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BIM APPLICATION IN SEISMIC STRENGTHENING OF REINFORCED CONCRETE BUILDING USING FRP MATERIALS

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Abstract

With the introduction of 3D graphic representation to improve workflows, communications, collaborations, and data exchange among all members involved in the project, the BIM (Building Information Modelling) methodology is completely transforming the structural industry. In general, BIM is fundamentally based on an information-sharing methodology among all stakeholders, implemented throughout the building's life cycle and materialized using specialized software in the virtual construction of a 3D digital model. In this particular case, the process of seismic assessment and strengthening of RC five storey building will be presented through a series of steps, using BIM methodology. Based on the previously performed analyses of the structure and obtained results, it has been defined which elements of the structure need to be strengthened. In this case, using the BIM platform PlanRadar for organizing and managing the process, it is demonstrated how the seismic assessment of the building and the process of strengthening the elements would be carried out. This methodology, using the PlanRadar platform, allows for the proper planning of all activities that are part of the strengthening procedure of the building. Each defined location in the structure contains its own data card. It specifies the name and type of the task, who defined the task and for whom it is intended, when it should start, the location in the structure, the type of strengthening, details of the strengthening for the structural element, as well as the steps for the gradual installation of the FRP materials. This procedure offers opportunities for complete control of the process, allowing for the review of both models (the architectural and the structural), as well as the ability to control whether the elements requiring strengthening are permissible for architectural reasons or due to other design phases.

Keywords: BIM methodology, strengthening, FRP materials, RC building

1. Introduction

By introducing 3D graphical representation to improve workflows, communication, collaboration, and data exchange among all project participants, BIM methodology completely changes the construction industry [1].

BIM comprises a set of interactive policies, processes, and technologies that create a working methodology capable of managing building design and project data in a digital format throughout the building's lifecycle [2]. It involves the virtual construction of a building in a 3D digital model, known as a Building Information Model. This methodology provides a comprehensive and interactive vision of the project, integrating the interdependencies between various building project phases (architectural, structural, and mechanical, electrical, and plumbing (MEP)) through technological connection of all stakeholders involved [3]. During the virtual construction of the digital model, the stakeholders continuously redefine and optimize their designs, updating the digital model accordingly [4].

In general, BIM is based on a methodology of information sharing among all stakeholders throughout the building lifecycle, using specialized software in the virtual construction of a 3D digital model [5]. The information and its management within BIM models are key aspects of the BIM methodology. The ability to communicate, reuse, and share data efficiently, without loss or misinterpretation among stakeholders using different software applications, is a fundamental requirement. This ensures the integration of collaborative procedures with the technologies inherent to the BIM concept [6].

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Currently, the entire process of seismic assessment of structures is often conducted using BIM methodology. In this specific case, a portion of the BIM methodology is applied to a seismic assessment, the need for strengthening, and the implementation of these measures for an existing reinforced concrete building.

2. Seismic assessment of existing reinforced concrete frame building

The first step in the seismic assessment of an existing structure is defining the structural system of the building as well as the quantity and quality of the materials used in its construction. In this case, since a construction and structural design project exists for the selected reinforced concrete building, most of the fundamental data such as the type of structural system, number of floors, type, quantity, and quality of materials used, are derived from the existing technical documentation.

According to the project documentation, the structure is regular in plan and elevation. It comprises six frames in one direction with spans of 6.00m and four frames in the perpendicular direction with spans of 4.50m. The building consists of five levels, where the ground floor has a floor height of 4.00m, while the height of all other floors is 3.00m. All floors have an identical layout, except for the top floor, which differs in the stairwell area and cantilevered extensions (Figure 1).

When examining the building frame by frame, frames 1 through 7 are identical, as are frames A through E (Figure 1). Structural elements are labeled according to their type, sequence number, and the floor on which they are located. For example, **Sn_f** represents a column, where **n** indicates the column's sequence number, and **f** indicates the floor on which the column is located. Similarly, **Bn_f** denotes a beam, where **n** indicates the beam's sequence number, and **f** indicates the floor on which the beam is situated.

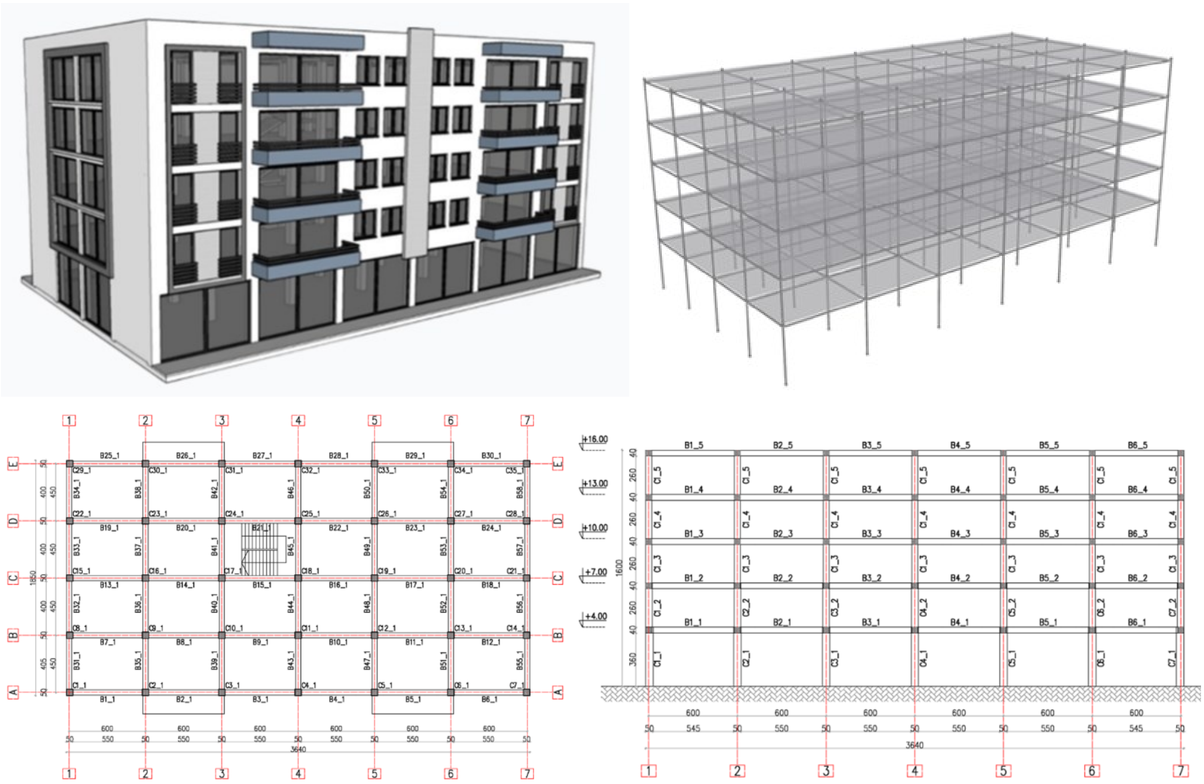

Figure 1. 3D of the building (BIM model) and 2D drawings

Considering the available project documentation, the geometric characteristics of the structural elements have been determined. It has been observed that the columns on the ground floor have dimensions of 50x50 cm, those on the first floor are 45x45 cm, and those on the second, third, and fourth floors are 40x40 cm. On the other hand, all beams on all floors have uniform dimensions of

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40x40 cm. The structural elements have been designed using concrete C25/30 and reinforcement type B500. The dimensions and reinforcement details for the columns and beams are presented in Tables 1 and 2.

Table 1. Embedded reinforcement in the columns

Columns				
Symbol	**Dimensions (cm)**	**Level**	**Longitudinal Reinforcement**	**Stirrups**
C1-1 to C35-1	50/50	Ground floor	8Φ18	Φ8/15cm
C1-2 to C35-2	45/45	First floor	8Φ16	Φ8/15cm
C1-3 to C35-3 C1-4 to C35-4 C1-5 to C35-5	40/40	Second floor Third floor Fourth floor	8Φ16	Φ8/15cm

Table 2. Embedded reinforcement in the beams

Beams						
Symbol	**Dimensions (cm)**	**Level**	**Longitudinal Reinforcement**			**Stirrups**
			Bn_f GL	Bn_f S	Bn_f GD	
B1-n to B30-n	40/40	All	2Φ14+3Φ14	5Φ14	2Φ14+3Φ14	Φ8/10/20cm
B31-n to B58-n	40/40	All	2Φ14+2Φ14	4Φ14	2Φ14+2Φ14	Φ8/10/20cm

Before initiating the process of modeling the structure, detailed geometric and material examinations were carried out to in order to determine the real characteristics and quantities of the embedded materials. Based on these investigations, it was found that the compressive strength of the concrete in some ground-floor columns significantly deviates from the designed strength outlined in the existing project documentation (Figure 2). The concrete strength of the selected columns in the figure 2 is smaller for 7 to 9 MPa than the designed one.

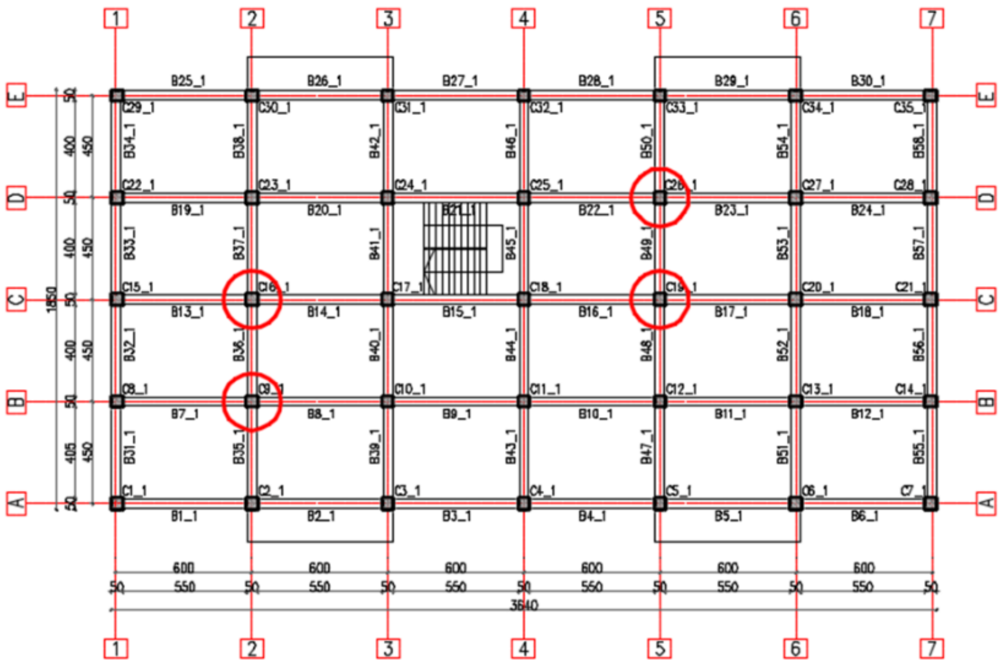

Figure 2. Columns with concrete strength smaller than designed one

Based on these observations, local strengthening of the ground-floor columns using CFRP materials was proposed. CFRP are placed with the fibres perpendicular to the element axis.

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3. Analysis of existing reinforced concrete frame building

Based on the defined element data (geometric characteristics, concrete strength, as well as the type, quantity, and arrangement of reinforcement) and the specified vertical loads (Table 3), structural BIM model was designed.

Table 3. Additional permanent and live load

Level	Permanent load (kN/m^2)	Live load (kN/m^2)	Snow (kN/m^2)
Ground floor	1.50	1.50	/
First floor	1.50	1.50	/
Second floor	1.50	1.50	/
Third floor	1.50	1.50	/
Fourth floor	1.00	/	1.00

After the local strengthening of the structural elements using CFRP was done (Figure 3b), the global load-bearing capacity of the strengthened structure was obtained. For this purpose, a nonlinear static analysis of the structure was performed using the SeismoStruct computer program [7] (Figure 3a).

a) b)

Figure 3. a) 3D model of strengthened structure (Seismostruct computer program), b) Strengthening detail of the columns using CFRP materials

In order to determine the maximum displacements of the structure, according to Eurocode 8 - Part 1 (EN 1998-1, Annex B), the N2 method was selected. In this case, the required displacements were derived using a response spectrum corresponding to a return period of 475 years and a peak ground acceleration of ag = 0.25g (Figure 4).

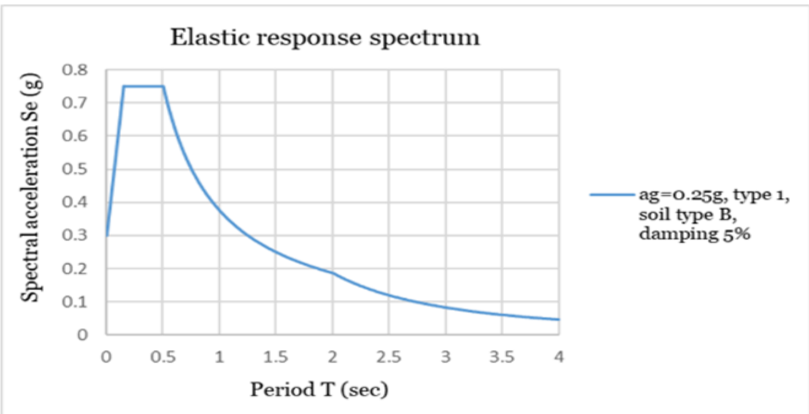

Figure 4. Elastic response spectrum

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To utilize the response spectrum for defining the required displacements, it was transformed into an acceleration-displacement response spectrum (ADRS). This transformation, involving converting the X-axis into a displacement axis, was carried out in accordance with Eurocode 8 - Part 3 (EN 1998-3, Annex B) (Figure 5).

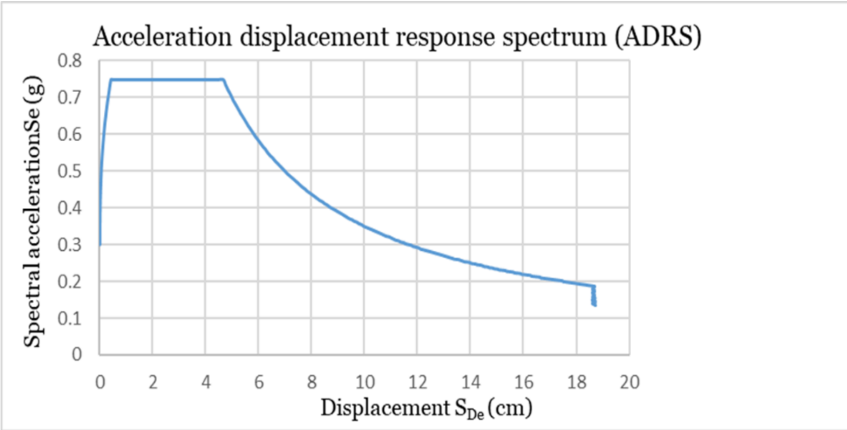

Figure 5. ADRS spectrum

Following the nonlinear static analysis, the obtained results for the structural capacity, along with the performed evaluations of the damage levels and performance criteria of the structural elements, indicate that the deformation capacity of the reinforced structure satisfies the required/target displacements for the selected type of earthquake (Figure 6).

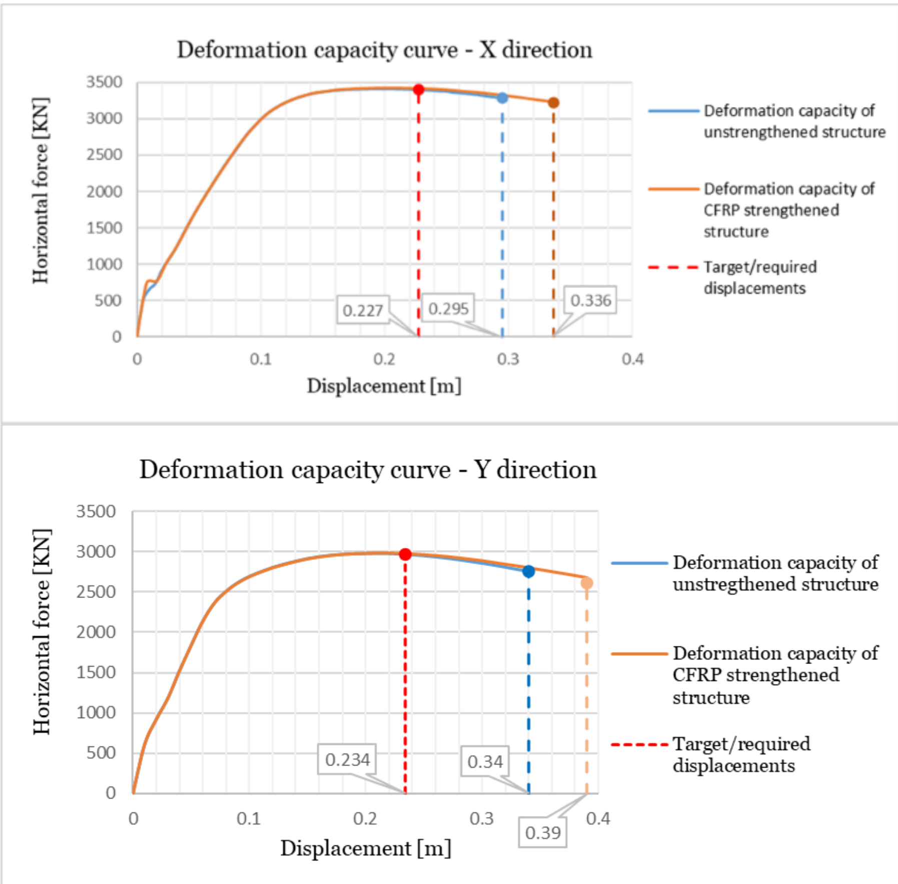

Figure 6. Deformation capacity curve in X and Y direction respectively

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4. BIM (Building information modelling) application in strengthening of the existing building

Based on the project documentation of the existing structure, a 3D model was created, including all architectural elements. This model was then exported as an IFC file, which, in line with BIM methodology, was used for seismic assessment of the structure.

Since prior analyses of the structure had already identified the elements requiring strengthening, the seismic assessment and strengthening process were organized and managed using the BIM platform PlanRadar [8]. This platform facilitates comprehensive control over the entire process, allowing users to review both architectural and structural models. Additionally, it enables verification of whether the proposed strengthening is feasible from an architectural or other project perspective. PlanRadar also supports collaborative teamwork by ensuring that all participants involved in the process have access to updates. Any changes made to the model by an authorized participant are recorded within the platform.

Based on the results of the analyses, key structural elements requiring strengthening were marked (Figure 7). Each marked location and defined task can be viewed by all participants in the process or restricted to specific individuals to whom the task is assigned. Once a task is completed or is in progress, its status is recorded in the program. This ensures seamless tracking and management of the strengthening process.

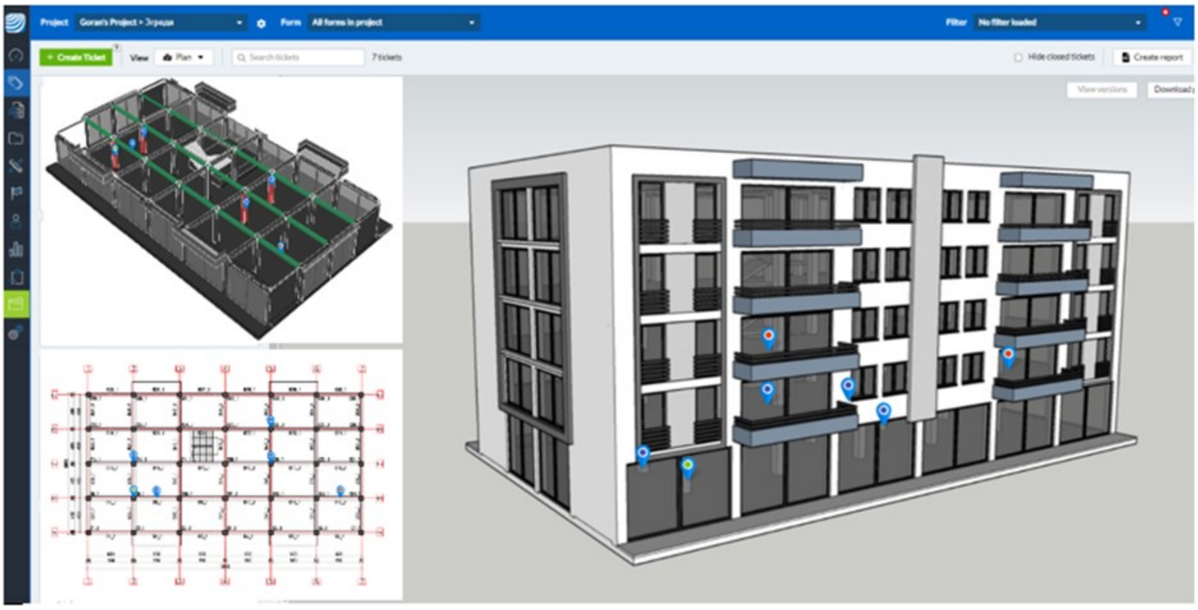

Figure 7. Determining the locations in the structure that require strengthening

Each defined location in the structure contains its own data card. The task's name and type are specified, along with the person who defined the task and the intended recipient. The start date, location within the structure, type of strengthening, and detailed strengthening for the structural element are also outlined. Additionally, the steps for the gradual installation of CFRP materials are defined (Figure 8).

This methodology, using the PlanRadar platform, enables effective planning of all activities involved in the seismic assessment and strengthening procedure.

In this particular case, the sequential approach to each step of the activities outlined in the procedure, along with the specified time frame required for their execution (4D dimension of BIM), is defined within the program (Figure 9). The program specifies the start and end dates for each activity in the procedure, as well as the time needed for its execution.

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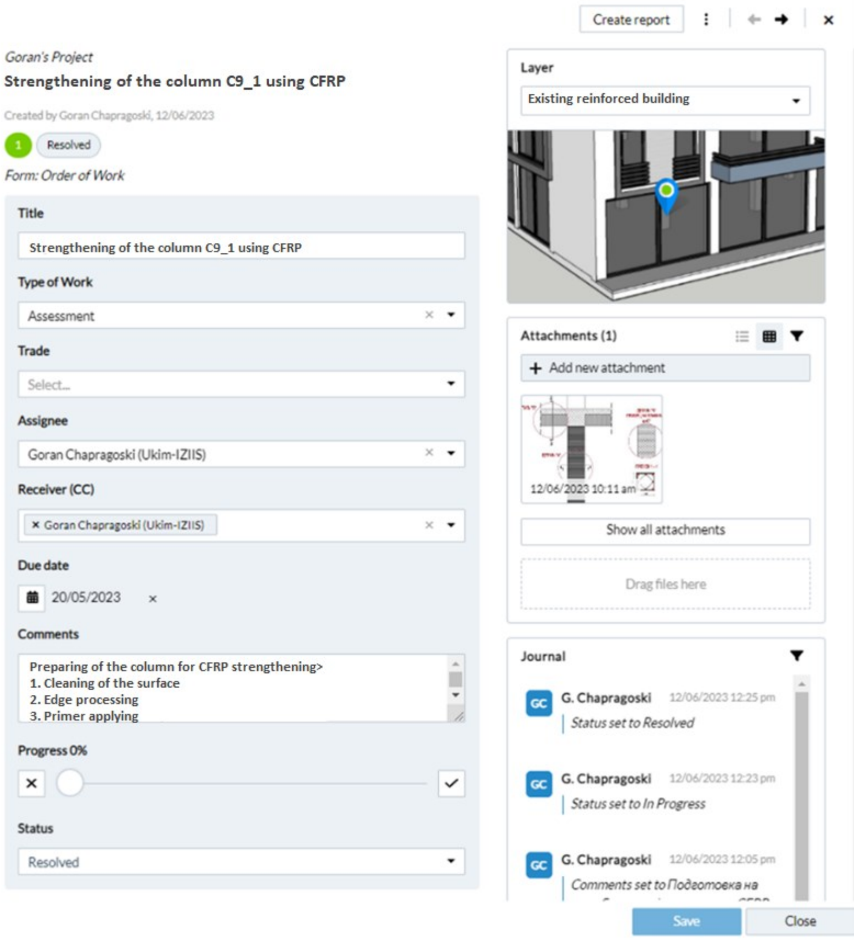
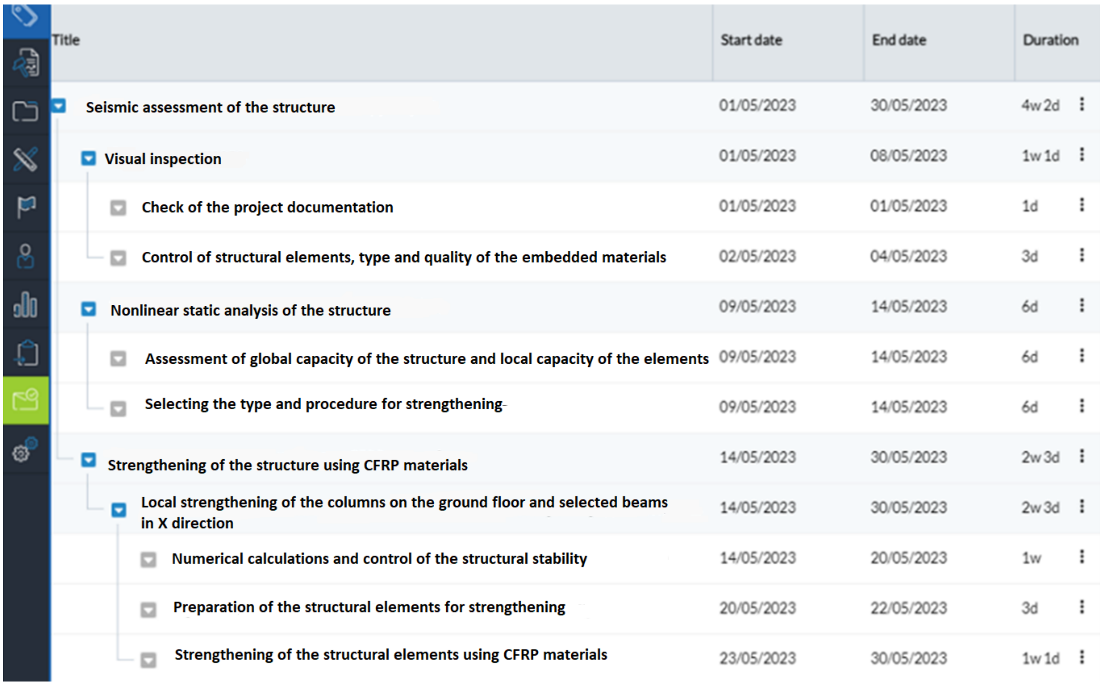


Figure 8. Data card for specific marked location



Title	Start date	End date	Duration
Seismic assessment of the structure	01/05/2023	30/05/2023	4w 2d
Visual inspection	01/05/2023	08/05/2023	1w 1d
Check of the project documentation	01/05/2023	01/05/2023	1d
Control of structural elements, type and quality of the embedded materials	02/05/2023	04/05/2023	3d
Nonlinear static analysis of the structure	09/05/2023	14/05/2023	6d
Assessment of global capacity of the structure and local capacity of the elements	09/05/2023	14/05/2023	6d
Selecting the type and procedure for strengthening	09/05/2023	14/05/2023	6d
Strengthening of the structure using CFRP materials	14/05/2023	30/05/2023	2w 3d
Local strengthening of the columns on the ground floor and selected beams in X direction	14/05/2023	30/05/2023	2w 3d
Numerical calculations and control of the structural stability	14/05/2023	20/05/2023	1w
Preparation of the structural elements for strengthening	20/05/2023	22/05/2023	3d
Strengthening of the structural elements using CFRP materials	23/05/2023	30/05/2023	1w 1d

Figure 9. Each step of the activities outlined in the procedure

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The current work diagram for the required construction activities, showing the duration of each activity and the subsequent or simultaneous activities that follow a specific task, is provided in Figure 10.

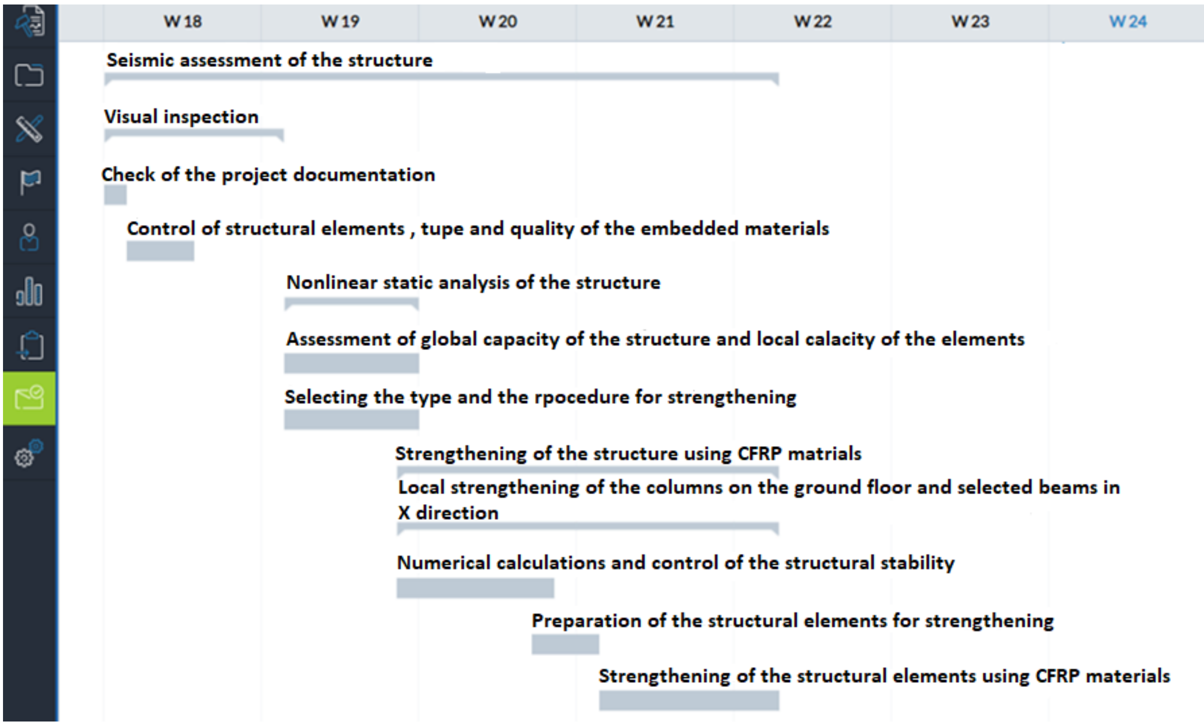

Figure 10. Curren working diagram

5. Conclusion

The entire process of seismic assessment and strengthening of a specific structure using CFRP materials, controlled and enhanced over a defined time period, is demonstrated through an integrated model utilizing the BIM software tool PlanRadar. This showcases that the entire procedure, from the assessment of the structure's seismic resistance to its strengthening with innovative building materials, can be seamlessly and efficiently managed through the Building Information Modeling (BIM) methodology.

The final outcome is a completed project containing comprehensive information about every step executed during the strengthening of the structure with CFRP materials. This data is stored in electronic format, ensuring accessibility for future interventions at any time.

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