the experimental tests.

Figure 7. Specimen no.3 during the experimental tests.

The Force - Displacement and corresponding moment-rotation curves are presented in Figure 8. It was noticed that the first micro-cracks appeared at a horizontal force of 45kN. This force is higher than the effective maximal shear force T_{ef}=7.94 kN in the transversal frame. The correspondent bending moment value at which the first micro cracks appear is M=58.5 kNm which is also higher than the maximum effective bending moment M_{ef}=8.2 kNm resulted from the structural analysis.

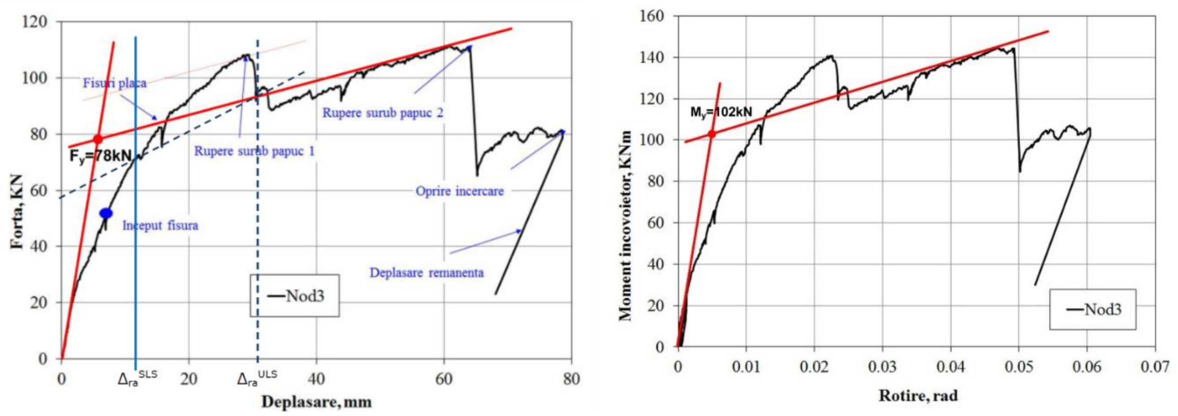
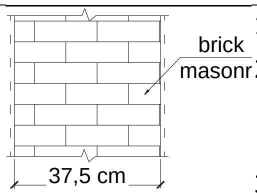


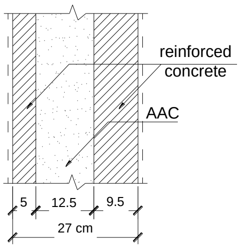
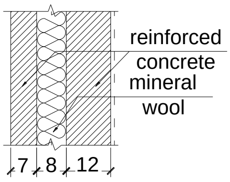
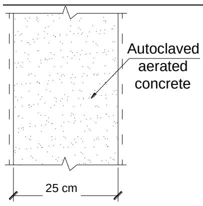
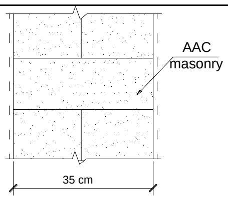
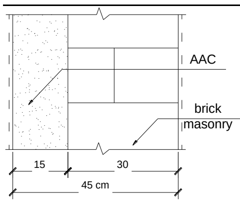
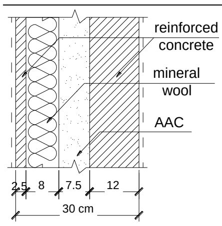
Figure 8. Experimental F-D and M-θ curves for specimen no. 3.

The yielding force derived by considering the ECCS rule resulted from the experimental tests on the joint is F_y=78 kN while the corresponding bending moment value is M_y=102 kNm.
The drifts admitted (Δ_{ra}^{SLS}, Δ_{ra}^{ULS}, θ_{ra}^{SLS}, θ_{ra}^{ULS}) according to Romanian seismic code P100-1-2013 are shown in the F-D and M-θ diagram. The tests show that these admitted limits are reached at values of horizontal forces that are far higher than the corresponding forces admitted (F^{SLS}=70 kN, M^{SLS}=91 kNm).

SUSTAINABLE THERMAL RETROFITTING SOLUTIONS

The largest part of the Romanian stock of multi-storey residential buildings needs immediate thermal retrofitting both for energy saving and improving the comfort of inhabitants. Considering 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 losses. Different techniques can be applied but they have to be compliant with existent structure and envelope. For an integrated design that include sustainability, the solutions that may be considered have to respect the criteria imposed in evaluation, as well as a conceptual global methodology. Figure 9 shows the principal typologies of existing walls, with their benefits and drawbacks.
The first Romanian requirements regarding heat transfer were given in 1960s for exterior walls, flat roofs and floors over basement. Table 1 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 national standards, but always increasing values were required. Thus, the insulation 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 insulation requirements were not followed by the updating 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 heat transfer.

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
		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

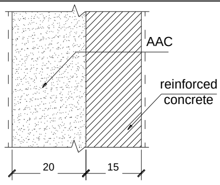
	1. Exterior plastering 2. Mineral wool 3. Plain aerated concrete masonry 4. Reinforced concrete	- fire resistance: good behaviour - vertical diaphragm action: good behaviour - thermo-insulation: fair - $R_{0,ef}$=1.61 m^2K/W	- prone to thermal-bridging - local damages in bad executed joints - environmental impact: low due to heat loss through wall joints

Figure 9. Design details and characteristics of wall typologies between 1960 and 1994.

Table 1. Romanian normative requirements for thermal resistance of envelope elements (values in m^2K/W).

Year	Standard	Ext. walls	Flat roofs	Floor over 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	C107/3-1997	1.80	5.00	2.90

The over-cladding typologies considered as retrofitting solutions in the present example account for both traditional (see Figure 10 – solutions 1 and 2) and modern (see Figure 10 – solutions 3 and 4) solutions.

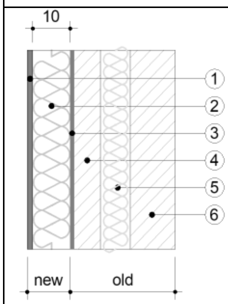
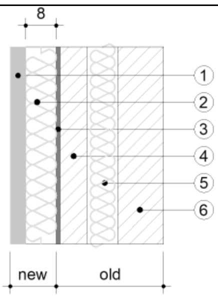
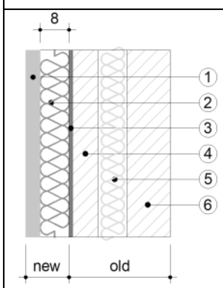
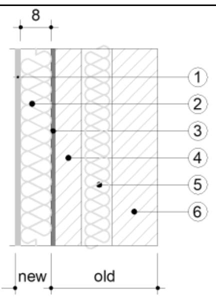
Solution 1		Solution 3	
	1. Exterior plastering / Polyester wire lattice (glass fibre) 2. Thermo-insulation (expanded polystyrene) 100mm 3. Existing finishing 4. Protection layer (concrete) 5. Embedded thermo-insulation 6. Reinforced concrete		1. Fibreboard siding 2. Cold-formed profile / Mineral wool 80 mm 3. Existing finishing 4. Protection layer (concrete) 5. Embedded thermo-insulation 6. Reinforced concrete
Solution 2		**Solution 4**	
	1. Fibreboard siding 2. Rigid mineral wool 80 mm 3. Existing finishing 4. Protection layer (concrete) 5. Embedded thermo-insulation 6. Reinforced concrete		1. PVC siding 2. Cold-formed profile / Mineral wool 80 mm 3. Existing finishing 4. Protection layer (concrete) 5. Embedded thermo-insulation 6. Reinforced concrete

Figure 10. Thermal retrofitting solutions for concrete walls (Tuca et al. 2011).

The sustainability performance for the proposed solutions is quantified through three quantities similar to the three sustainability pillars (social, environmental and economic), characteristic for thermal retrofitting: thermal resistance to heat transfer, environmental impact and life-cycle costing. The *thermal resistances* are presented in function of retrofitting solution as presented in Figure 9 and 10. The total thermal resistance results as the sum of resistances of all layers composing the envelope. The solutions can fulfil the actual normative regarding the heat transfer for external walls (1.81 m^2k/W).
The *environmental impact* was considered through a Life-Cycle Assessment (LCA) conducted using SimaPro computer software (SimaPro 2008). The analysis was conducted on unit area of the constructive element. For each solution, average weights of materials per square meter were calculated as inventory. For the life-cycle approach the production, installation and end-of-life stages were integrated.
The *economic assessment* estimates the cost of principal materials and integrates the cost for mechanical fastening, man-power and machinery. The prices are evaluated for the current economic environment in Romania (Tuca et al. 2011).
In general, the selection of a solution in a multi-criterial analysis is subjective and give rise to different interpretations. However, the final choice in retrofitting of existing buildings represents a decisional task, based on a multi-criterial analysis. Economic, social and environmental aspects should be considered. Several methods could be employed in decisional process for choosing a suitable solution.

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SUSTAINABILITY SESSION

SUSTAINABILITY SESSION SUMMARY

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Today more than 3.6 billion people live in cities and this number is expected to increase up to 6.7 billion by 2050. Cities are responsible for about 71% to 76% of the global CO_2 emissions from final energy use (including electricity).

Therefore, cities have a primordial role in the fight against climate change and this session started with a discussion on the sustainability of cities and, in particular, in the estimated costs to decarbonise cities around the world.

The retrofit of existing buildings has a major potential towards the above goal and thus, following this keynote presentation, three additional presentations were made, focusing on the retrofit of existing buildings, combining structural and energy requirements.

Summary of Presented Papers

1. **Keynote Lecture:** The Economics of Low Carbon Cities (Prof. Andy Gouldson)

In this keynote presentation, made by *Prof. Andy Gouldson* from the University of Leeds, the results of the 'Climate Smart Cities' programme were presented, which evaluated the scope to decarbonise cities (by investing in low-carbon measures) in different places around the world.

The basic methodology used in the cities studies includes 3 stages:

- An assessment of recent trends in the city's energy use, energy expenditure and GHG emissions, and projection of these trends (including for different sectors) over the next 10-15 years (the business as usual (BAU) baselines);
- An evaluation of the marginal costs, direct benefits and carbon saving potential of a wide range of the low-carbon measures that could be adopted in different sectors in the city in the next decade (with 5% real interest rate);
- An aggregation of the findings and the presentation of the economic case for investment in these options at scale in different sectors in the city over the next 10-15 years.

The results were presented focussing on a particular case study – the city of Leeds:

- Its carbon emissions currently come from the transport (36%), domestic (26%), commercial (21%), industrial (16%) and waste (1%) sectors.
- Compared to 2005, it has a target of reducing its carbon emissions by 40% by 2030 and 80% by 2050.

In addition, a broader summary of results was presented:

- To exploit the cost-effective measures, 0.4-2.0% of city-scale GDP could be invested each year for the next ten years. This would generate direct savings of 2.1-8.7% of city-scale GDP in 2025 and carbon reductions of 15-39% relative to BAU trends.
- If these findings were replicated and similar investments were made in cities globally, then they could generate reductions equivalent to 10–29% of global energy-related GHG emissions in 2025.

2. A Life Cycle-based methodology
3. to integrate seismic risk into combined energy-structural retrofit strategies (Menna, C., Vitiello, U., Mauro, G.M., Asprone, D., Bianco, N. and Prota, A.)

In most cases, existing buildings do not cope with seismic demands and new energy requirements. Moreover, recent events highlighted the need to couple energy concerns with structural aspects to avoid tragic consequences and optimize the integrated performance of buildings.

A life-cycle based decision making framework for the retrofit of existing buildings was proposed by *Menna et al.,* aiming to integrate energy and environment aspects and overall costs, in a life cycle approach.

The approach is applied to a three-storey RC building assumed to be located in three different Italian locations and subjected to different seismic and climate requirements.

For two of the locations considered in the case study, the coupled approach led to a more cost-effective solution, when compared to a retrofit solution addressing only energy requirements.

4. Introducing a holistic design framework for the sustainable renovation of existing buildings (Passoni, C., Marini, A., Belleri, A. and Menna, C.)

A holistic approach for renovation interventions was also proposed by *Passoni et al.* The authors identified the major barriers to renovation as: (i) lack of awareness, particularly in relation to safety issues, (ii) the need to relocate building functions and occupants during retrofitting activities, (iii) high initial costs of the renovation, and (iv) the long duration of renovation activities.

To overcome such barriers new principles were proposed like, for instance, interventions should be carried out from the outside of the building thus avoiding relocation of occupants and reducing the costs. Furthermore, such interventions should have a holistic perspective and address different criteria (energy, structural, costs, etc.). The evaluation of the best retrofit solution is made by a multi-criteria approach. The main innovation of the proposed approach is the consideration of the new criteria from the beginning of the design process.

The authors suggest further research to improve the existing design tools and life cycle approaches by including the new proposed principles, with the aim to select the most sustainable retrofit solution.

5. A potential methodology for a sustainable integrated retrofit of existing buildings (Romano, E., Iuorio, O. and Negro, P.)

The discussion provided by *Romano et al.* recognized that a building renovation focused solely on energy measures could be a long term failure investment, as many buildings are additionally affected by structural deficiencies.

Hence, a methodology for the Sustainable Integrated Retrofit of existing buildings was introduced, which integrates sustainable and structural requirements. The proposed approach is based on the Sustainable Structural Design (SSD) methodology developed at the Joint Research Centre.

The discussion included the potential application of the approach in the retrofitting of existing buildings subjected to abnormal loads, focusing on a particular application: precast concrete Large-Panel System (LPS) multi-storey buildings.

The application of the proposed approach to LPS buildings deserves further research due to their inadequate structural performance under normal and abnormal loads and their poor energy performance.

Open points:

- Need to show that building owners may profit from the couple retrofit (energy and structural improvement) of buildings;
- Need of incentives and initiatives to promote the retrofitting of buildings;
- Lack of awareness of the general public for the structural inability of buildings to cope with current structural requirements (particularly buildings located in vulnerable areas).

Keynote Lecture

THE ECONOMICS OF LOW CARBON CITIES

Andy Gouldson

University of Leeds, Leeds, United Kingdom

ABSTRACT

As cities account for 75% of global energy related greenhouse gas emissions, they will be crucial actors in the fight against climate change. In this presentation I will present the results of the 'Climate Smart Cities' programme that has evaluated the scope to decarbonise cities around the world. The results clearly show that there is economic potential to make substantial carbon cuts in cities in diverse contexts, including through the retrofit of buildings, and that exploiting this potential could be crucial in building commitment, capacities and momentum to climate action. However, the results also highlight the limits to these economic opportunities and the need to plan for deeper and more radical change if cities are to make their full contribution to the fight against climate change. Key features of these limits and some of the ways in which they might be overcome will be discussed.

SUSTAINABILITY AND MARKETING FOR THE FUTURE OF THE PRECAST CONCRETE INDUSTRY

Antonella Colombo

Assobeton

ABSTRACT

According to last official data, the investments in the Italian construction sector have been reduced by more than 60% during the last 10 years. The new economical contest is requiring an innovative construction sector able to satisfy different requests from both public and private investors. It is important to provide adequate answers in terms of sustainability, energy efficiency, safety, comfort, quality and customisation of solutions. Innovative strategies to give back value to a traditional construction material are then badly needed. In this light, the transition towards the circular economy is an important strategic input, implying a passage from “necessity” to “opportunity”. Another important key aspect is the ability to communicate the new identified values to investors. Thanks to its inherent peculiarities, the precast concrete industry seems to be the more promising sector.

A LIFE CYCLE-BASED METHODOLOGY TO INTEGRATE SEISMIC RISK INTO COMBINED ENERGY-STRUCTURAL RETROFIT STRATEGIES

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ABSTRACT

Most of retrofit process applied to existing buildings is mostly targeted at the improvement of building energy consumptions over the building lifetime, neglecting possible interactions with other sources of uncertainty. Indeed, recent Italian earthquakes highlighted the need to couple energy aspects with structural design to avoid tragic consequences and optimize, at the same time, the rational use of environmental and economic resources. The interaction between the two aspects has never been managed following design codes due to the absence of a methodological framework. Motivated by these considerations, this study aims to integrate energy and structural aspects in a life cycle-based decision-making framework for the retrofit design of existing buildings. As a case study, the methodology is applied to a three-storey building assumed to be located in different Italian locations. These are characterized by different climatic conditions and seismicity.

INTRODUCTION

Most European existing buildings were built before 1980s without any seismic provisions and or design concerns for energy efficiency and environmental sustainability. Over the last decade, due to the low rate of new buildings construction, the attention of engineers and practitioners has been focused on the refurbishment/retrofit of existing buildings. Generally, the design framework for refurbishment/retrofit interventions is intended to pursue a set of objectives, indicators or performance criteria belonging to the key objectives of sustainable development; these are commonly represented in terms of a triple bottom-line strategy (Willard, 2002; Menna et al, 2013), i.e., through the simultaneous fulfillment of environmental, economic and social goals. However, many of the studies dealing with large-scale retrofit have focused deeply on single aspects, such as mechanical or energy performance of retrofitted/renovated existing structures (Asadi et al., 2012; Ascione et al., 2015; Napolano et al., 2015), while few works have dealt with the integration of other sustainability objectives.

The methodology herein presented aims to integrate energy, environmental and overall cost sustainability objectives in a life cycle perspective and is referred to existing reinforced concrete (RC) buildings. In detail, a wide domain of energy retrofit scenarios is firstly considered and numerically treated in order to identify the cost-optimal solution for a given structure. Afterwards, the influence of the cost-optimal energy retrofit solution on the expected economic losses due to seismic events is assessed. The final step consists in the determination of the cost-effective strengthening strategy for a given strengthening level (i.e. strengthening intervention associated with a given safety level) over the building life-cycle.

As a case study, the methodology is applied to a three-storey RC building assumed to be located in different Italian locations characterized by different climatic conditions and seismicity.

METHODS

The methodology herein presented is composed of different analytical steps and aims to quantify the overall economic lifecycle costs associated with combined energy and structural retrofit of an existing RC building, considering seismic risk that characterizes the building location. It should be

pointed out that also other sustainability aspects can be included in the analysis (e.g. environmental loads) but are not included in this study for sake of brevity.
In particular, the energy performance refers to a set of energy retrofit measures (ERMs) applied to the existing building whereas the structural performance is considered in order to quantify the economic losses due to seismic induced damage. The methodology comprises the following four main steps:

- Step (1) — Optimization of building energy retrofit from a wide set of possible and compatible combinations of ERMs, using cost-optimal analysis.
- Step (2) — Assessment of seismic economic losses for the "as built" existing building throughout its lifetime by the quantifying seismic induced damages and the related economic investment to restore the damaged components.
- Step (3) — Integration of energy and structural aspects by linking cost optimal ERMs to the level of seismic induced damage of the non-structural components (using proper engineering demand parameters and component performances).
- Step (4) — Assessment of the influence of optimal ERMs on seismic economic losses by quantifying the difference in global costs (i.e., updated savings and payback time) with respect to the as built configuration.
- Step (5) — Definition of structural retrofit strategies based on a set of possible solutions by minimizing upgraded seismic economic losses (i.e. including cost optimal ERMs).

The outcomes of this methodology can be useful for the selection of proper ERMs, looking at the overall cost-effectiveness (or, more in general, other sustainability parameters) of the retrofit itself throughout the building life cycle.

CASE STUDY

A reinforced concrete (RC) structure has been assumed as case study for implementing the procedure described above. The building is a typical example of an Italian facility built in the 1970s according to the old building code and without any seismic or energy prevision. The floor plan has an approximate rectangular shape and dimensions of 48.1 m × 18.1 m, with a total area of about 870 m^2. The total height of the building is 10.1 m and it consists of three floors with a story height of 3.2 m, except for the first floor, which is 3.7 m. The structure is composed by RC frames in two directions. The foundation system is composed of RC footings and connection beams framed in two orthogonal directions. Each story hosts five apartments.
The building envelope presents low thermal resistance, like large part of Italian existing buildings (built before the 1980s). In this regard, the vertical external walls are in hollow bricks and have thermal transmittance (i.e., U-value) equal to 1.23 W/m^2K. The horizontal envelope is in mixed brick-reinforced concrete and the U-value is equal to 1.05 W/m^2K for the roof and to 0.90 W/m^2K for the basement floor. Finally, the windows are double-glazed with wooden frames and have U-value equal to 2.67 W/m^2K as well as solar heat gain coefficient (SHGC) equal to 0.691.
The building is assumed to be located in three different Italian cities, namely Benevento, Lattarico and Spoleto. These are characterized by different climatic conditions but a similar level of seismic risk. Indeed, the PGA (peak ground acceleration) demand values are 0.251 g for Benevento, 0.260 g for Lattarico and 0.221 g for Spoleto, considering as seismic demand a severe earthquake with a return period of 475 years, according to the Italian National Building Code. As concerns the climatic scenario, Benevento, Lattarico and Spoleto belong, respectively, to the Italian climatic zone C, D and E.
Steps (1) to (3) of the proposed methodology for the case study were completed following the approach presented by the authors in Mauro et al. (2017) and Menna et al. (2020) and not reported for sake of brevity. Then, in order to estimate the most cost-effective strengthening solution, the costs of each strengthening solution and the related building seismic economic losses at different

intensities of the retrofit interventions were computed. In this case study, retrofit strategies aiming at increasing ductility, stiffness, and strength, or all of them, were selected. In particular, the following retrofit strategies have been investigated:

1) Insertion of RC shear wall-based strengthening solution (i.e. insertion of shear walls to sustain the seismic action in both the longitudinal and transverse directions).
2) RC jacketing-based strengthening solution (i.e. RC jacketing of beams and columns to increase the flexural and shear capacity of members, as well as ductility, and to increase the global structural stiffness).
3) FRP – RC jacketing-based strengthening solution (i.e. a combined strengthening solution based on the previous solution and the shear strengthening of beam-column joints and beams using FRP sheets to prevent brittle failure mechanisms).

RESULTS AND DISCUSSION

Figure 1 summaries the discounted payback times resulting from Step (4) and Step (5) and for the three building sites investigated. In two of the three building site cases, the coupled approach was more cost-effective if compared to only energy retrofit including EALs evaluated throughout the building lifetime. Indeed, the discounted payback times of the combined approach were significantly reduced depending on the particular site. In addition, for Benevento site, the discounted payback time of the combined approach was higher than the case of the retrofit with only ERMs. This was a consequence of the investment cost; indeed, in that case the investment cost for the energy retrofit measures was significantly lower than that of the seismic retrofit.

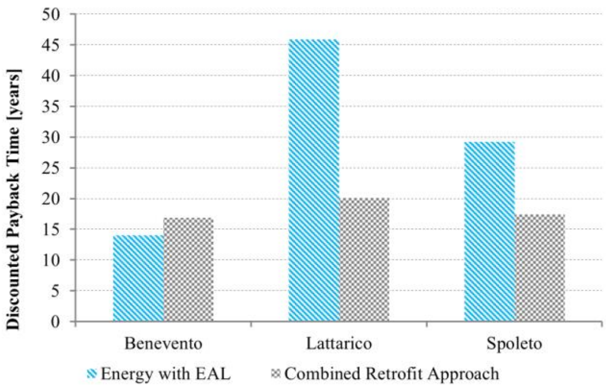

Figure 1. Discounted payback time of the approach presented.

It is interesting to note how the proposed step-by-step methodology can support decision making process since it couples different aspects of retrofit design, such as energy consumptions and costs, considering the influence of the building site features and hazards.

ACKNOWLEDGEMENT

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INTRODUCING A HOLISTIC DESIGN FRAMEWORK FOR THE SUSTAINABLE RENOVATION OF EXISTING BUILDINGS

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ABSTRACT

In the last decades, sustainability has become a priority worldwide and the major objective of European policies defining future societal development. Being responsible for the greatest amount of GHG emissions, the construction sector - particularly the existing building stock - is acknowledged as among the major sources of environmental burden and as requiring urgent and serious renovation actions. Existing buildings need substantial retrofit interventions tackling their multiple deficiencies, concerning energy inefficiency, obsolescence and structural vulnerability. In this scenario new frameworks are required, which should overcome the fragmented nature of the current design standards in favor of a unitary approach, enabling the design of holistic renovation interventions. Such frameworks should as well acknowledge and propose solutions to overcome the major barriers to the renovation, while addressing new business models and integrating updated sustainable principles. In this paper an overview of a 4-step design framework, which is rooted and inspired by Life Cycle Thinking principles, is presented. Unlike other sustainable design frameworks available in the literature, which consist in ex-post assessment tools, the proposed framework stems also as a design tool to be addressed from the initial conceptual design steps to determine the selection of the most suitable retrofit solution.

Keywords: Sustainable Building Renovation; holistic design framework; Life Cycle perspective, Life Cycle Thinking

INTRODUCTION

The growing interest in sustainability issues has highlighted the need for a deep renovation of the existing building stock, which is obsolete under many point of view and is one of the major source of environmental burden (Marini et al. 2014). Although these interventions are considered a priority for the achievement of the EU targets, building owners do not feel the urgency to retrofit their assets, both because they are not aware of the inherent risk and multifaceted needs, and because they do not find it profitable. As a result, the renovation rate is very low (about 1%; BPIE 2011; La Greca and Margani 2018), and it is mostly referred to retrofit measures targeting the sole energy efficiency, and more rarely to urgent retrofit interventions on damaged structures. A new holistic approach to building renovation is thus still needed to boost effective actions on the existing building stock, contextually targeting safety, resilience and sustainability. In this paper, the overview of a new sustainable holistic design framework is illustrated. The framework is inspired by more comprehensive sustainable principles and incorporates criteria to overcome the major barriers to the renovation.

The major causes of the low renovation rate of the existing buildings were thoroughly investigated by BPIE 2011 and La Greca and Margani (2018) and identified in: lack of awareness – especially when structural retrofitting is concerned, the need to relocate the building functions and the inhabitants, the high initial costs of the renovation and the long duration of the works. In order to **overcome these barriers** while guaranteeing social and economic sustainability of the renovation measures, new principles should be adopted. As an example: interventions should be preferably carried out from outside the building, thus avoiding inhabitants' relocation and reducing the high costs connected to the demolition of the finishing. They should contextually address all the building multiple needs – energy, structural, and architectural; such an holistic approach would imply a series of co-benefits, including reduction of time and costs thanks to a shared construction site, investment of the savings obtained with the energy efficiency improvement to finance the structural intervention, elongation of the building structural life and long term protection of the investment, etc. (Marini et al., 2016; 2017).

Furthermore, sustainability of the renovation should be pursuit by embracing a **Life Cycle perspective** (Marini et al., 2018; Passoni et al., 2018). Other criteria, such as eco-efficiency, adaptability, reparability, demountability and selective dismantling, should be introduced to select and design the best retrofitting technologies to minimize impacts and costs over the building life cycle. Prefabrication, standardization of components, adoption of dry techniques, all allowing demountability and selective dismantling, would guarantee the reduction of waste both during the installation phase and at the end of life, would reduce costs and duration of the construction works. The adoption on structural fuses, into which damage could be lumped, would enable reparability of the system after an earthquake, dramatically reducing the GHG emissions and the costs connected to the debris disposal and reconstruction actions.

INTRODUCING A NEW HOLISTIC DESIGN FRAMEWORK FOR SUSTAINABLE RENOVATION

Recently, new frameworks for the sustainable design of retrofit interventions on existing structures were proposed (Mauro et al., 2017; Wei et al., 2016a; Lamperti Tornaghi et al., 2018, among others). These methods embrace the principles of holistic energy/structural renovation of existing buildings and introduce new procedures to compare different solutions by estimating costs and GHG emissions at the construction stage and during the operative phase, also considering seismic risk. Those methods present usually two main drawbacks. First, impacts are estimated only at the end of the design process (both adopting a traditional design method or more advanced genetic algorithms). A great effort should thus be spent prior to choose the best retrofit option, reducing the applicability of those frameworks to a limited specialized community and to relevant constructions. Second, GHG emissions are expressed in terms of costs, often adopting conversion parameters that could be neither straightforward nor representative of the actual environmental impacts. Doubts on the appropriateness of oversimplifying the problem of impact estimation adopting a LCC procedure based on monetary unit has already been expressed by Gluch and Baumann (2004).

A new holistic design framework is here proposed, which overcomes such main drawbacks (Figure 1). The framework consists in a **four step procedure**, namely : 1) assessment of the existing building under a holistic perspective aimed at identifying possible deficiencies (energy audit, structural/seismic assessment, etc.); 2) prescreening of the possible retrofit strategy on the basis of the new economic, social, and environmental LCT principles; 3) design of the selected retrofit solutions adopting a multi criteria performance based design, i.e. considering from the beginning the possible interferences among the structural/energy/functional/etc. layers of the intervention; 4) selection of the best retrofit option under a sustainable point of view, adopting for the assessment of the impacts the most updated Life Cycle procedures, which also includes seismic risk (Wei et al. 2016b; Belleri and Marini 2016; Menna et al., 2013), and Multi Criteria Decision Making (MCDM) approaches for the evaluation of the best retrofit alternative (Caterino et al., 2009).

With respect to the other new frameworks, particular importance assumes the second step of the method (Figure 2), which entails a shift from an ex-post assessment to a procedure in which the sustainable principles are addressed in each phase of the design. The prescreening of the possible retrofit interventions in the first step enable stakeholders, decision makers and design professional to jointly define pre-requisites and criteria to be addressed in the conceptual design of the renovation action. Those criteria may be both quantitative (e.g. construction costs, performance targets, etc.) and qualitative (e.g. from outside, use of dry solutions/prefabrication, etc.).

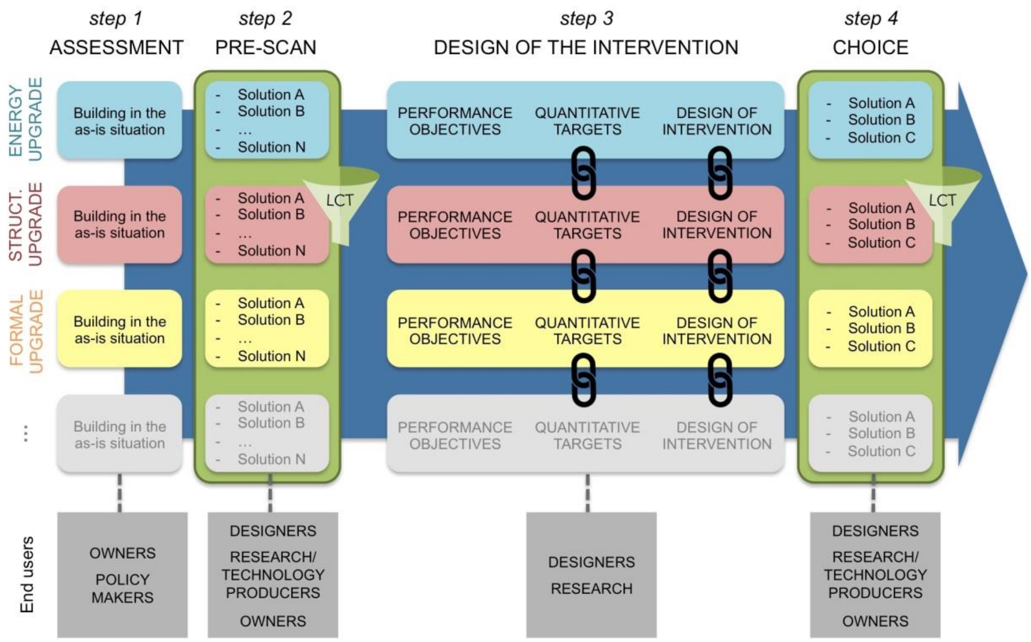

Figure 1. Sustainable Building Renovation Design (SBR-D) Framework (adapted from: Passoni et al., 2020).

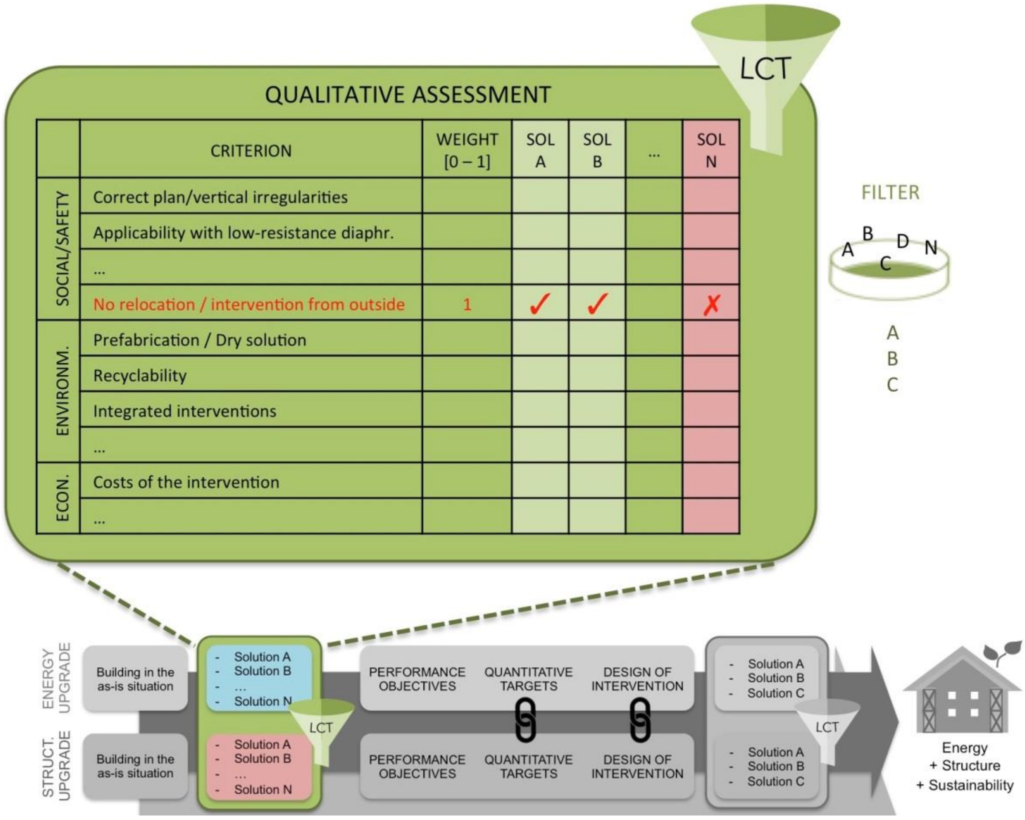

Figure 2. Sustainable Building Renovation Design (SBR-D) Framework - Step 2: pre-screening of the possible retrofit solutions under a LCT perspective (adapted from: Passoni et al., 2020).

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A POTENTIAL METHODOLOGY FOR A SUSTAINABLE INTEGRATED RETROFIT OF EXISTING BUILDINGS

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ABSTRACT

The awareness of huge burdens produced by the construction sector on triple bottom line of the Sustainable Development - Planet, People, Profit - is recognized at international level since the last decades. Nevertheless, action plans to tangibly face this issue are still considered mainly for CO_2 emissions and energy consumption reduction. The ambitious European challenge to achieve a drastic saving of energy use in building sector is at the forefront of all Member States in pursuing sustainable, resilient and fair cities. In the perspective of a low carbon economy, construction sector is recognized as the main attractor towards eco-friendly practices for both new and existing buildings, therefore the energy retrofit of the current European building stock is highly required in order to meet the *2050 Energy Roadmap* targets. Nevertheless, a building renovation exclusively focused on energy measures could be a long-term failure investment. Existing buildings, beyond a poor energy performance, could be often affected by structural deficiencies due to a lack of maintenance and/or an inadequate structural reliability according to the current design codes for both normal and abnormal loads. Thus, a multi-performance life-cycle oriented retrofit approach is crucially needed.

This study proposes a preliminary discussion for a potential Sustainable Integrated Retrofit (SIR) methodology for existing buildings which integrates sustainable requirements with structural ones. Principles for an integrated retrofit focused on the concept of life time engineering and quantitative methods for holistic assessing sustainable and structural performance are firstly exposed on the basis of research advances on sustainable structural design. Then, the *Sustainable Structural Design (SSD)* methodology developed at the Joint Research Centre in Ispra is referenced with the aim to underline the feasibility of this approach also for retrofitting existing buildings under accidental loads.

INTRODUCTION

Nowadays, the urban environment is more populated than the rural one with over half of the world's seven billion inhabitants - around 55% - living in cities and urban areas in 2016. This trend is expected to increase to 66% by 2050, considering the process of rapid urbanization occurred over the past six decades (1950 – 2010) which will make the planet for two-third urban (UN, 2016). A direct effect of this exponential urbanization is the growing exposure to unsustainable trends for both industrialized and less developed urban communities facing with depletion of resources, global warming, an inefficient use of water and energy, a poor quality of life, a greater possibility of economic losses in case of natural disasters, a higher risk of catastrophic extreme events exposure. An urgent action to promote sustainable and smart cities is highly recommended at universal level thanks to the *2030 Agenda for Sustainable Development* (UN, 2015) in order to lessen the enormous burdens produced on the Planet. Indeed, the present generation has the responsibility to allow also *future generations to meet their needs* in line with the most accredited definition of sustainability, as firstly stated by the Brundtland report (1987).

In this uncontrolled context, the built environment is regarded as a central component to the liveability of the earth as underlined by *the 2020 Europe Strategy*, considering that the European construction sector plays a key-role on the three dimensions of Sustainable Development because of several negative impacts produced on Environment, Economy and Society. The 2012 Rio+20 Conference outcome - *The future we want* - recognized that cities can lead the way towards economically, socially and environmentally sustainable societies, but a holistic approach to urban planning and management is needed in order to improve living standards of urban and rural

dwellers (UN, 2014). Although international and European efforts in terms of both action plans and legislative instruments have been carried out in the last two decades to address the promotion of sustainable constructions ensuring at the same time several benefits related to the three dimensions of sustainability, in practice attention is still deserved mainly on environmental and energy aspects. According to the World Resources Institute (2016), the building sector has the largest unrealized potential for cost-effective energy and emissions savings, therefore it is clear that the achievement of an energy-efficient building stock is a high-priority issue for Europe. In that line, the ambitious EU goals of reducing CO_2 emissions by at least 80% and energy consumption by as much as 50% by 2050, according to the *EU 2050 Energy Roadmap* could be achieved thanks to the construction sector. In particular, existing buildings perfectly fit in reaching those targets if an adequate energy retrofit and energy-using equipment replacement is envisaged.
The EU existing building stock, which accounts for 25 billion m^2 of useful floor space with 75% representing the residential sector, is also affected by many social and economic problems related to people well-being, financial value, urban quality besides the acknowledged poor energy performance and ecological issues. Nevertheless, retrofit is often approached by a solving episodic problem exhibited by the building. It is evident that interventions focused solely on a unique aspect (i.e. the energy performance) will result in a business dead-end for the existing building heritage which instead needs to be retrofitted as a sustainable construction (Iuorio and Romano, 2017). Moreover, existing buildings could present various structural deficiencies due to natural aging, unplanned maintenance, a poor initial design and/or execution of the works, absence of specific codes provisions at the time they were built leading to an inadequate structural performance both in ordinary and exceptional conditions (Landolfo and Vesikari, 2011). During its lifetime, a structure could be also subjected to natural hazards such as earthquakes or extreme weather conditions and/or extreme events such as fires, blast or malevolent attacks which may produce detrimental effects on structural safety if the structure is not able to resist those abnormal loads. Thus, several requirements related to the triple bottom line of sustainability, as well as safety, reliability, robustness of structures need to be balanced in a holistic way in order to appropriately retrofit an existing building. Focusing exclusively on a single issue makes retrofit intervention limited to address only part of the criticalities, neglecting the complexity and the interrelation of all the building system deficiencies. In the majority of building retrofit projects designers face to only one aspect of the required improvements which often corresponds to the energy interventions in terms of minor renovation. In such a way, the easiest, fastest and cheapest solution is apparently considered, but it could become a long term failure. Thus a holistic interaction among environmental, economic, social and structural requirements is needed considering that the EU existing building stock could be a significant resource to enhance *Planet, Profit and People* benefits of future cities towards sustainability.
This study is aimed at underlining the importance of envisaging a radical transformation of existing buildings through integrated renovations which have been recognized as a fundamental EU research need (Marini et al., 2014). In that line, main principles of an integrated approach for a sustainable retrofit are defined on the basis of research carried out for the sustainable design of new structures. The difficulty of combining different performances into an unique decision result is overcome thanks to the *Sustainable Structural Design (SSD)* methodology developed at the Joint Research Centre in Ispra, resulting particularly suitable for the development of a Sustainable Integrated Retrofit aimed at simultaneously satisfying structural retrofit and sustainability requirements. Finally, the potential application of this approach for retrofitting existing buildings subjected to abnormal loads is introduced with a particular focus on precast concrete Large-Panel System (LPS) multi-storey buildings.

AN INTEGRATED APPROACH FOR SUSTAINABLE RETROFIT: BASIC PRINCIPLES

Nowadays, the perception of buildings as holistic products has led to the ambitious challenge in the field of civil engineering to design and/or retrofit safety structures at reasonable cost with low environmental burdens. One of the main effort in this direction is to balance different building performances related to structural engineering, economy and environment in a holistic way in order to achieve an effective strategy for a comprehensive building renovation. Thus, best sustainable practice for existing building retrofit is needed.

In line with the traditional approach, structural design is mainly focused on the construction phase and the first use stage. According to Sarja (2003), *maintenance and repair are reactive.* Their need is not considered at the original design, and during use they are mostly realized at a very advanced stage of deterioration, causing huge investments in repair measures, or even the need of demolition. In such a way negative impacts on the economy, environment and society are produced. A holistic evaluation of structural performance, instead, is needed not only considering codified structural design rules (e.g. in Eurocodes), but also responding to questions about the estimation of durability, the maintenance plan, the inspection and the monitoring of structures (Landolfo, 2012). Moreover, recent exceptional incidents underscored that the damage due to unsatisfactory structural performance leads to considerably high economic, environmental and social impacts. Thus, resilience to natural hazard and/or extreme events should be achieved to ensure sustainability for new and existing buildings. According to Griffin (2016) a multi-performance retrofit intrinsically focuses on resiliency of existing buildings, increasing their lifespan and ensuring resources will not be lost in a natural disaster or in an abnormal events.

In that line, design for the life-cycle becomes the possible answer to proactively conceive sustainable retrofit solutions for existing buildings. In the last years particular attention of structural engineering research has been devoted to the sustainable structural design of new buildings. The same approach used in Landolfo et al., (2011); Cascini et al., (2013) and Romano et al. (2020) for various studies facing to this research issue can be easily and effectively applied to sustainable retrofit interventions on existing buildings (Romano et al., 2015). In those works, a multi-performance time-dependent sustainable structural design approach is defined with the main goal of maximizing mechanical, durability, economic and environmental performance of a structure during its whole life-cycle, reducing at the same time the negative impacts played on the triple bottom line of sustainability (Landolfo et al, 2011). The sustainable integrated retrofit should be characterized by three key-points, as defined in the above mentioned method:

1. It is a **multi-performance** based design approach, focused on the extension of the number of requirements to be satisfied.
2. It is a **life-cycle** oriented methodology: the time unit considered goes beyond the ordinary design working life, including all the stages of the construction's life, from cradle to grave.
3. It is focused on the use of **quantitative methodologies** addressed by ISO standards in order to assess the various performances.

With regard to the latter, the evaluation of the environmental performance is addressed by the **Life Cycle Assessment (LCA)** methodology in accordance with ISO 14040:2006 & ISO 14044:2006. It is aimed at assessing environmental impacts from the extraction of raw materials to the end of life of a given product or process by identifying energy and materials used and wastes released to the environment. The economic performance is assessed thanks to the **Life Cycle Costing (LCC)** methodology in the respect of ISO 15686-5:2008. LCC is an effective method to estimate costs in monetary terms arising during the life-cycle of a construction: beyond the initial costs, the evaluation of maintenance, inspection and repair costs, as well as dismantlement ones are ensured, showing the real value of the investment. Finally according to **Life Cycle Performance (LCP)** assessment methodology in the respect of **ISO 13823:2008**, the structural performance could be assessed by a parameter measuring the reliability of a structure such as the failure probability in accordance with a specific limit state and/or a reliability indicator. Moreover, the verification of durability, considering service life scenario based on the prediction of the deterioration that will act on the structure leading to a decrease of performance can be assessed. According to a life cycle analysis, on the basis of ordinary maintenance operations and/or potential exceptional events during the use stage of the working life of the structure, it could be possible to define the period of time beyond that the structural performance is not ensured as required at the design stage.

In order to integrate all the obtained results in a global parameter on the sustainable level of the structure, a multi-criteria decision making (MCDM) analysis would be needed because of the different measure units of each performance result.

TOWARDS A POTENTIAL SUSTAINABLE INTEGRATED RETROFIT (SIR) METHODOLOGY

An approach to overcome the gap of combining different performances metrics - Structural, Environmental and Economic - in a global decision result could be found in Romano et al., (2014) and Tsimplokoukou et al., (2014) with its validation at building level in Lamperti Tornaghi et al., (2018).
A potential **Sustainable Structural Design (SSD)** methodology is provided in order to include environmental aspects in structural design throughout the entire life-cycle of a structure, following three main steps:
1. Environmental performance assessment through the *Life Cycle Assessment* (*LCA*);
2. Structural performance assessment through the *simplified Performance-Based Assessment* (*sPBA*);
3. Combination of environmental and structural results in economic terms.
In such a way, all the requirements of a building are holistically balanced, obtaining a unique quantitative assessment parameter to compare alternative solutions, addressing at the same time sustainability and structural performance. The main steps composing the methodology framework (Figure 1) are briefly presented hereinafter.

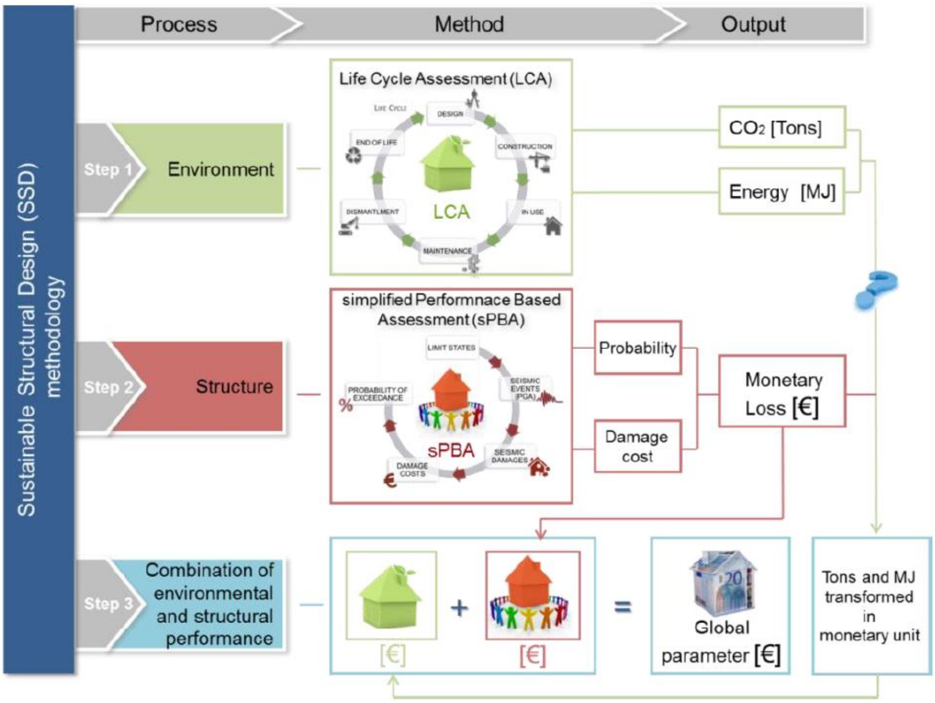

Figure 1. The flowchart of the three steps of the Sustainable Structural Design (SSD) methodology (Figure source: *Romano et al., 2014, p. 22*).

First step

The first step of the SSD methodology is the environmental performance assessment through the *Life Cycle Assessment (LCA)* methodology which allows environmental burdens or impacts to be assessed from extraction of raw materials to the end of life of a given product or process. According to ISO 14040:2006 & ISO 14044:2006, the LCA methodology follows its four standardized steps in order to define the environmental performance of a structure expressed in tons of CO_2 for emissions in the air and in MJ for energy consumptions. The open question is how to combine this environmental performance with the structural one, considering that the abovementioned performances have different measure units. The second and third steps of the SSD methodology have the aim to solve this problem.

Second step

The second step of the SSD methodology is the structural performance assessment, referring to the methodology for the Performance Based Earthquake Engineering (PBEE), developed by the Pacific Earthquake Engineering Research (PEER) center. PEER has developed a detailed methodology for the seismic Performance-Based Assessment (PBA) of buildings, bridges and other engineered facilities that allows building performance to be predicted in a probabilistic format. The PBA methodology has the aim to describe the performance of a building in terms of losses due to damages to buildings components, following four consecutive analysis stages: (1) *Hazard analysis*; (2) *Structural analysis*; (3) *Damage analysis* and (4) *Loss analysis*. The product from each of these steps is associated to a corresponding generalized variable: *Intensity Measure (IM)*; *Engineering Demand Parameter (EDP)*; *Damage Measure (DM)* and *Decision Variable (DV)*. Further details can be found in Zareian and Krawinkler (2009). This methodology follows a rather complicated approach, but the objective to incorporate monetary losses and seismic risk into the structural assessment turns out to be really interesting and efficient. Such a comprehensive approach to PBA may not be necessary for most ordinary structures, therefore a ***simplified PBA*** **(sPBA)** process can be considered. Focusing on the SSD methodology, the sPBA consists into the evaluation of costs and the expected monetary losses for each limit state considered, at which different peak ground accelerations and inter-storey drifts correspond. The aim of this analysis is to obtain the total expected loss *(L)* in each configuration through the *total probability theorem.* This simplified approach allows structural behaviour to be assessed in economic terms considering monetary loss in relation to damages that a structure could be subject throughout its entire life-cycle. It could be useful to consider different damage scenarios during the lifespan of a building, already in the design phase. In such a way an a-priori analysis about the management of a building could be carried out, considering the expected annual loss (EAL) in terms of reconstruction cost percentage, in order to understand for instance whether it is preferable a refurbishment or a reconstruction.

Third step

The third step of the SSD methodology has the scope to define a global assessment parameter that allows stakeholders to consider at the same time structural, environmental and economic performances of buildings. In details, a way to convert environmental analysis into economic terms has to be defined. In particular, it is necessary to transform tons of equivalent CO_2 and MJ of energy in monetary unit, so that structural and environmental performances can be considered as the sum of structural and ecological costs, obtaining a global sustainable result. Firstly unitary price of CO_2 and energy have to be considered. Once the price of carbon emissions and energy (i.e. electricity and gas) has been defined, environmental results, assessed by the LCA methodology can be converted into *'ecological costs'*, expressed in monetary units. In particular, the price of one ton of CO_2 and one kWh of energy have to be multiplied by the total quantity of CO_2 emissions and energy, calculated with LCA analysis. In such a way structural results could be summed to environmental ones because both are expressed in monetary unit, obtaining a global sustainable assessment parameter.

It is worth noticing that PBEE implies design, evaluation, construction and maintenance of engineered facilities whose performance under common and extreme loads respond to the different needs and objectives of owners-users and society. Thus, it is clearly underlined that structural assessment through that methodology can be carried out not only for seismic loads. Indeed, it consists into a quantitative evaluation of the performance of a given building aimed at facilitating an informed decision making for risk management. Although the SSD methodology has been introduced for the sustainable design of new structures under seismic loads, it could be also suggested for the retrofit interventions of existing buildings leading to a potential Sustainable Integrated Retrofit methodology. In particular, it could be particularly suitable in case of accidental loads such as blast (Romano et al., 2018). In that line, the controversial step of the SSD methodology turns out to be the second one related to the structural assessment. Developments to extend PBEE considering extreme loads (namely blast hazards) have already taken place. Whittaker et al. (2003) modified the PBEE to a performance-based blast engineering, considering similar steps even if significant differences with regards to IM variables are observable. In case of earthquake engineering IMs are the peak ground acceleration and spectral acceleration, whereas for blast they are the weight charge, standoff and location. Differences in simulation procedures and component response (EPD) are also remarkable.

FUTURE DEVELOPMENTS

Further research in this direction is needed considering that the development of the Sustainable Integrated Retrofit for blast events based on the SSD methodology could address the multi-performance renovation of a specific class of existing buildings, namely the precast concrete Large-Panel System (LPS) tower blocks. Those residential buildings, consisting of load-bearing walls and slabs connected by on-site wet or dry joints, were widely spread in East and North European countries between the 50s and 70s and they still account for a large extent of EU residential buildings stock. LPS buildings deserve significant research interest in terms of retrofit for their inadequate structural performance under normal and accidental loads because of their inherently vulnerability to extreme events due to the difficulties in providing continuity and ductility in such a system where joints result the weakest structural points. In that line, the progressive collapse of the LPS apartment block Ronan Point in London in 1968 due to an internal gas explosion is emblematic of this criticality, also showing lack of redundancy. Although some efforts to define provisions for robustness have been made, they still remain rather generic and the structural reliability of LPS continues to be an open-issue as demonstrated by severe damages exhibited by different European LPS buildings subjected to accidental loads in the last decades. Moreover, scientific attention is currently paid to their poor energy quality, requiring drastic measures to respect the current energy regulations. The recent disaster of Grenfell Tower in London, which had been renovated to improve its energy-efficiency only one year before the tragic fire event, is particularly indicative of the crucial need of a multi-performance retrofit for existing tower blocks.

Recommendations and provisions for concrete LPS buildings investigating retrofit scenarios with regard to structural and energy deficiencies should be considered. The Sustainable Integrated Retrofit based on the SSD methodology perfectly suits this challenge of renovation, becoming a potential strategy which regards the implementation of energy and structural retrofit (both for normal and accidental loads) in a holistic process for tower blocks upgrading.

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CASE STUDIES SESSION

CASE STUDIES SESSION SUMMARY

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Summary of Presented Papers

In the following, a brief overview of the papers presented is given. Scope of the short summary presented is to highlight the main questions raised during the session with the aim of pinpointing the needs for a roadmap on building retrofit integrating structural safety, environmental/thermal and economic performances in a sustainable perspective.

1. **Keynote lecture:** Case study – Structural assessment of existing building large panel system-built (LSP) residential blocks for accidental loads – background to the development of the current UK guidance (Stuart Matthews)

The study looks at Robustness and Durability of LPS buildings, which have been affected by serious accidents both in the past and recently (e.g. Ronan Point and Grenfell Towers).

The paper provides an overview of updated technical evaluation criteria and the associated guidance for undertaking a structural assessment of an LPS dwelling block for accidental loads. It reports the program of work undertaken. In particular:

1. Structural identification;
2. Static load tests/element removal: these tests were carried out both on real buildings and through Finite Element Models. Tests on three buildings were presented.

The work allowed to understand the circumstances which may contribute to failure in a LPS system.

Although the work presented gives an important contribution towards the assesment of structural safety in LPS Buildings, no indications are given on the retroftitting strategies to be adopted.

2. Seismic assessment and retrofit of typical pre-code school masonry building – case study (Roberta Apostolska)

The paper deals with the seismic assessment of the seismic vulnerability of existing school buildings in Macedonia. The existing buildings can be grouped into three main categories: 1) non-earthquake resistant; 2) moderate earthquake resistant; 3) earthquake resistant.

The non-earthquake resistant school buildings are more than 30% of the whole building stock, which poses a significant seismic risk to the country.

A masonry school building was presented as a case study. The layout of the presented work is reported below:

1. Review of the existing documentation;
2. In-situ inspections and tests;
3. FEM analyses (considering both the static loads and the seismic loads);
    a. Elastic static analysis
    b. Analysis of the dynamic response
4. Seismic assessment of the existing building.

The vulnerability assessment has been carried out by looking primarily at the Ultimate Limit State. The results allowed to conclude that the existing building was able to withstand the vertical loads but not seismic actions; for this reason, to increase the seismic safety of the structure, RC jackets to the walls were applied.

To summarize, present retrofit procedures in Macedonia targets only specific requirements (mechanical resistance). However, in the last years since the first national regulation for the energy performance of the building was issued (2013), some initiative/examples are conducted where also energy upgrading of the building has been addressed.

3. A case study: Seismic retrofitting on an existing multi-storey R.C. building in northern Italy (Franco Mola and Elena Mola)

In this work, a retrofit solution was proposed for an existing RC building according to the Italian Building Code (NTC 2018).

The paper focuses on the structural aspect of the retrofitting. The layout of the presented work is reported below:

1. Review of the existing documentation and material tests;
2. Discussion of the structural analysis carried out by FEM: modeling assumptions and methods;
3. Retrofit solution discussion: Jacketing of infills and introduction of a new slab (4 cm).

4. Retrofitting the existing reinforced concrete buildings for seismic resistance and energy efficiency (Dionysios A. Bournas)

The work explored innovative solutions by combining inorganic textile-based composites with thermal insulation for the structural and the energy retrofit of existing RC buildings.

In looking at traditional, uncoupled, solutions for the seismic upgrading of buildings, it is concluded that they are not generally optimal, as shown in the summarizing table below.

Jacketing	FRP	TMR
NO due to the costs	NO, because not sustainable	NO, if only in structural components; the damages on the infill panels are not avoided (70-80) % of the total cost

The solution envisaged consists in combining a high strength textile reinforcement (i.e. carbon, glass) for the seismic retrofitting of both structural and non-structural members, integrating an additional insulation layer to the reinforcement for achieving the energy retrofitting.

Through an approach based on the expected annual loss, the financial feasibility and benefits of the proposed solution were highlighted. A prototype of the panel was applied to a case study.

5. Opportunities and barriers to the deep rehabilitation of the collective buildings in East Europe (Ludovic A. Fülöp, Viorel Ungureanu, Nagy Zsolt, Daniel M. Muntean)

The presentation discussed the business potential of deep-renovation in East-European countries and presented the outcome of a small survey highlighting the renovation priorities for the occupants.

A survey based on multi-criteria decision-making tools highlighted the priorities of Romanian occupants. The following aspects were discussed:

Deep renovation vs façade intervention: it is required to carry out an extensive renovation of structures and building services, repairing damages and improving the quality of dwelling.

Customer behavior: Most of the apartments are owner-occupied, and the following issues were observed:

- Home ownership rate very high, with a consequent low mobility;
- Global view of façade neglected: “Not mine, not my problem”;
- Nominal net income quite low;
- Low level of trust;

- Only younger generation accepts credits.

A selected example of deep renovation was then described.

6. Opportunities and barriers to integrated retrofit in UK: the case of LEEDS (O. Iuorio, N. Nikitas, E. Romano & P. Negro)

The work summarized the importance of looking at the energy efficiency of building in a more holistic way.

The study concentrates on LPS buildings in Leeds, showing that they are both thermally inefficient and unsafe from a structural point of view, approaching the end of their design service life.

The paper concludes that there is an impellent need to conceive retrofit interventions in an integrated way, putting the safety and wellbeing of the occupants at the center of investments, concluding that more coordinates approaches could have more social and economic benefits.

Concluding Remarks

The case study session highlighted many issues that must be addressed to reach the ambitious European targets and to introduce a more holistic and sustainable approach to the renovation:

- all the case studies were focused on either structure or energy. Only in two cases, the issue of both energy and structural retrofitting was addressed. Sustainability and resilience of the solutions proposed was nowhere addressed;
- the ownership schemes play a fundamental role in the renovation of the existing building stock; the owner mindset, probably, can be considered as an additional barrier to the renovation, in additions to known barriers such as costs, disruption of the works, needs of relocating inhabitants, etc.;
- From a structural point of view, it can be observed that structural retrofit interventions lead to un-tangible benefits (different for energy savings where they are tangible, leading to immediate economic saving and increased comfort), and for this reason it is more difficult to “understand”.

Following the above observations, it becomes even more evident that a new approach to the renovation is required, coupling structural, energy and sustainability issues through an integrated, holistic approach.

Among the issues emerged in the discussion, one of the important aspects would be to make structural retrofit works tangible, for instance by introducing a payback time for the structural retrofit, and by putting restraints to the possibility of selling buildings with low structural safety.

In any case, sustainability, safety, and resilience cannot be pursued independently and therefore, the now withstanding sectorial code approach should be abandoned, giving place to an integrated approach.

This new approach has to overcome the major barriers to the renovation thus replacing sectorial codes and traditional design methods for both the energy and structural retrofit, addressing at the same time sustainability and resilience. For such an approach to succeed, it is important to develop retrofitting strategies which would minimize typical barriers to renovation, such as limiting disruption of the construction site and avoiding inhabitants’ relocation.

Also, the advantages of an increased safety and sustainability of the retrofitted building should become tangible, not only in terms of quality of life, but also economically, through proper economic incentives for integrated retrofit works, and by introducing market barriers on sales of unsafe or unsustainable buildings or dwellings.

Keynote Lecture

ASSESSMENT OF LARGE PANEL SYSTEM (LPS) RESIDENTIAL BLOCKS FOR ACCIDENTAL LOADING: FIELD TESTING AND THE DEVELOPMENT OF NEW GUIDANCE – A CASE STUDY

Stuart Matthews

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ABSTRACT

There are many high-rise and low-rise large panel system-built (LPS) residential blocks in the Europe which are expected to remain in-service for an extended period. To achieve this goal numerous blocks will require integrated retrofits to deliver sustainable extensions of the working life of such blocks. This will necessitate a multi-disciplinary approach, bringing together experts from different fields including structural engineering, energy performance, and economic evaluation working within a framework of life time thinking.

Block owners have an ongoing responsibility for the safety of their LPS blocks. In the case of high-rise LPS blocks current UK guidance requires owners to instigate programmes of periodic inspection and structural assessment of their blocks. Of particular concern is the resistance of existing residential blocks to accidental loads and actions. In light of recent events these considerations also need to include their behaviour in fire.

LPS residential blocks carry the enduring implications of the collapse in 1968 of the south-east corner of Ronan Point, a 22 storey LPS built residential block situated in north London. Whilst it is commonly recognised that this incident resulted in the introduction of 'disproportionate collapse' as a structural concept and to changes in the then UK Building Regulations, the issues relating to the ongoing management of the remaining population of existing LPS residential blocks are perhaps less widely appreciated.

Depending upon the nature of their construction, LPS residential blocks generally contain flats, but in some cases the accommodation is in the form of maisonettes or some other form of multi-floor arrangement. The associated variations in layout can add to the complexity of making assessments.

LPS dwelling blocks are basically gravity structures, as are traditional masonry constructed buildings. They typically comprise precast reinforced concrete floor and roof components spanning onto storey high structural precast (generally plain) concrete wall panels. Vertical loads are carried to the ground through the structural wall panels, which also provide stability against lateral loads.

Historically the guidance used for the structural assessment of LPS dwelling blocks for accidental loads has been the *Ministry of Housing and Local Government* (MHLG) *Circulars 62-68* and *71-68*, which were produced shortly after the Ronan Point incident. MHLG Circulars 62/68 and 71/68, along with various other related guidance from that era, were never withdrawn and notionally remain in force today. In the 1990's it became clear that the then existing guidance had become outdated by subsequent developments.

This paper provides an overview of updated technical evaluation criteria and the associated guidance for undertaking a structural assessment of an LPS dwelling block for accidental loads published in the UK in 2012.

It summarises the programme of work undertaken in support of these developments. The work gives a better appreciation of the circumstances which might contribute to failure in an LPS dwelling block and to the likelihood of their occurrence. Specific activities described include a review of hazards and their contribution to the risk environment, full-scale structural tests to failure and related studies. The outcomes were brought together in a methodology for the through-life management of LPS dwelling blocks.

SEISMIC ASSESSMENT AND RETROFIT OF TYPICAL PRE-CODE SCHOOL MASONRY BUILDING – CASE STUDY

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EXTENDED ABSTRACT

The territory of the Republic of Macedonia is situated in a seismically active region with an increasing seismic risk. The roughest general categorization of the building stock done according to the main structural system and year of construction comprises of three basic building types: (1) non-earthquake resistant masonry buildings; (2) moderate earthquake resistant confined masonry buildings and (3) earthquake resistant RC buildings. According to some raw estimation, the percentage of non-earthquake resistant buildings built up to 1970 (before enforcement of first seismic design code in 1964) of the existing building stock is over 30% which poses significant seismic risk to the country. What is more important is the fact that non-earthquake resistant masonry buildings are actually unreinforced plain masonry buildings and this type of structural system is very often applied in a school and hospital buildings, built before 1970.

Selected case study, presented further in the text, primary school building "Lirija" in Tetovo, Republic of Macedonia could be considered as a typical representative of pre-code design masonry buildings.

Within the frame of the study, experimental and analytical investigations for definition of the stability and safety of the existing structural system of the school building under gravity and seismic effects have been carried out, (IZIIS Report 2017-20).

The structural system of the building is represented by massive masonry constructed of stone at the basement and bricks at the ground floor and the above story. The foundations are constructed of stone. The floor structures over the basement and the ground floor, in the part over the schoolrooms are finely ribbed. Over the halls and the sanitary knots, they represent RC slabs, while the roof floor structure is constructed of wood beams. The roof structure is constructed of wood, with a roof cover constructed of tiles. There is no official data on the year of construction of the building, but it is assumed that it had been built prior to the enforcement of first seismic design code in 1964.

The layout of the structure is presented below (Figure 1).

The following activities have been realized within the study:

- A detailed review of the available existing documentation;
- In-situ insight and inspection of the structure;
- Identification and analysis of dead and imposed on the bearing structure;
- Assessment of loads due to expected seismic effects;
- Definition of dynamic characteristics by ambient vibration method.

Based on data from the above listed activities, the following analysis were carried out: (i) elastic static analysis carried out on a 3D mathematical model (Figure 2), (ii) analysis of elements up to ultimate state of strength, deformability and ability of the bearing elements and the system as a whole to dissipate seismic energy, i.e. ductility capacity, and (iii) analysis of the dynamic response of the system to real seismic effects, with intensity and frequency content expected at the considered location.

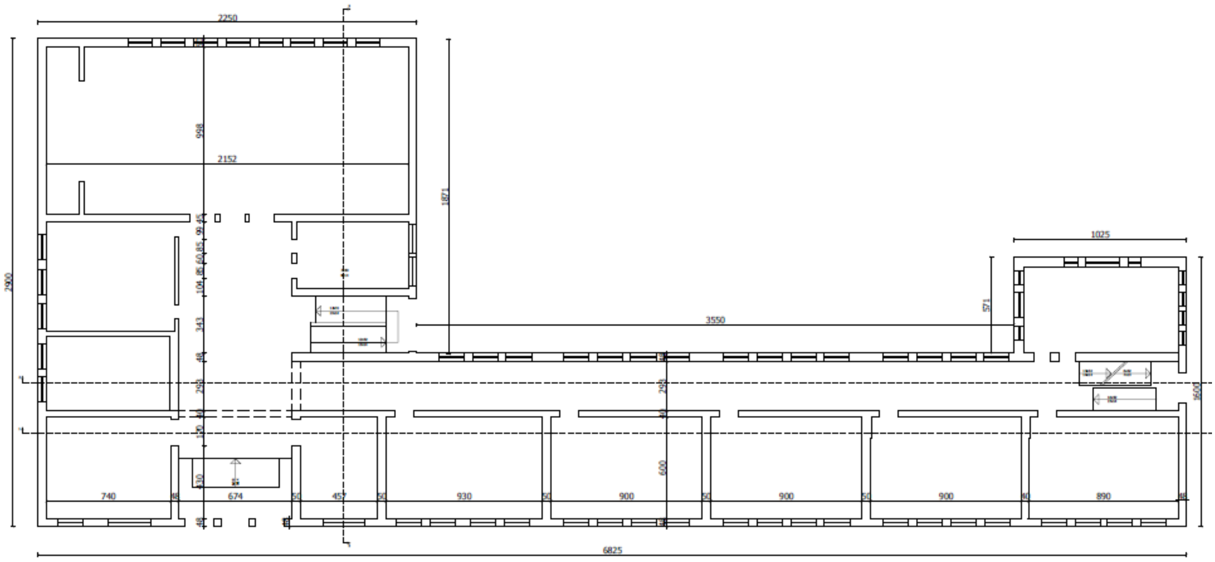


Figure 1. Layout of the ground floor.

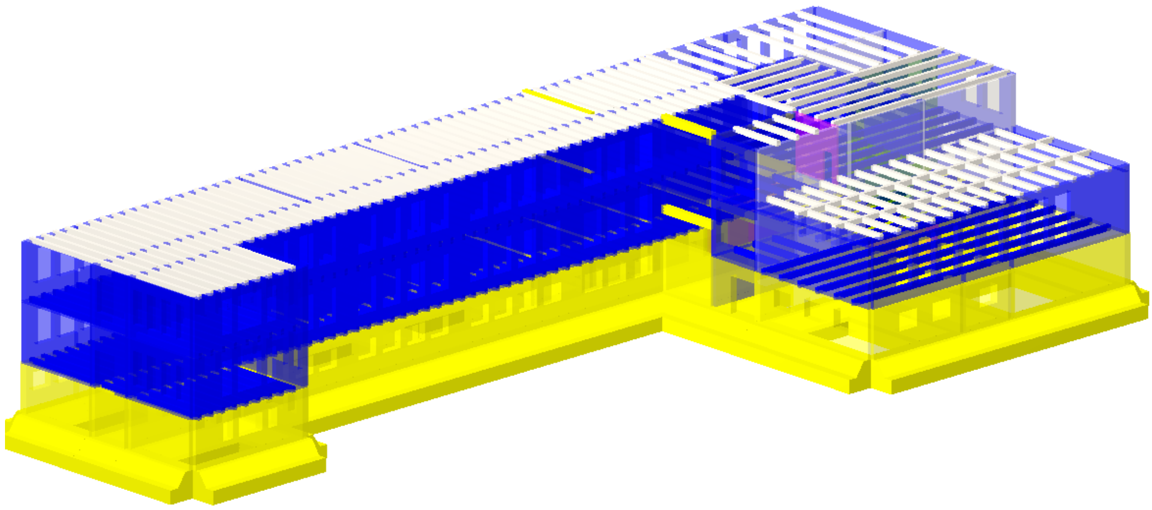
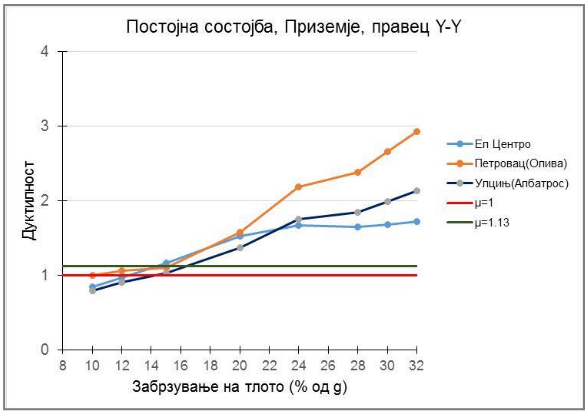
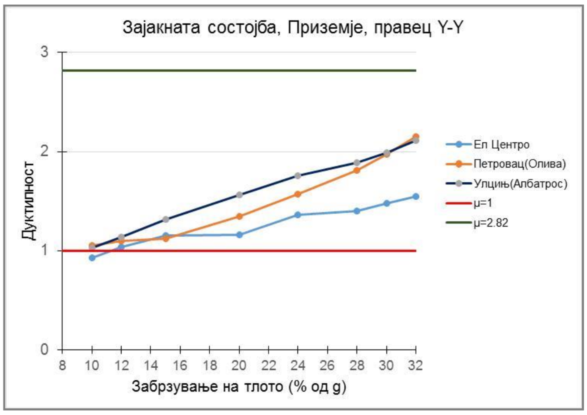


Figure 2. 3D mathematical model for elastic analysis of the existing system.

Based on the results obtained from the analyses, the seismic assessment of the existing structural system has been performed. It can be concluded that the existing structure of the building possesses sufficient bearing capacity, but not a sufficient deformability (ductility) capacity (Figure 3a), particularly in transverse direction, which is, in fact, characteristic for such massive and non-ductile structures as are the traditional masonry structures.

To increase the seismic safety of the structure, structural measures for strengthening of the system are anticipated. These include: incorporation of horizontal RC belt course over the first storey and guniting , i.e., construction of RC jackets on both sides of the walls (Z8, Z10, Z11, Z12 and Z13) with RC columns at both ends of the jackets, at all three heights (Figure 4). With these anticipated structural interventions for strengthening of the existing structure, the ductility capacity of the structure (ground floor and upper storey) in longitudinal direction will not be altered, but the ductility capacity in transverse direction identified as vulnerable will be increased (Figure 3b).





a) Existing structural system b) Strengthened structural system

Figure 3. Comparison of the ductility demand versus ductility capacity – transverse direction.

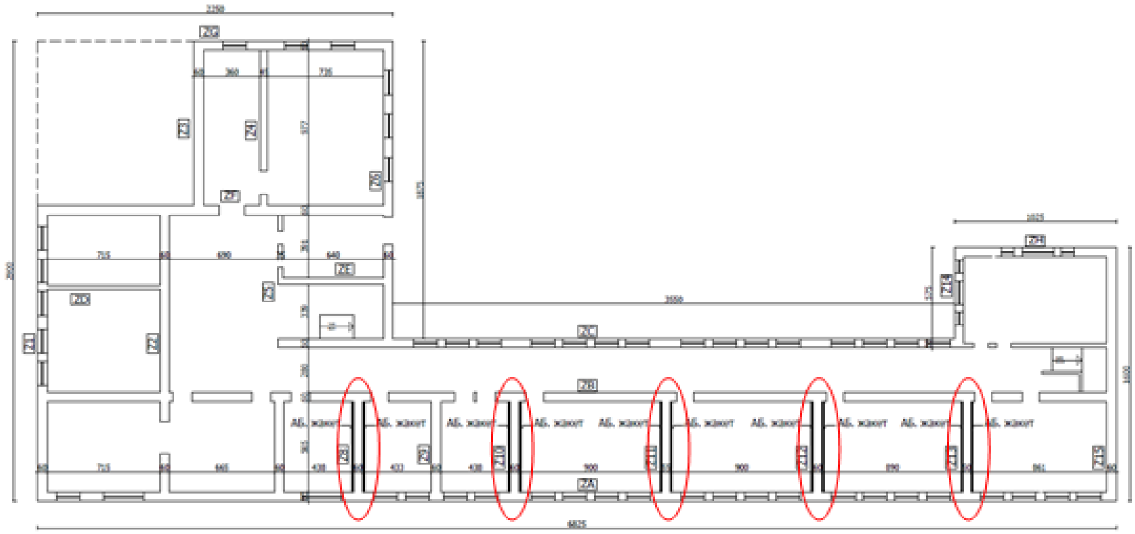


Figure 4. Characteristics floor plan with anticipated strengthening.

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A CASE STUDY: SEISMIC RETROFITTING OF AN EXISTING MULTI-STOREY R.C. BUILDING IN NORTHERN ITALY

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EXTENDED ABSTRACT

Seismic vulnerability assessment and retrofitting of existing buildings has become a core activity among professional engineers in Italy, due to the seismic prone nature of the Country and to the obsolescence of its building stock.
According to the prescriptions of the recently published NTC 2018, i.e. the updated version of the Italian Building Code, the design of a retrofitting intervention tailored to different performance levels and possibly coupled to architectural interventions aimed at improving the energy performance of the building is possible.
Nevertheless, for professional engineers, some issues regarding how to correctly carry out structural analyses for vulnerability assessment and how to effectively design retrofitting interventions are still open.
In the present case study, a multi storey r.c. building dating back to the 1960 and currently intended to become an office and residence unit for the Italian Polizia Stradale, is analyzed.
The case study can be considered representative of current practice: the different steps of the vulnerability assessment will be presented and discussed.
At first, the preliminary document collection phase and the design of material tests will be presented, followed by a discussion of the structural analysis phase, with a focus of the modeling assumptions and methods and their effects on the results. Finally, the criteria adopted for the design of the retrofitting intervention and its implementation will be presented.

RETROFITTING THE EXISTING REINFORCED CONCRETE BUILDINGS FOR SEISMIC RESISTANCE AND ENERGY EFFICIENCY

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ABSTRACT

This work explores innovative techniques by combining inorganic textile-based composites with thermal insulation for the simultaneous seismic and energy retrofitting of the existing reinforced concrete (RC) buildings. The overall effectiveness of the combined energy and seismic retrofitting is demonstrated via a case study on a five stories old-type RC building. Moreover by proposing a common approach based on the expected annual loss (of consumed energy or expected seismic loss), it is possible to evaluate the financial feasibility and benefits of the proposed combined retrofitting approach. The preliminary results suggest that the payback period of the intervention can be reduced for seismic zones, if energy is applied concurrently with seismic retrofitting by exploiting advanced construction materials, thanks to large savings related to the labor costs.

INTRODUCTION

The issue of upgrading the existing building stock is of great importance and priority for all EU countries. In Member States (MS) of south Europe, collapses or serious damages of existing buildings during strong earthquakes have resulted in significant economic losses, severe injuries and loss of human lives. Moreover, in all MS, the low energy performance of old buildings, which is mainly attributed to the low thermal insulation of their envelopes, increases their energy consumption. Therefore there is a tremendous socio-economic and environmental need for upgrading existing RC and masonry buildings to enhance their safety and energy efficiency in order to meet more demanding standards such as the Eurocodes (EN 1990 – EN 1999) and the Energy Performance of Buildings Directive (EPBD) (2010; European Parliament, 2016).

Buildings are responsible for 40% of EU energy consumption and 36% of CO_2 emissions in EU. At the same time, the strong earthquakes occurred the last decade in MS of south Europe pointed in a cruel manner up the problem of the poor seismic resistance of the existing EU building stock. In particular, a number of old concrete and masonry buildings, that were not designed according to the modern EU standards (i.e. Eurocodes[1]), collapsed under seismic excitations resulting in significant economic losses (only the cost for reconstruction in Italy is estimated above EUR 30 billion for that period), severe injuries and loss of human lives. Moreover, structural damage was observed on several buildings, which had previously undertaken energy efficiency upgrades taking advantage of national subsidies.

To achieve cost effectiveness, a novel approach is explored in this work, investigating a hybrid structural-plus-energy retrofitting solution which combines inorganic textile-based composites with thermal insulation systems for RC building envelopes, aiming to simultaneously upgrade their seismic resistance and energy efficiency. The feasibility and effectiveness is demonstrated and briefly summarised via a case study of a five stories RC building, whereas more details on this new concept are presented in Bournas (2018), Mastroberti et al. (2018), Gkournelos et al. (2019), Pohoryles et al. (2020) and Gkournelos et al. (2020).

COMBINED SEISMIC AND ENERGY RETROFITTING CONCEPT

The concept for achieving simultaneous seismic and energy retrofitting in a building envelope is illustrated in Figure 1. This solution simply combines high strength textile reinforcement (i.e. carbon,

[1] http://eurocodes.jrc.ec.europa.eu/#

glass) for seismic retrofitting (of both structural and non-structural members), whereas an additional insulation material is integrated to the reinforcement for achieving the energy retrofitting. The strengthening procedure starts with the seismic strengthening of the masonry-infilled RC frames with TRM and then the thermal insulation material is added straight afterwards, while the mortar is still in a fresh state. This allows with one intervention to achieve both of the required safety and energy performance, while keeping the overall cost low by dramatically reducing the labour cost.

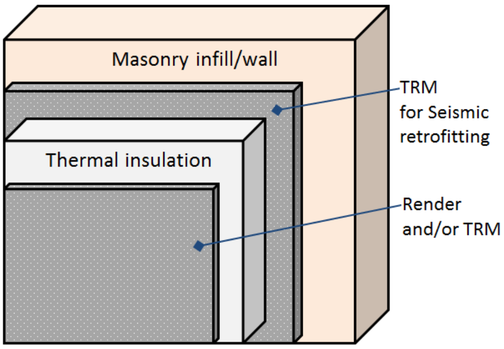

Figure 1. Schematic view of the combined seismic plus energy retrofitting system: TRM Jacket + insulation material on a masonry infill/wall (Bournas, 2018).

EVALUATION OF THE CONCURRENT SEISMIC AND ENERGY RETROFITTING

A simple approach for the integrated assessment of energy efficiency and earthquake resilience was presented by Calvi at al. (2016). Following a similar method, this study evaluates the buildings' seismic risk and energy performance in a combined manner. The building performance related to earthquake resilience is assessed in accordance with the predicted value of seismic expected annual loss (EAL_S). The index of the EAL_S, which can be calculated following a deterministic (e.g. Bournas, 2018; Calvi et al. (2016) or probabilistic approach (Mastroberdi et al. (2018), provides the average value of loss that a building will sustain annually over its (remaining) life span due to seismic action. On the other hand, the energy performance is based on the buildings total annual energy consumption, and the relevant mean annual energy cost (annual energy consumptions multiplied by their relevant energy unit costs). Therefore, by considering the building total value, the corresponding seismic and energy expected annual loss, namely EAL_S and EAL_E, can be expressed by the ratio of the average annual cost (of consumed energy or expected seismic loss) to the building total value, providing two analogous indexes that can be compared directly:

$$EAL_S = \frac{expected \;\; seismic \;\; loss}{total \;\; building \;\; value} \qquad EAL_E = \frac{annual \;\; energy \;\; cost}{total \;\; building \;\; value} \tag{1}$$

The concurrent seismic and energy retrofitting using TRM jacketing and thermal insulation of the envelope, would result in reducing: (a) the seismic expected annual loss ($\Delta EAL_S = EAL_{S,as\ built} - EAL_{S,retrofitted}$) as result of the savings in expenditure for future reconstruction, and (b) the energy expected annual loss ($\Delta EAL_E = EAL_{E,as\ built} - EAL_{E,retrofitted}$) as a result of lower expenditure for warming and cooling the house. Consequently, the total reduction in expected annual losses is actually the total economic benefit of the combined retrofitting that is equal to $\Delta EAL_S + \Delta EAL_E$.

The economic effectiveness of retrofitting interventions depends on the payback period; this is the time at which the return of initial investment will be achieved. An integrated retrofitting solution is economic effective if the payback time is lower than the residual life of the building after retrofitting. To evaluate this, it is necessary first to determine the break-even point for a building subjected to (seismic, energy or seismic & energy) retrofitting:

$$t_{break} = \frac{Retrofit\,Cost \;\; / \, Buidling\;Cost}{\Delta EAL} \tag{2}$$

CASE STUDY

To evaluate the integrated seismic and energy retrofitting, the response of an existing non-ductile 5-story pilotis-type building (Figure 2), constructed in southern Europe in the 1960s, was considered in the case study. All beams have a cross section of 250x500mm with 4Φ16 at the top flange and 2Φ16 at the bottom at the supports, while the central columns are 450x450mm with 8Φ16, the side columns are 400x400mm with 8Φ14 and the corner ones 350x350mm with 4Φ20. The detailing of the steel reinforcement was calculated according to a set of simplified provisions existing in the Greek territory before 1980. Concerning the exterior wall infills, all of them are 19 cm thick that corresponds to double-leaf infills of 6-hole masonry blocks, which were mostly used in the construction practice of south Europe of that era. It is also assumed that they have an opening that occupies the 25% of the total wall area, a percentage that was decided after examining the old practice in Italy and Greece. It is noted that the basic layout of the building was selected in a way to represent a large family of RC frame buildings.

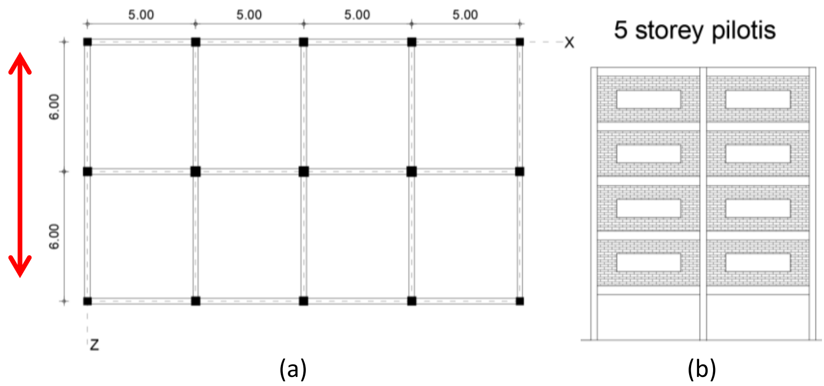

Figure 2. (a) Plan of the 5-story building; (b) Views of ZY planes for the infilled frames and the pilotis configurations (Bournas, 2018).

The retrofitting approach presented in Figure

1 was applied in the case study combining TRM jacketing with insulation materials. More specifically, based on the findings of Koutas et al. (2014), the infills of the first 3 stories were strengthened with glass TRM jacketing (2 layers for the ground floor and 1 layer for the 2nd and 3rd floors in the weak frame). For what concerns the pilotis configuration, the two external RC frames at the ground floor (in the building's weak direction) were infilled with masonry walls, prior to the application of the TRM jacketing.

The methods for calculating the seismic and energy expected annual losses (EAL_S and EAL_E), as well as the estimated retrofitting costs are provided in Bournas (2018). Note that these values must be considered as rather case specific and of preliminary nature, and are derived to have later a frame that will allow the conceptual discussion on the proposed concurrent seismic and energy retrofitting. The values of the EAL_S were computed, for 3 PGA levels corresponding to small, medium and high seismicity and are presented in Table 1.

Table 1. Computed EAL_S for the 5-story building configurations subjected to multiple seismic excitations.

5-story pilotis-type building				
Site seismicity	PGA (g)	EAL_S - % (Initial)	EAL_S - % (Strengthened)	ΔEAL_S
Low	0.1	0.33	0.21	0.12
Medium	0.2	1.44	0.39	1.05
High	0.3	2.92	0.53	2.93

The energy consumption of the building was calculated equal to 263kW/m^2, which given the considered energy unit cost and total building value, yields to EAL_E equal to approximately 2.0% (Bournas, 2018). It should be noted that the value of the EAL_E would have been higher if the cooling of the building during the summer months is considered. A more detailed thermal analysis considering also the energy consumption due to cooling is presented in Gkournelos et al. (2018). The TRM jacket was integrated with Polyurethane (*PUR*) thermal insulation panels, applied around the entire wall-envelope of the building. The energy retrofitting scenario considered was targeting at achieving 50% reduction of the overall thermal energy consumption. To satisfy the targeted reduction, the 5 cm PUR panel insulations were combined with double-glazed low emissivity windows. As a result, the energy expected annual loss ΔEAL_E ($EAL_{E,as\ built}$ - $EAL_{E,retrofitted}$), owing to the lower expenditure for only warming the house, was reduced to 1%, for energy insulated building.
The feasibility of the combined seismic and energy retrofitting is explored by comparing the break-even point (payback period in Eq. 2) for the building configuration considered in this case study. Table 2 includes the break-down of the costs for each of the retrofitting schemes normalised to the building cost, the reduction in *EAL* after retrofitting (*ΔEAL*), as well as the calculated pay-back period of the retrofitting interventions (t_{break}). It is noted that these parameters are presented for all retrofitting scenarios, namely applied separately or simultaneously, to allow for comparisons among the sole energy or sole seismic retrofitting versus the concurrent seismic and energy scenarios.

Table 2. Calculated payback time for the 5-story building considered.

	Energy Retrofitting	**Seismic retrofitting**			**Seismic & Energy Retrofitting**		
PGA (g)	-	0.1	0.2	0.3	0.1	0.2	0.3
Retrofitting/Building Cost (%)	9	7	7	7	11.5	11.5	11.5
Retrofitting Savings *ΔEAL* (%)	1.0	0.12	1.05	2.93	1.12	2.05	3.93
***t* (years)**	**9**	**58.3**	**6.7**	**2.4**	**10.3**	**5.6**	**2.9**

CONCLUSIONS

The overall effectiveness of the combining energy and seismic retrofitting was demonstrated via a case study of a five stories old-type RC building. In addition by proposing a common approach based on the expected annual loss (of consumed energy or expected seismic loss), it was possible to evaluate the financial feasibility and benefits of the combined approach. It was shown that the payback of the retrofitting intervention can be significantly reduced when seismic is applied concurrently with energy retrofitting by combining advanced construction materials, thanks to large savings related to the labour costs.

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OPPORTUNITIES AND BARRIERS TO THE DEEP REHABILITATION OF THE COLLECTIVE BUILDINGS IN EAST EUROPE

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INTRODUCTION

Prefabricated concrete multi-storey buildings are an important share of the building stock in East-European countries. To highlight but a few numbers, there are 508 thousand such apartments exist in Hungary (Dénes, 2000; Kecskés, 2006), 1.2 million in the Czech Republic and Slovakia (Krajčovičová et al., 2010) and about 2.4 million households in Romania (INNSE, 2003). They are also typical for the cities of Poland, Lithuania, Latvia, Estonia and Bulgaria within the European Union.
In most countries, the reputation of the technology has been compromised by the low-quality buildings erected in the past. There are however exceptions, for example in Finland multi-storey concrete prefabricated buildings are popular (see Figure 1). In most countries, the legacy of a large building stock approaching its technical design life is a challenge to both occupants and authorities.

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

Extending the service life of the buildings, both from technical point of view and in terms of market worthiness, has to be coupled with improving the energy efficiency, given the inadequacy to today's standards and targets[1]. Upcoming renovation task offers great business opportunities but is also hindered by challenges related to costs and the ability of owners to manage complex interventions. National authorities have partly been passive due to the lack of funds or focusing exclusively on thermal rehabilitation.
In this paper, we discuss the business potential of renovation in East-European countries and present the outcome of a small survey highlighting the renovation priorities of occupants. We also present a comparison of the ownership structure in Finland and Romania, arguing that the way ownership of apartments is organized in Romania, and other East European countries, is a hindrance to implementing deep renovation with disadvantages to the owners themselves. We conclude by highlighting examples for deep renovation, ranging from complete demolition to partial demolitions and demolition with reuse of the building components.

[1] http://ec.europa.eu/europe2020/targets/eu-targets/

ESTIMATED BUSINESS POTENTIAL OF RENOVATION IN EAST-EUROPEAN COUNTRIES

Since the EU target is to reduce greenhouse gas emissions with 80-95% by 2050, compared to 1990 levels, there is a legislative push for energy renovation. Household energy consumption of new and existing buildings has to be reduced since buildings account for 40% of Europe's energy consumption. Therefore, many governments (e.g. Romania, Hungary, Czech Republic etc.) operate subsidy schemes for energy renovation. Limiting the focus of reconstruction to energy rehabilitation is somehow understandable when funds are limited (Table 1).

Table 1. Value of residential renovation in the Czech Republic, Poland, Romania and Finland[2].

	2006 € mill.	2011 € mill.	Average growth (%/y)	€/capita	2011 € 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 shown by the renovation-need modelling of Riihimäki et al. (2012), extensive facade renovations of multi-storey buildings are pressing in many East European countries (see Figure 2). The models were using the renovation-need function based on total façade areas and include the known government programs to accelerate renovation.

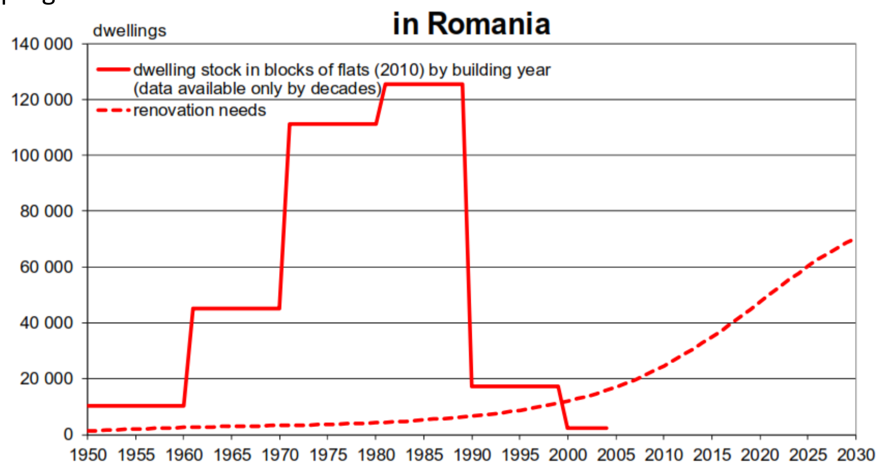

Figure 2. Renovation need of façades in multi-storey dwellings by year (Riihimäki et al., 2012).

In Romania a large part of the renovation need is upcoming. Many buildings were built in the 1970s and 1980s, thus the multi-storey residential building stock is quite young. The moderate renovation needs, forecasted by the model for the present time is attributed to (1) the overestimation of the quality of the initial facades (2) the underestimation of the effect of lack of maintenance from the 1990s. Even with these moderate estimates, about 30,000 flats are in need of renovation and the need will grow in the coming years. A pessimistic estimate is that about 80% of the dwellings would come to the end of their service life within 20 years unless serious measures are taken (UN, 2001).

RENOVATION PRIORITIES OF OCCUPANTS

As discussed earlier most renovation measures today are strictly energy focused, with many top-down government programs. The EU goals drive the national legislation of countries[3]. These top-down initiatives should be applied in an interconnected fashion with the wishes of the occupants and broader societal sustainability targets.

[2] Riihimäki et al., 2012 (Sources, Euroconstruct 2011 and Buildecon: Romania construction market report)
[3] http://ec.europa.eu/europe2020/pdf/targets_en.pdf

By a survey based on multi-criteria decision making (MCDM), we highlighted a few priorities of Romanian occupants of multi-storey dwellings. There is general (1) agreement on the importance of internal comfort, but (2) varying attitude on accessibility and adaptability of the internal space of the apartments. Responders expected a minimum standard on (3) safety and (4) spatial distribution of the internal space. They showed the most flexibility concerning (5) maintenance cost, price and location (Fülöp and Riihimäki, 2013). The responses highlighted properties of the dwelling to be improved by the city authority (31%), the homeowner association (HOA) with moderate effort (35%) and with substantial effort (28%), Fig 3. Hence, the HOA's are very important facilitators of the renovation of the collective building stock.

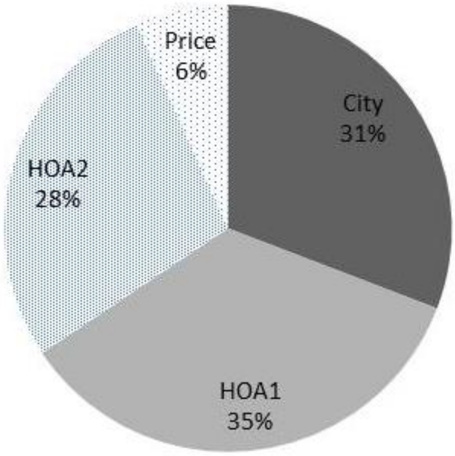

Figure 3. The administrative level for carrying out improvements desired by occupants.

The HOA1 slice of the above chart includes measures related to *indoor quality* and *reducing maintenance cost* (e.g. thermal insulation or air exchange measures). These may be improved by the renovation of a single apartment owner, a practice often seen on buildings. Hence, if HOAs do not act together to respond to the expectations of their members, owners will act in isolation jeopardizing the aesthetics, the thermal performance and even the structural safety of the entire building.

Additional qualities desired by occupants are also within the control of the HOA, but with substantially more effort and expense (HOA2). These are deep-renovations targeting aspects of social sustainability of the building stock, spatial system, adaptability and accessibility. The spatial system is a strong driver of choice in the MCDM, also linked with the adaptability of the internal spaces. Accessibility is a wider societal concern, given the ageing population.

DEEP RENOVATION VERSUS FAÇADE INTERVENTIONS

As the tower building stock ages, the most pressing problem is adequacy to today's living standards. Even if some argue that "*up to now the estate-life satisfies a certain group of the society*" (Egedy, 2000), this is often not a choice, but a social restraint. Parallels exist between housing estates in Western Europe, and the ones in East-Europe, the main difference being the share on the housing market (Egedy, 2000).

With ageing, it is required to carry out an extensive renovation of structures and building services. These interventions should be coupled with efforts to improve the quality of dwellings not only to repair various damages. Extensive renovations are long and burdensome processes for occupants, which constitute a lasting financial burden. Hence, besides the energy renovation programs, national government should also focus on benchmarking such deep renovations.

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)[4] "major renovation" is where: (a) the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25%

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

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.

THE EFFECT OF THE OWNERSHIP MODELS

In most East European countries, the apartments in collective buildings were sold to the tenants by the state. As an outcome, most of the apartments are now owner-occupied without an outstanding loan (Figure 4).

The ownership model of most tower buildings in Romania is a *condominium* type ownership. 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-property extends to commonly used parts of the buildings, land, foundations, cellars, stairways, elevators, external walls, roofs, depositing areas, entrances etc. Owners are organized in homeowner associations or HOA's, for the purpose of managing the co-owned parts of the property.

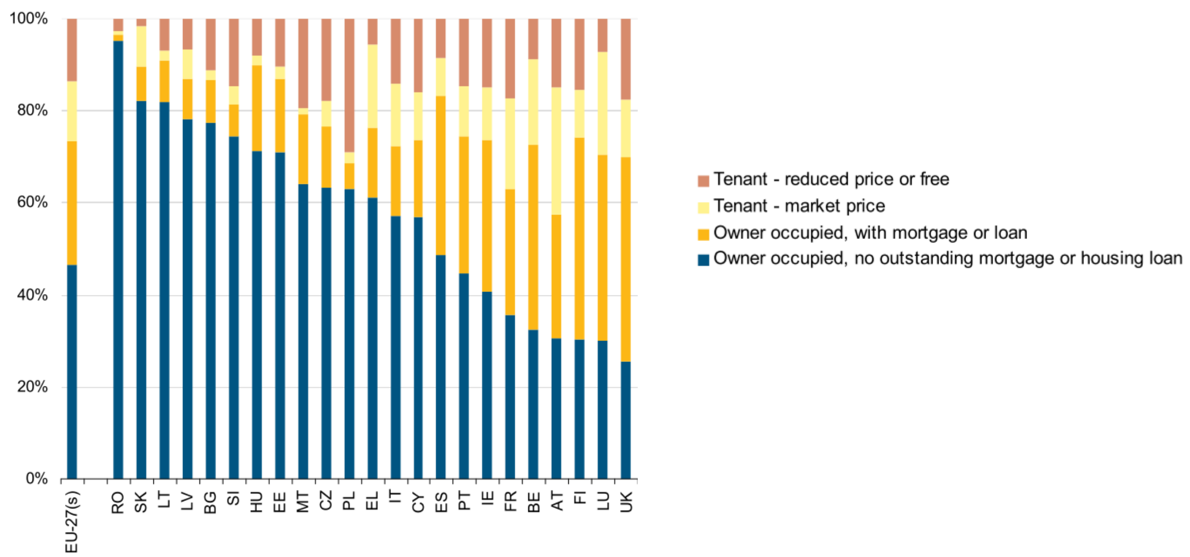

Figure 4. Distribution of population by tenure status in 2009 (Rybkowska & Schneider, 2011).

An alternative model for owning buildings, extensively used in Finland, is the *collective ownership* model. In such buildings, the right to reside in an apartment is tied to the ownership of shares in the housing company. The housing company owns the building/buildings, and the shareholders own the housing company. The ownership of shares associated with an apartment 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 framework of high ownership rates within a *condominium*, finding a workable maintenance and upgrading solutions is difficult. It may take the full agreement of all owners in the HOA to contact a bank loan in order to finance renovations. Even with lowered decision threshold, HOAs have little own budgets to finance deep renovation or assets to use as a guaranty for bank-loans. In these scenarios, the intervention of the state by grants or loan guarantees is essential.

In the *collective* ownership, the situation is different. Once the decision is taken by the owners meeting, the contracting of the bank loan is done by the housing company. The guaranty is the collectively owned building, and the individual shareholder pays the interest corresponding to shares in the housing company; or pay off his share of the housing company loans. Apartments, more precisely shares, are sold on the market with outstanding renovation loans; the loans are simply transferred to the new shareholder/owner.

As a summary, at the market psychographic one can observe the attitude, that: (1) "Home" is a priority for people, but "Home" is ending at the apartment door, or at the entrance to the building; (2) therefore, the public area is out of focus and often neglected.

While the collective ownership model offers a functional way of maintaining building stocks of collective buildings, the implementation of similar models in East European countries may be difficult. In these countries the push for collective dwellings has been implemented in the pre-1989 era when every aspect of life in society has been subordinated to the professed political ideology of equalitarianism. Then, the political power used every means to take over society often using violence; and housing policy was but an instrument to destroy the boundary between private and public, systematically reshape or destroy the sense of communities (Szende, 2015). A clear dependence between the developments in East-European countries and the political directives coming from Moscow are also well documented (Stroe, 2015). With such historical background, a coordinated initiative towards deep renovation needs to be planned with special regards to sensitivities of the occupants.

SELECTED EXAMPLES OF DEEP RENOVATION

As shown above, HOAs are in control of most of the renovation measures desired by the owners and advantageous for the city. On the other hand, severe limitations of the HOAs to acts within the confines of a *condominium* ownership scheme were highlighted. In order for HOAs to be active, they need to be empowered by legislation to enforce renovation measures even over the wish of a few individual owners (e.g. by majority vote). But, both façade renovation of the tower buildings, let alone deep renovation, is mostly carried out when the buildings are owned by the organization.

On one end of the spectrum, there is the “demolish and rebuild” approach promoted in Saint Petersburg[5]. This program is a very large scale, involving the demolition of old building and re-development on 22 city blocks. Old buildings were demolished, occupants moved, owners compensated. Larger buildings were built on the emptied plots and are being sold on the market[6]. There are complains of the previous occupants and the system is mostly applicable in countries where authorities have considerable influence on the decision (e.g. most owners are tenants).

Benchmark partial demolition and refurbishment projects of tower buildings are planned in Hungary[7]. The program, called “Minőségi Otthoncsere” (Quality Home Exchange), is benchmarked by the city council of Hódmezővásárhely. The city offers to buy the apartments of several owner-occupied tower blocks or to subsidize the moving to single-family houses. The offer was given to 210 owners, the long-term plan being a systematic deep-renovation of the structures involving partial demolition. The physical reconstruction has not been put into practice[8]. However, it was noted that upscaling the project would require authorities to provide temporary or even permanent housing while demolishing buildings. Such a need could facilitate the creation of a public rental housing program, which is very limited in most East-European countries.

Other trends regard over-roofing of the flat-roof buildings. The solution seems adequate to solve the lack of dwellings with spacious new apartments. In the context of the renovation, the plumbing of the building and access routes are improved. A disadvantage of these interventions is that the increased number of occupants is putting pressure on the already overloaded local infrastructure.

Other more innovative interventions at the functionality of the buildings, building envelopes, upgrading the existing systems for heating, ventilation and cooling or integration of a local smart energy grid could be envisaged (see Figure 5). All these possibilities can be primarily applied to a group of buildings.

On the other side of the spectrum compared to complete demolition are examples of partial demolition (Lahdensivu et al, 2015), coupled with the reuse of the demolished elements. Hence, the environmental burden of this renovation is reduced.

[5] http://www.spbren.ru/

[6] www.spbren.ru/kvartiry-v-novostroikah/zavershennye/

[7] www.delmagyar.hu/hodmezovasarhely_hirek/indul_a_minosegi_otthoncsere_program_vasarhelyen/2544475/

[8] www.locatar.ro/Forumhttp://hvg.hu/gazdasag/20170530_Vissza_lehet_bontani_a_paneleket_de_mi_lesz_utana

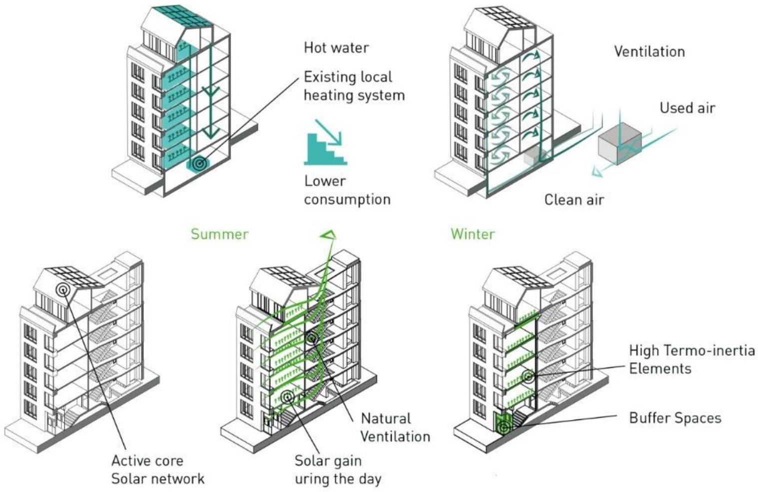

Figure 5. Building new operation system diagrams.

CONCLUSIONS

There is a significant building stock in most East European countries in need of renovation and upgrade. These buildings are mostly legacy of the pre-1989 political system and come attached with some particularities and sensibilities of the occupants. Since, very significant proportion of the population lives in these buildings, large-scale renovation is complex social, economic and technical question.

At present, the private ownership rate of the apartments is very high, hindering occupant mobility. High ownership rates, together with a particular implementation of the condominium ownership model based on decision process by quasi-agreement of the occupants, creates meagre prospect for deep renovation.

The thermal rehabilitation of the building stock is successful in many countries, driven by substantial subsidies paying for up to 80% of the renovations. However, deep rehabilitation with the aim to upgrade the functionality of the buildings is very rare. Such interventions would require larger scale of construction works, higher costs and additional disturbance to the occupants. Deep renovation, unlike façade renovation, also requires temporary housing of the occupants, creating an additional obstacle. Technological challenges for deep renovation are more significant, but not unmanageable.

Overall, national authorities should strengthen the leverage of the owners' group over individual owners, because deep renovation of the buildings will require the owner group to act together. This can be achieved by legislation respecting the sensitivities of the population.

City authorities can implement good-practice example renovations on their own buildings, as a pull for the private market. At the same time, city authorities could attempt to increase their share on the market, implementing rental-housing programs and creating a buffer for occupant relocations or exchanges. With private ownership rates at 80-90%, and no alternative housing options, it is impossible to implement works that require occupants to move away even temporarily.

Since homeowner associations (HOAs) lack the technical knowhow to manage renovation, city authorities could providing professional advice. Switching to professionally management of the properties would also be beneficial[9]. At present, each HOA is undertaking renovation individually. At the end, the valuable experience gained in the process is lost. With professional management organizations looking after properties of several HOA, the renovation experience from one project could be re-utilized in the next within the property management organization.

Finally, the private sector companies can embrace a more active role in facilitating renovation. Media companies, collecting and distributing information to the property management market, can thrive on the obvious income stream from targeted advertisement of the construction products and

[9] http://www.matinkylanhuolto.fi/en/matinkylanhuolto/

services[10]. At the same time, besides providing direct information streams to legislation and product descriptions, they can stimulate the renovation by e.g. experience exchanges between OMAs[11].

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OPPORTUNITIES AND BARRIERS TO INTEGRATED RETROFIT IN UK: THE CASE OF LEEDS

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ABSTRACT

Tower blocks in UK are at a critical stage. They were built at a time when no energy efficiency requirements were considered. They are now approaching the end of their design service life and they are damp, and cold place to live. Starting from the analysis about the diffusion of multi-storey buildings in EU, this work debates the structural and energy criticalities of tower blocks, with special attention to large panel concrete buildings. Drawing the attention on two main tragic events, i.e. the Ronan Point Collapse and Grenfell tower failure, this work unfold the necessity to develop more holistic retrofit approaches, aiming to the development of best practice for energy, safety and social benefits.

INTRODUCTION

The exponential grow of urban areas in both industrialized countries and in the Global South is responsible for depletion of natural resources and global warming. The built environment plays a key role on the triple bottom line of the sustainable development -Planet, People, Profit- and as such, the international community is promoting the development of a sustainable building market. In line with the 2020 European Strategy (United Nations, 2015) and the 2050 Roadmap, buildings energy efficiency is at the core of worldwide discussion about sustainable development and low-carbon economy. Thus, energy retrofit is a central to the discussion of architects and engineers, going from the building to the city scale.

In recent years, extensive exploration of retrofitting family buildings have been carried out. In the UK, the improvement of low-story buildings has been largely explored as testified by the New Barrack estate scheme and Kirklees Warm Zone scheme (Webber et al., 2015), or by the "Retrofit for the Future" programme, which outcomes are superbly synthesized in Marion Baeli book (Baeli, 2013). The 20 case studies exemplify pioneering approaches for a wide variety of UK construction typologies (solid masonry, cavity walls, timber frame). Fabric and heating, ventilation and air conditioning (HVAC) improvements are analysed. It clearly states "there is not a one size fits all approach" in retrofit, and it aims to build knowledge and confidence in the retrofit process. However, the retrofit of flats is not discussed. Sparse information about possible retrofit strategies and associated costs for intermediate flats is provided in (Gleeson, Yang and Lloyd, 2011), but no insights are provided for the retrofit of full tower blocks, consisting of many, interlinked flats. Multi-storey buildings have always had controversial fame, housing lower income people and offering poor comfort to the habitants. There has been a tendency of demolishing rather than converting them, with consequent strong environmental impacts. In an attempt to shift this trend the High-rise hope program (Lane, Power and Provan, 2014), led by the CASE centre, analysed energy efficiency measures and their social impacts on low-income areas, having as focus high-rise buildings. Its attention was on the £16.13 million regeneration project led by the London Borough of Hammersmith and Fulham, aimed to transform the visual impact of Edward Woods at both estate and wider neighbourhood scale, while delivering energy consumption and costs reductions. The project involved extensive work on building fabric, communal areas, integration of renewables and the construction of 12 penthouses for private sale. It demonstrated that the benefits of improving energy efficiency go far beyond energy bill savings, having significant influence on human health, industrial productivity, fuel poverty alleviation and consequent national benefits. However, this scheme has been an extraordinary example, which certainly the recent tragic Grenfell tower event is shading. Since then, UK industry and policy are trying to quantify the scale of the problem. In order to discuss the challenge of improving energy efficiency and reducing fuel poverty across UK, this paper analyses the case of tower blocks in Leeds, with special attention to Large Panel Systems, and makes the case for a holistic retrofit approach, highlighting open questions in the final discussion section.

LARGE PANEL SYSTEMS

Large-Panel concrete systems have been used since the Second World War to house large number of low-income people in short time. Indeed, the adoption of low cost large structural components (floor slabs and wall panels) manufactured in factory and assembled on site became a widely spread construction systems in East, West and North Europe since its first application that dates back to the end of 50's in Soviet Union. Pre-cast Panel systems are usually used in two main design schemes, depending on the load-bearing structure: (1) Frame Panel - all the base loads are borne by the building's frame, using the panels as enclosure elements; (2) Large-Panel (frameless) System (LPS) – large panel for walls and slabs perform the load-bearing and enclosing functions simultaneously. A large segment of these building typologies are still present in the European residential building stock, mainly in Romania, Macedonia, Bulgaria, Hungary, Czech Republic and UK. LPS are gravity structures, comprising of precast reinforced concrete floor and roof components, spanning onto one-storey high structural precast concrete wall panels. Components are connected by various forms of dry or wet joints made on site. Vertical loads are carried to the ground through the structural wall panels which also provide stability against lateral loads. When properly joined together, horizontal elements act as a diaphragm that transfers lateral load to the wall panels. LPS buildings are inherently vulnerable because of the difficulties in providing continuity and ductility in such a system. Their vulnerability under accidental loads gained interest in 1968 after the partial collapse of the Ronan Point apartment block in London (UK), when a gas explosion blew out load bearing walls of a 21 storey tower, causing the collapse of an entire corner of the building (Currie, Reeves and Moore, 1987). This phenomenon can be triggered by many different actions such as explosions caused by gas or explosives; impacts of vehicles or planes; earthquakes; human errors. Several studies on the assessment of structural performance of LPS dwelling blocks for accidental loadings have been conducted. In UK, BRE (Matthews and Reeves, 2012) undertook a program of full-scale testing on three pre-Ronan Point LPS blocks situated in Sandwell, Leeds and Liverpool, before their demolition. However very little knowledge has been developed around best practice for their structural retrofit. So that, a large portion of those buildings have never been retrofit and, when the opportunity is unfold, technologies are applied without solid experimental databases. This is certainly the case across UK cities, such as Leeds in West Yorkshire.

OPPORTUNITIES AND CHALLENGES IN LEEDS, UK

The city of Leeds is the third largest city in the UK with an urban population of 2,454,000. Leeds housed a rising population after the two World Wars in high-rise buildings, known across UK as "Tower blocks". Today the city retains 116 apartment blocks, higher than seven storeys, which were widely built between 1957 and 1972, and that constitute the 14% of Leeds City Council Housing stock. The towers house 8000 tenants and they are realized by twelve different construction typologies, which can be classified in twenty-two different thermal profiles. The tower blocks constitute for the council an important burden, for which the council is developing a 10 years investment plan from 2016 (Arup, 2016). The investment plan aims to achieve the ambitious objectives of reducing both carbon emissions by 40% and tenants energy bills by 10% between 2005 and 2020. These constructions are either in reinforced concrete frames, or constructed with a large concrete panel system. During previous energy efficiency campaign, some buildings have been improved through an extensive cavity wall insulation or an insulated cladding system. All these differences result in a wide variation of walls U-values that range from 0.34 to 1.56W/m2K. Moreover, most of the heating infrastructure is outdated and in need of replacement. The investment strategy developed by Arup for Leeds City Council defines five recommended interventions, providing at each intervention a scale of priority, ranging from 1 (high priority) to 4 (low priority). The priorities are as follows: priority 1, a) community heating system, b) new hot water cylinder; priority 2, c) new electric heater and controls; priority 3, d) cladding - external wall insulation; priority 4, increased roof insulation. The scenarios have been developed according to a cost effective invest-to-save strategy, based on a balance between carbon saving and reduction of energy bills. The developed strategy looks at the towers as part of a complex city and defines community-heating clusters as a priority. What appears controversial is the poor importance given to retrofit of the building fabric. Indeed, although few have gone through previous insulation improvement, the resulting transmittance values are still far from the current UK target.

It appears clear that the strategy tends to shift the problem from fabric improvement to heating system updating. In such a way energy efficiency is surely obtained, but the requalification is approached by solving an episodic problem, rather than thinking to a long-term investment. Indeed, focusing exclusively on a single problem makes retrofit intervention limited to solving only part of the criticalities, without considering the complexity and the interrelation of all the deficiencies of the building system. Any retrofit solution conceived having in mind only one aspect is bound to failure in a long-term perspective. An energy retrofit approach that focuses solely on equipment upgrades is 'effective but limited in the overall energy savings it can generate' (Griffin, 2016).

An integrated renovation based on the envelope retrofit could instead have the potential to improve the energy performance, ensuring at the same time also other benefits related to the three dimension of sustainability (Iuorio and Romano, 2017). Energy retrofit of Leeds tower blocks should be considered as a driver for structural retrofit, energy upgrade and urban regeneration. As such, interventions on both the fabric and the structure could allow these buildings to improve the architectural quality and the structural safety (Romano, Iuorio, Nikitas and Negro, 2018), ensuring added property value, which can bring to a global urban regeneration.

CONCLUSIONS

This work discusses the importance of looking at energy efficiency of multi-storey buildings in a more holistic way. The tragic Grenfell Tower event, that in June 2017, caused the a death tall of 71 people and many more injured, following a fire explosion in London, has brought the public attention to reflect on the approach used for the improvement of energy efficiency of multi-storey buildings. However, the building under discussion also belongs to the same typology of buildings that in 1968 were subjected to the Ronan Point collapse. Time passed and many towers are still at risk of blast explosion. This paper raises the question: when will retrofit interventions start to be conceived in an integrated way? Is not the time of making the safety and the wellbeing of the occupants at the center of the investments? Studies demonstrate the benefit that a more coordinated approach could have in terms of social benefits and industrial productivity. Building efficiency should be regarded as a mechanism capable to unlock social criticalities that are connected to technical problems. Improving energy efficiency of existing buildings should be regarded as a way to enhance local competitiveness through energy productivity, and strengthen city's economic and climate resilience.

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