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STRUCTURAL RECONSTRUCTION OF THE BELFRY, MONASTERY AND CHURCH OF ST. FRANCIS ON THE KAPTOL IN ZAGREB

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Abstract

This paper presents the structural reconstruction process of the St. Francis complex, which includes the belfry, monastery, and church on Kaptol in Zagreb. The complex dates back to the 13th century and is located in the heart of Zagreb's historic center. Constructed entirely in masonry, it reflects the architectural principles and construction techniques of its time, with design solutions tailored to the function of each individual space and structure. Over the centuries, the complex has endured various forms of damage caused by multiple earthquakes, fires, and wartime destruction, necessitating several phases of restoration. The most recent damage resulted from two significant earthquakes in March and December 2020, rendering the complex unfit for use. The company Spegra Ltd. from Split, Croatia, conducted a comprehensive structural rehabilitation, ensuring the building's full static and structural stability in accordance with the restoration project. To address the diverse causes and types of damage, as well as the complex structural behavior of various elements, appropriate technological solutions and materials were applied. Since the complex is a protected cultural heritage site, all restoration work was conducted with the utmost care, in close collaboration with conservation specialists and under their constant supervision.

Keywords: Spegra, Franciscan monastery, rehabilitation, structural reconstruction, earthquake

1. Introduction

The Franciscan monastery, church, and belfry form a harmonious architectural complex at Kaptol 9, in close proximity to Zagreb Cathedral, and are an integral part of the city's historic core (Fig. 1). Characterized by a diverse floor plan and dynamic spatial composition, the complex spans multiple levels, with interiors thoughtfully arranged to accommodate their respective functions. The building's overall dimensions are approximately 77.10 × 45.50 meters, with a registered floor area of 2,582.00 m², as recorded in the Land Registry. The total height, measured from the lowest point of the landscaped terrain to the top of the tower, is approximately 59.55 meters.

Figure 1. Franciscan complex, Zagreb [1]

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The Franciscan presence in Zagreb dates to the 13th century. Initially, the monastery belonged to the Hungarian Province of St. Mary and served as the administrative center of the Zagreb Custody (Fig. 2). In the 17th century, it became the principal house of the newly founded Illyrian Custody of St. Ladislaus the King, which soon evolved into a province. By 1900, the monastery had become the seat of the Provincial Minister of the Croatian Franciscan Province of St. Cyril and Methodius. According to tradition, St. Francis of Assisi, founder of the Order of Friars Minor, is said to have stayed at the monastery during his journey to the Holy Land.

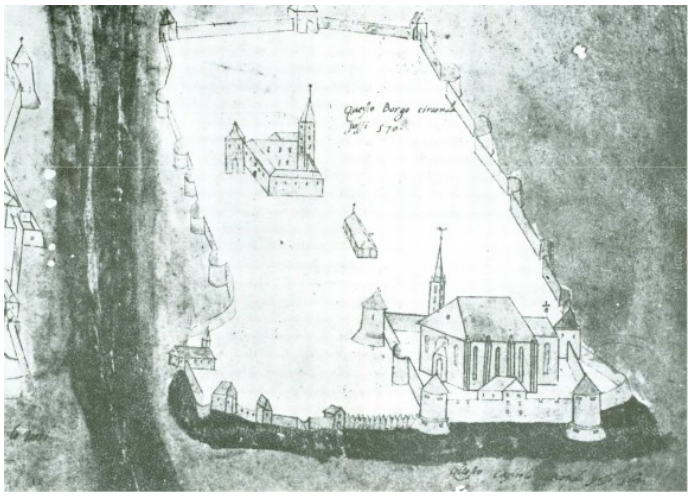

Figure 2. Photo of the plan of Kaptol at the beginning of the 16th century (Zagreb City Museum) [2]

In the 16th century, during the conflict between the supporters of Ferdinand Habsburg and John Zápolya, the monastery sustained significant damage. A few years later, around 1560, due to a dwindling number of friars, it was abandoned. At the beginning of the 17th century, Franciscan Provincial Franjo Drašković led the return of the friars to the monastery and oversaw the restoration of the church.

Throughout its history, the monastery has endured significant damage and destruction. It was devastated by the great fire of 1645, followed by fires in 1674 and 1731, the great earthquake of 1880 (Fig. 3), and heavy destruction during World War II on February 22, 1944. [3].

Figure 3. Removing the cap from the belfry of the Church of St. Francis of Assisi in Zagreb after the earthquake of 1880. [2]

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The most recent damage, which led to the comprehensive structural restoration of the monastery, church, and belfry complex, was caused by the earthquakes of March and December 2020. The first earthquake, measuring M=5.5 on the Richter scale and known as the "Zagreb Earthquake," inflicted initial structural damage, striking Zagreb, and its wider metropolitan area on March 22, 2020, at 6:24 AM (Fig. 4). This main seismic event was followed by a series of aftershocks.

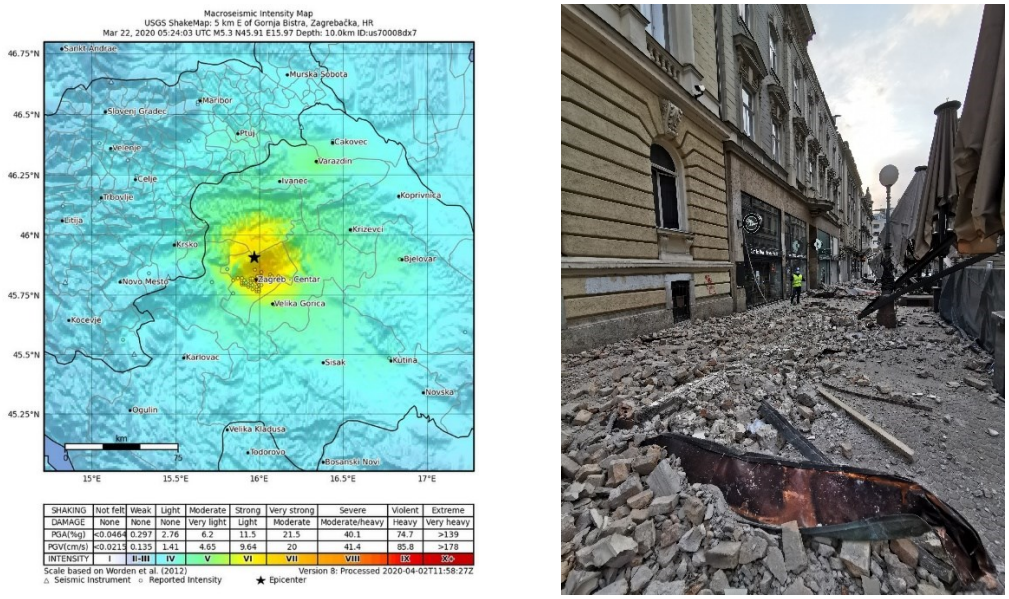

Figure 4. Macroseismic map of the “Zagreb” earthquake (March 22, 2020, at 6:24 a.m.), streets of the city of Zagreb after the earthquake [3, 1]

The second earthquake, measuring M=6.4 on the Richter scale, known as the "Petrinja Earthquake" or the "Banovina Earthquake," struck on December 29, 2020, at 12:19 PM, with its epicenter located 3 km southwest of Petrinja, heavily impacting Sisak-Moslavina County. These earthquakes caused extensive damage to the structural elements of the Franciscan complex, comprising the Church of St. Francis, the monastery building, and the bell tower. Due to the severity of the damage, the complex was taken out of use, as its structural instability posed a serious threat to human safety and a risk of further collapse. Some of the documented damage is shown in Fig. 5.

Figure 5. Photos of some damage to the structural parts of the Franciscan complex [1, 4]

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2. Restoration works conducted in accordance with the project

To repair the damage caused by the earthquakes, a comprehensive restoration and refurbishment was planned, incorporating extensive and high-quality seismic reinforcement of the entire complex, including the church, monastery, and bell tower.

The layout of the Franciscan complex, along with its key structures, is illustrated in Fig. 6.

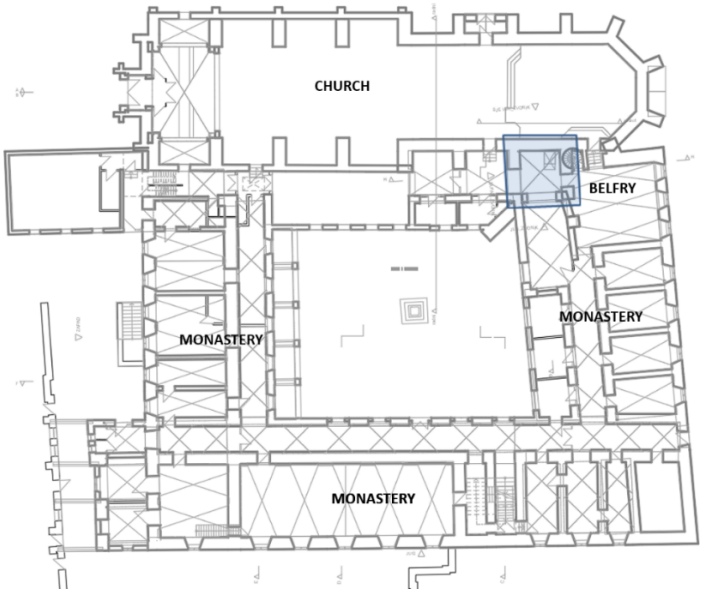

Figure 6. The layout of the Franciscan complex [5]

As per the General Urban Plan (GUP) of the City of Zagreb, the complex is situated within the city's construction zone and is recognized as a protected immovable cultural heritage site (No. Z-202). Given this designation, all planned interventions were conducted with the utmost care and expertise to ensure the preservation of both the authenticity and historical significance of the structure, as well as each of its individual elements and details. The works were conducted under the continuous presence and supervision of conservation specialists.

In accordance with the restoration project [5,6], the structural rehabilitation of the complex was organized into three key areas: the church, the belfry, and the monastery.

Works on the Church of St. Francis of Assisi:

- Installation of geotechnical micropiles adjacent to the church nave buttresses at a depth of 15 meters
- Structural rehabilitation of all walls, buttresses, and vaults of the church
- Repair and enhancement of the mechanical properties of masonry (grouting of discrete and mesh cracks in walls, repointing of masonry joints)
- Strengthening of existing walls (application of reinforced mortar, reinforcement with carbon fiber fabrics at discrete crack locations)
- Integration of existing load-bearing structural elements (installation of tie rods and carbon fiber tendons)
- Dismantling of vaults and installation of LLN arch beams in the western part of the nave
- Replacement of the church roof structure, including all roof elements
- Conservation and restoration of stone elements, paintings, and stained glass windows

Works on the belfry:

- Structural rehabilitation of the bell tower walls
- Installation of an internal lining system (thin-walled reinforced concrete linings and high-performance mortar coatings), structurally connected to the existing church walls and monastery floor structures via short slabs and beams

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- Wrapping of the bell tower with carbon fiber fabrics, particularly in the areas of lintels above large openings
- Repair and enhancement of the mechanical properties of masonry (grouting of discrete and mesh cracks in walls, repointing of masonry joints)
- Installation of a new vertical circulation system within the bell tower and horizontal bracing at monastery floor levels
- Complete conservation and restoration of stone elements, including replacement of deteriorated stone components
- Replacement of the dome structure, along with all associated structural elements

Works on the monastery building:

- Reconstruction, removal, and rebuilding of masonry walls
- Demolition of massive vaults above sections of the second floor
- Removal of massive walls above the refectory, which were supported by vaults spanning the refectory
- Horizontal stiffening through the construction of vertical structural elements, including wall linings and high-performance mortar coatings
- Horizontal stiffening through the installation of floor overlays and new inter-floor slabs
- Repointing and consolidation grouting of masonry walls
- Implementation of FRCM, FRP, and VVM systems using single-sided formwork and thin reinforced concrete diaphragm slabs within inter-floor structures
- Construction of a new roof structure

2.1. Church renovation

The load-bearing walls of the church are built from massive unreinforced masonry, consisting of solid brick bonded with lime mortar. The central part of the church is covered by a masonry vault, which rests upon these walls. Due to the height of the walls and the support reactions generated by the masonry vaults, buttresses were constructed to enhance the structural stability. Given their critical role and their position as the final structural element in the load-bearing system, the buttresses suffered significant damage. Figures 7–9 showcase various rehabilitation works conducted on the buttresses, as well as their final, restored state.

Figure 7. Damage to the church's buttresses [1, 5, 4]

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Figure 8. Renovation of the church's buttresses [1, 5]

Figure 9. The final appearance of the church's buttresses [1]

As previously noted, the vaults of the church are constructed as massive masonry structures. The first earthquake ("Zagreb Earthquake") caused significant structural damage to the vault, necessitating immediate shoring to prevent collapse. This temporary support system proved crucial in preventing further deterioration, not only of the vault itself but also of other structural elements of the church during the second earthquake ("Petrinja Earthquake"). Despite these stabilization efforts, the western section of the vaulted ceiling, having sustained severe initial damage, could not be effectively preserved or repaired. Consequently, it was replaced with a honeycomb-structured system made of glulam (laminated timber), over which prestressed hollow-core slabs were installed to enhance structural integrity. Figures 10–12 illustrate the extent of the vault damage, as well as its final restored condition following rehabilitation.

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Figure 10. Damage to the church vaults [4, 5]

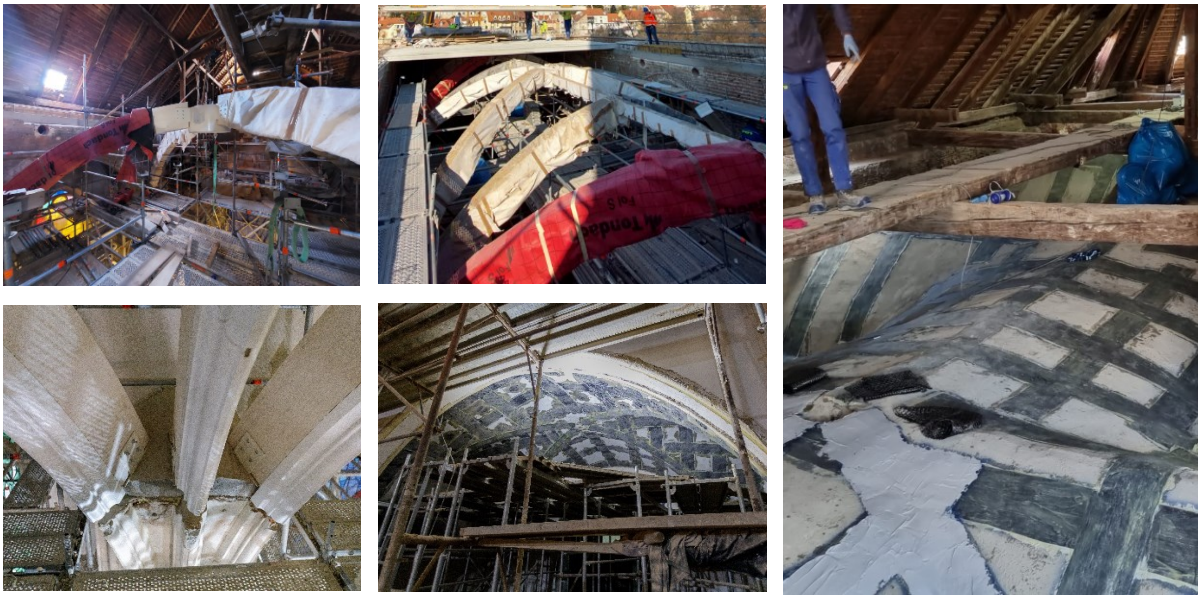

Figure 11. Renovation of church vaults [1]

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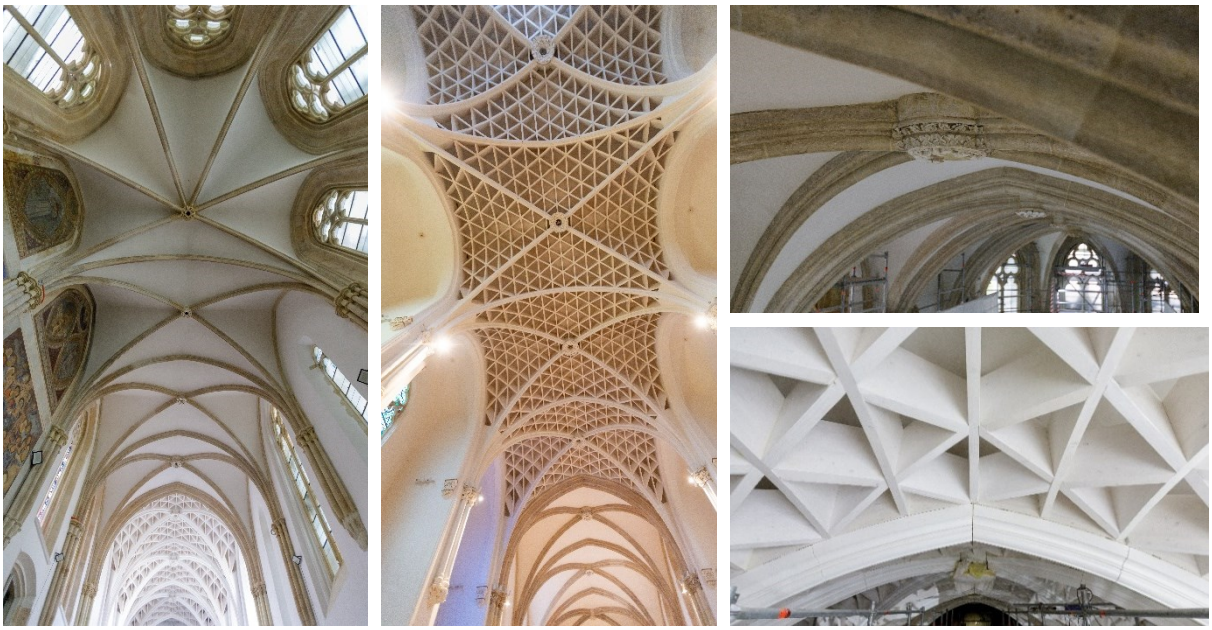

Figure 12. The final appearance of the church vaults [1]

The damage sustained by the church walls, particularly the western gable wall, which suffered the most severe deterioration, along with the rehabilitation measures undertaken, is illustrated in Figures 13–15.

Figure 13. Damage to church walls [1, 5]

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Figure 14. Repair of church walls [1]

Figure 15. The final appearance of the church [1]

2.2. Renovation of the belfry

In plan view, the belfry transitions from a trapezoidal base to a square footprint, measuring 6.0 × 6.6 m, with a total height of 59.55 m. Over the centuries, it has undergone various structural modifications and sustained multiple instances of damage. By the time of the recent earthquakes, it stood as a masonry structure with large openings, featuring wooden staircases and galleries, while the bells were supported by a metal framework. The damage observed in the cantilevered section of the belfry is consistent with its structural frame system with rigid crossbeams, where cracks developed in the lintels due to seismic forces. Figures 16–18 illustrate key damage patterns, the rehabilitation process, and the final restored condition of the belfry.

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Figure 16. Belfry damage [5, 1]

Figure 17. Belfry renovation [1]

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Figure 18. The final appearance of the belfry [1]

2.3. Renovation of the Monastery

The monastery, much like the rest of the Franciscan complex, has endured multiple instances of structural damage and deterioration throughout its history. With a footprint of 55 × 38 m, it comprises a partially underground basement, a ground floor, two upper floors, and an attic. Built as a massive masonry structure, its irregular configuration in both plan and elevation contributed to significant structural distress during the Zagreb and Petrinja earthquakes. Figures 19–21 provide an overview of the damage sustained, the rehabilitation process, and the final restored state of the monastery.

Figure 19. Damage to the monastery [1, 4, 5]

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Figure 20. Monastery renovation [1]

Figure 21. The final appearance of the monastery [1]

3. Conclusion

As a result of the devastating impact of the two recent earthquakes and the structural condition of the Franciscan complex (belfry, monastery, and the Church of St. Francis) significant structural damage was sustained throughout the site. Consequently, the entire complex was deemed unsafe for use and temporarily secured to prevent further deterioration or collapse. A comprehensive structural reconstruction and strengthening project was conducted by Spegra Ltd, Split, Croatia, under the leadership of Chief Site Engineer Ante Mlinar, MCE, and Site Engineer Ante Kelava, MSc. Civ. Eng. The project incorporated conceptual and engineering reinforcement measures in accordance with the design solution developed by lead architect Damir Foretić, MCE, and structural engineer Prof. Dr. Sc. Boris Trogrlić, MCE. The project spanned 34 months, with a total cost of €20,000,000.00. The restoration and strengthening works involved a diverse range of engineering methodologies and advanced technologies, carefully selected to align with the specific needs of each structural intervention. Since the Franciscan complex is a protected cultural heritage site, all work was conducted under strict supervision and in close collaboration with conservators, ensuring the preservation of its historical and

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architectural integrity. Figure 22 provides a selection of views and detailed snapshots capturing various stages of the reconstruction process.

Figure 22. Some views and details [1, 4]

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