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SEISMIC AND ENERGY UPGRADING OF EXISTING RC BUILDING

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Abstract

This paper presents the preliminary results of the project called Establishment of the national training centre for nearly Zero Energy Buildings (nZEB). The project is funded by EEA Grants (Energy and Climate Change Programme). Seismic condition assessment and upgrading of existing RC structures are presented with a case study building in Zagreb. New technologies were applied and followed by numerical modeling and verifications. A strategy for energy retrofitting will be presented. As the integrated approach should be respected in the renovation of existing buildings, this case study can represent an example of good practice in seismic and energy retrofitting.

Keywords: assessment, RC, renovation, case study, energy

1. Introduction

Devastating earthquakes recently struck Southern Europe, and the same problems regarding the vulnerability of the building stock appeared in Italy [1], Albania [2], Greece [3], Turkey [4], and Croatia [5]–[10]. Most damaged objects are older masonry buildings built according to older codes without proper consideration of seismic loads. However, in all the countries, there was also slight damage to RC buildings [11]–[17]. In Croatia's scenario, these buildings were built in1960s, with plain bar reinforcement and lightly reinforced shear walls.

The poor energy efficiency of public buildings in Croatia has been addressed in the main energy policy documents, the National Energy and Climate Plan (NECP) for the period 2021-2030 (adopted at the end of 2019) [18] and the Long-Term Strategy for Energy Retrofit of the National Building Stock by 2050 (adopted at the end of 2020). The latter document introduced the concept of comprehensive renovation, which includes not only energy renovation measures but also optimal measures to improve the overall regulatory requirements for the building. Instructions were published on assessing the existing condition and what measures should be considered to increase fire safety, ensure a healthy indoor environment, and improve the mechanical resistance and stability of the building, especially to reduce the operational seismic risk. This analysis was introduced as a mandatory document to be submitted when applying for public grants. It is up to the building owner to decide on the scope of the retrofit and the savings target. A higher savings target and a larger scope of improvements allow for a higher percentage of capital cost funding. This leads to one of the problems hindering nZEB renovation potential in Croatia today, namely how to efficiently communicate the relevant regulations and recently developed methodologies related to nZEB standards to all key stakeholders involved in the renovation of the existing building stock. nZEB projects lead to complex partnerships where there is not only one investor, but the active participation of the local government and the neighborhood is required.

In 2021, a comprehensive pilot project to renovate a public office building was initiated to apply the nZEB standard [19]. The entire process of developing the design documentation, as well as the steps of the regulatory approval process and construction work, is thoroughly documented and monitored by the expert group and has the role of a living laboratory for all stakeholders. The project's overall objective is to improve the knowledge of professionals dealing with buildings and to raise the awareness

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of other stakeholders on all aspects of building renovation by introducing innovative technical solutions that meet nZEB requirements. This will be achieved by establishing a national training center for nZEB.

2. PDP-nZEB project

The project is financed from the „Energy and Climate Change“ Fund, part of the Financial Mechanisms 2014 – 2021 in Croatia, courtesy of the European Economic Area (EEA). The PDP aims to raise awareness and increase the relevant stakeholders' capacities in the field of the energy performance of buildings to implement innovative technical solutions of the nearly zero energy standards. The goal will, inter alia, be achieved by establishing a national training center targeting experts' education tied to the nearly Zero Energy Buildings (nZEB).

Addressing the poor energy performance of public buildings is at the core of Croatian energy strategies and action plans. The newly implemented building standard – nearly zero energy building (nZEB)- has been adopted; however, the actual implementation is still lagging behind. One of the growing issues in Croatia today is how to transfer the respective regulations efficiently and recently developed methodologies regarding nZEB standards to all the key stakeholders. This project will therefore support the key stakeholders in realizing all the benefits of nZEB standard. The project will prove that nZEB approach, although innovative, is the optimal and cost-effective solution for the renovation of public buildings. The project also aims to capitalize on the results of the key Norwegian initiatives developed by the well-known research institution SINTEF, regarding nZEB and zero-emission neighbourhoods (Figure 1).

This objective will be explicitly achieved by the following main activities:

- Development of all the required documentation needed for achieving nZEB standard while retrofitting the existing public building
- Deep retrofit of the existing public building with state-of-the-art technologies which will be thoroughly documented and monitored by the group of nZEB experts
- Design of the training programme and project development assistance for nZEB projects for the neighborhood with the action plan on how to achieve the zero-emission neighborhood
- Established cooperation with Norwegian scientific institutions and other nZEB initiatives.

In this manuscript, just the idea of seismic upgrading will be presented. The energy evaluation of the real case study is still ongoing. It pertains to the advantages of seismic retrofitting of existing building stock according to the "full Eurocode 8" [20], as well as the discussion of evaluation methods of RC structures and the implementation of new technologies in the evaluation process. The processes are demonstrated through a specific case study and a detailed plan of activities for the specific case study.

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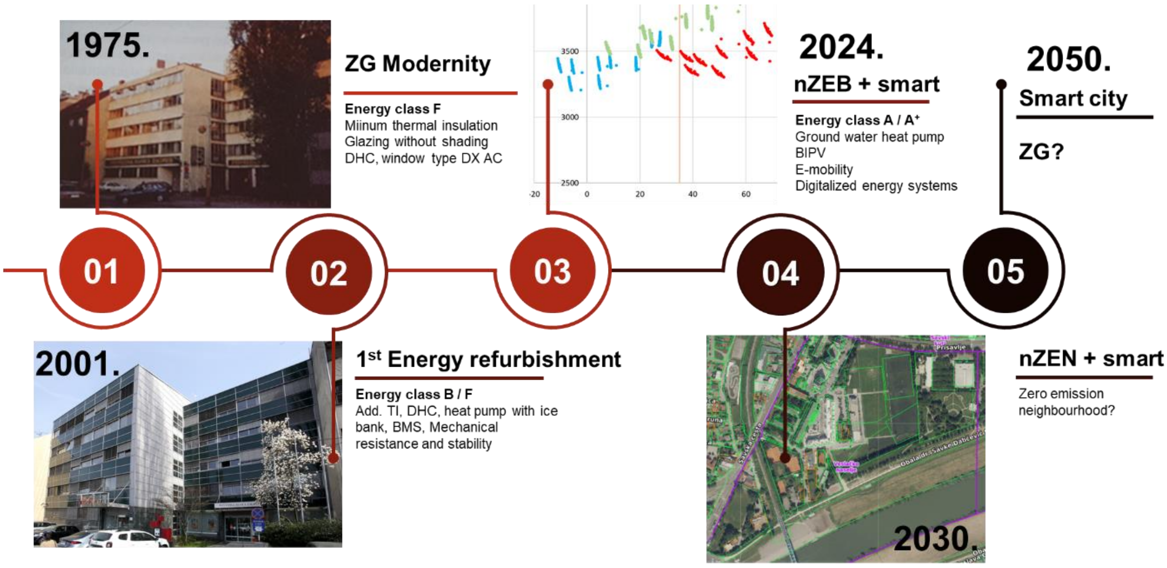

Figure 1. nZEB vision

3. Case study building

For the successful renovation of buildings damaged by the earthquake, appropriate measures must be taken to repair and strengthen the building without compromising the mechanical properties of the material and the properties of the structure, which contribute to the durability of the building. Following the obtained results, a proposal of measures for repair and reinforcement of buildings is given. Measures should follow the seismic design and be in line with the conservation and restoration rules [21],[22] but also be in line with energy demands [18],[23].

The office building was built in 1975 and was refurbished for the first time in 2001. Energy consumption, energy costs, and associated CO_2 emissions for the existing facilities were analyzed. The specific annual electricity consumption is 90.51 kWh/m^2, district heating consumption is 65 kWh/m^2, and CO_2 emissions are 90 tCO_2. The total annual energy cost is 30,775 EUR or 14.93 EUR/m^2. All energy efficiency indicators show a high potential for energy and cost savings. A detailed energy study to determine the energy retrofit concept has been conducted. This includes modelling of the building's energy demand, assessment of energy performance, and identification and analysis of cost-effective and technically feasible energy efficiency measures combined with the integration of on-site available renewable energy sources suitable to meet the nZEB target. The maximum savings potential estimated can achieve energy consumption and CO_2 emissions reduction by ten times and energy consumption reduction by five times. There were 720 combinations of energy efficiency measures tested for specific technical systems (including subsystems) such as heating, ventilation, and air conditioning (HVAC), lighting system, and building envelope improvement [11]. Next, a multicriteria analysis provided insight into specific criteria such as primary energy, global cost, CO_2 emission, and operational costs to define the optimal nZEB solution. Along with the energy demand and CO_2 emission reduction, further building system digitalization and energy storage systems are planned.

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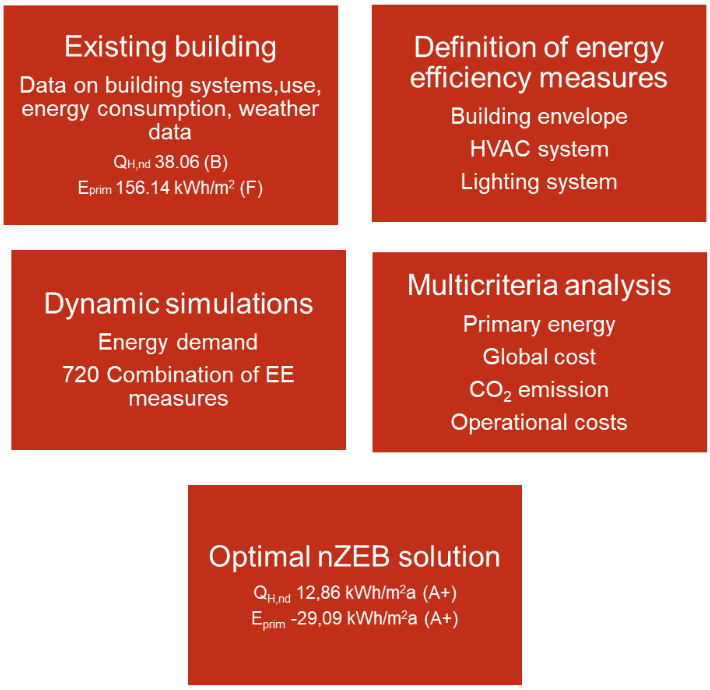

Figure 2 Methodology for selection of optimal nZEB solution

The case study building is divided into three structural sections, labeled as sections A to C. The structural system of sections A and C is a combination of uncoupled shear walls and frames, while section B is comprised only of shear walls. Reinforced concrete walls are 20 cm thick (except in the basement, where the walls are 30 cm thick), and the columns have a cross-section of 30 × 40 cm on which the beams with a height of 40 cm are supported. Floor structures are RC slabs with a thickness of 14 cm. There are six stories, including the basement and attic, with a total height of 18.53 m. The foundations are constructed as pad foundations for the columns and foundation beams for the shear walls. In the following figures, the building is shown (Figure 2), followed by the laser scanning procedure with Leica Bulk 360 (Figure 3) and BIM model (Figure 4).

Figure 3. Front view of the case study building

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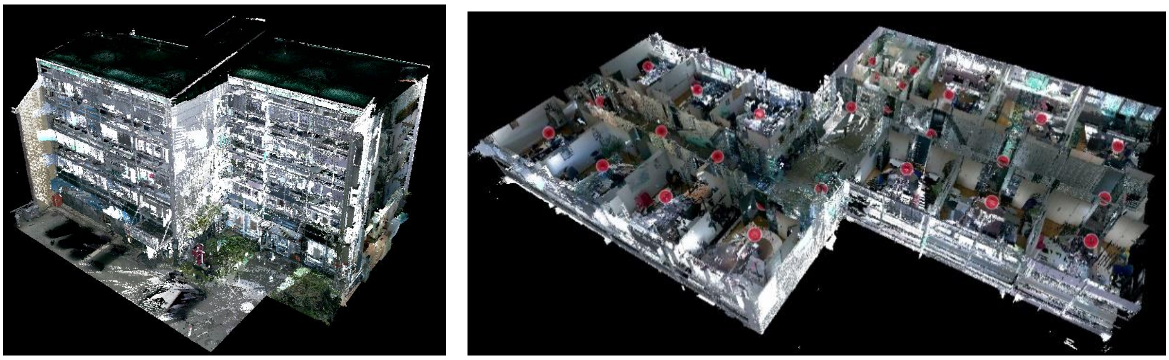

Figure 4. Laser scanning procedure: case study building (a) and scanning locations for one floor (b)

Figure 5. BIM model

In order to determine the material mechanical properties of the constructive elements, a detailed visual inspection, and non-destructive and semi-destructive investigative works, were required.

The compressive strength of concrete was determined with the standard test method for obtaining and testing drilled cylindrical specimens. The numerical model for the case study building was developed in the SCIA software for static analysis using the finite element method (FEM). All load-bearing elements were defined in the model, including RC shear walls, columns, beams, slabs, and the steel structure of the roof.

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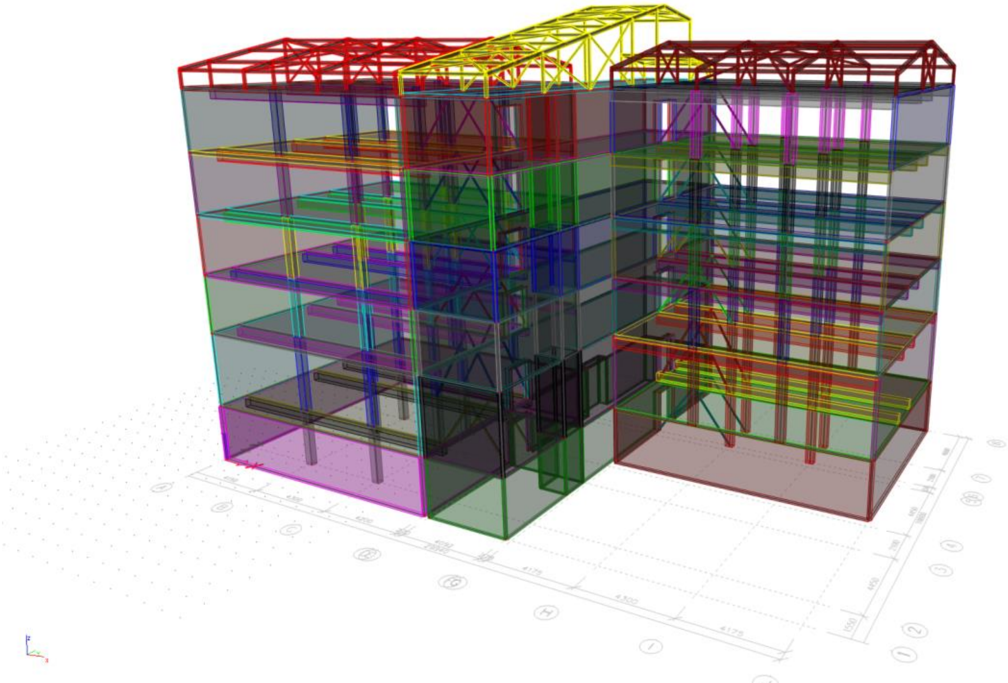

Figure 6. FEM model

In situ testing showed that the shear walls are reinforced with rectangular meshes on each side of the wall, consisting of Ø8 bars spaced 15 cm in the vertical and 25 cm in the horizontal direction. The whole FEM procedure with the results is shown by Stepinac et al. [11]. The summary of the results showed that the shear failure of walls (basement and ground floor), and the shear failure of columns are the main issues that need to be addressed with the strengthening project. Additionally, global modal analysis proved that all three sections lack lateral stiffness in direction X. In accordance with the results, several preliminary solutions for strengthening are given and presented in Figures 7-9.

Figure 7. Strengthening solution no.1 (Elements in red require FRP jacketing)

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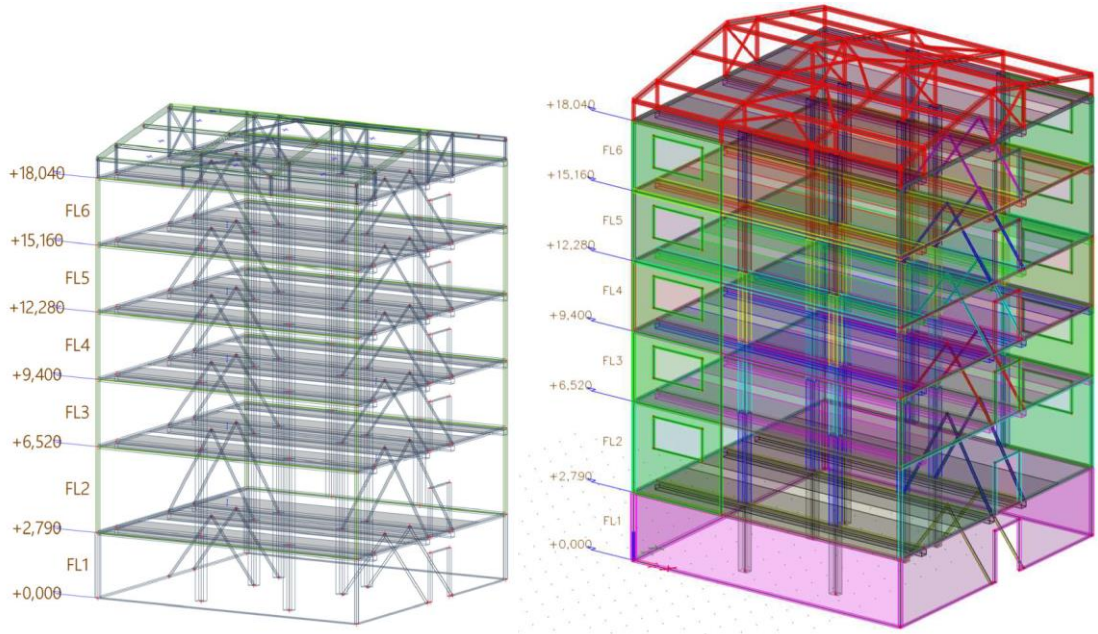

Figure 8. Strengthening solution no.2 – additional steel bracing,

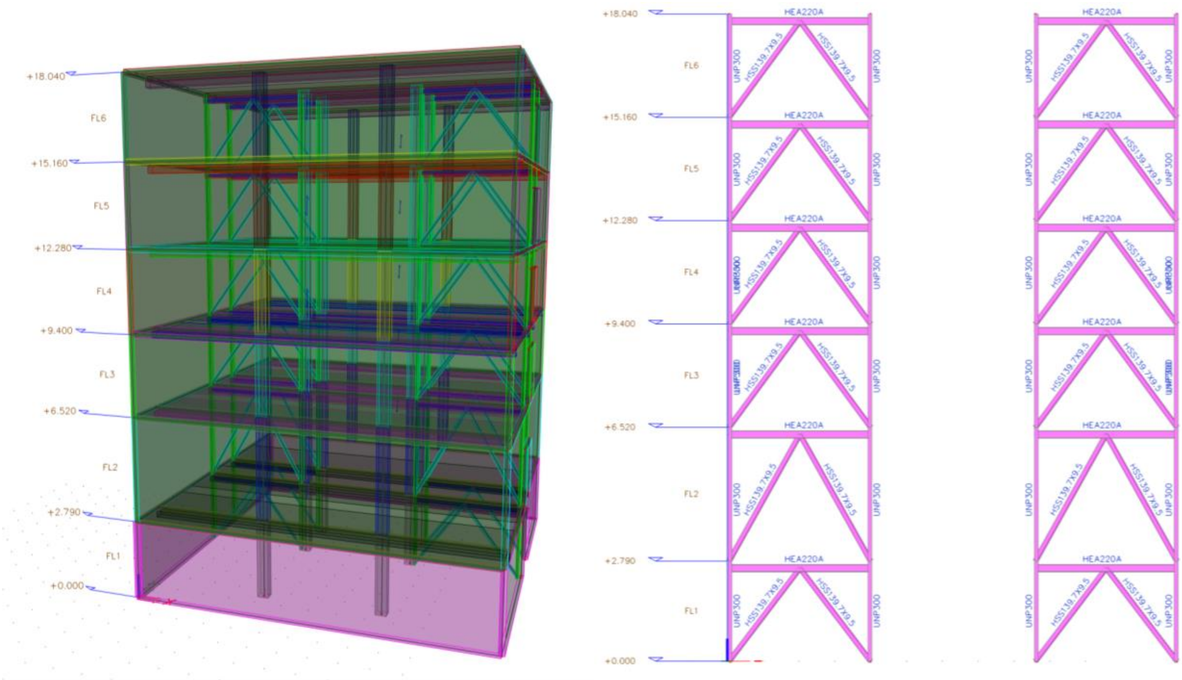

Figure 9. Strengthening solution no.4 – additional steel frames

4. Discussion and conclusions

Determining the actual seismic behavior of existing structures is of great importance for future management and the economic and purposeful strengthening of the load-bearing structure [11]. Modern software solutions and design methods are an essential part of the assessment, but they are only as useful as the input parameters are reliable [24]. So, precise information is crucial from condition assessment to FEM modelling and seismic and energy upgrading. Assessing existing buildings is always connected to many epistemic and aleatory uncertainties, and reducing them often requires extensive on-site testing. The critical aspect is knowing if gathering additional information is worthwhile. A Value of Information

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(VoI) analysis is introduced to answer this question, as seen in [25]. It quantifies the expected utility or benefit increase due to additional or predicted information. It allows decision-makers to know each assessment's benefits before deciding while maximizing the utility.

The integrated nZEB refurbishment approach is based on improving the building elements and systems performance. The airtight building envelope is a major requirement for the nZEB standard and is investigated by relevant measurements. When refurbishing existing buildings, a detailed investigation of the existing structure helps define the best air-tightness and heat retention systems. Building systems should be based on on-site renewable energy generation to reduce operational costs and CO2 emissions.

It remains to be determined if the optimal nZEB solution can be implemented, as the administrative barriers have hindered the permitting procedure. The groundwater wells are located on publicly owned property, and the consent of the City of Zagreb is required to perform the investigation works for the groundwater use and later on for implementation of infrastructure works. It took many stakeholders' careful and lengthy discussions to determine the competent City Office to issue the consent. If administrative barriers remain unresolved, a less effective nZEB solution will need to be implemented, not using available on-site renewable energy to its fullest potential.

In this short overview of one case study building, the authors wanted to show the whole procedure and the complexity of the processes.

In addition to seismic upgrading, energy updating is significant, and these two approaches must be presented as integrated procedures. PDP-nZEB project is trying to show it primarily to the Croatian audience. The first part of the seismic assessment procedure is presented in this paper, together with numerical modeling based on laser scanning and the implementation of BIM. Subsequently, more complex analyzes, including the nonlinear pushover method, are performed, and the reinforcement proposals are updated accordingly. The project team has been selected, and design documentation for the specific building systems is being prepared. The design process has been documented for training designers for nZEB retrofits. The goal of this project is also to promote the nZEB standards to local governments so that the strategic value and environmental benefits of such projects are recognized, and local governments can take ownership as initiators and participants in improving the built environment.

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