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STEEL IN ARCHITECTURAL HERITAGE PROTECTION

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Abstract

The current article presents some steel structural solutions implemented in archaeological and architectural heritage protection applied in Romania using case studies. The paper summarizes also some of the engineering challenges of the project team during the design process.

Keywords: *steel structure, design challenges, historical monument, ruin protection.*

1. Introduction

The preservation of built heritage today increasingly requires an interdisciplinary approach, in which close collaboration between the fields of architecture, archaeology, and engineering is essential. In this context, steel structures offer modern solutions for the protection of buildings and archaeological sites of historical value. The use of steel structures makes it possible to create temporary or permanent reinforcements, to relieve existing building fabric with minimal intervention, and to develop transparent yet durable coverings and structural elements.

Such interventions, however, pose significant engineering and heritage conservation challenges, as contemporary structural solutions must be harmonized with conservation principles and the historical context of the site.

This article presents four case studies in which steel structures were successfully applied during both the design and execution phases.

2. Case Studies on the Protection of Monuments and Archaeological Ruins

In the course of unique projects, practical solutions and decisions often emerge that are not found in standard manuals or theoretical curricula. Case studies allow for the structured and reflective dissemination of such experiences. In complex fields such as the protection of built heritage, case studies help to reveal how architecture, engineering, heritage conservation, and archaeology can effectively collaborate.

Moreover, new materials, structural systems, or design methods are often tested for the first time in the context of one-of-a-kind projects.

2.1. Castrum in Turda

The first case study presents the architectural intervention aimed at protecting the archaeological remains of the Fifth Macedonica Roman Legion fortress located in Turda, Romania (the ancient Potaissa). It highlights the applied steel structural solutions and the engineering challenges encountered during the design process. The project's objective was to create a large-span covering struc-

Fig. 1. *Castrum Turda in the Spotlight during the Night of Museums. (Source: TurdaNews)*

ture along with a partially suspended steel walkway system, which both protects the uncovered ruins from weathering effects and allows visitors to directly observe the site without causing damage.

The covering measures approximately 40.35 meters in width and 70.35 meters in length and includes a suspended pedestrian system extending roughly 230 meters in four directions — two longitudinal and two transverse — providing safe visitor circulation.

Special attention was given to preserving the historical context, applying minimally invasive solutions (such as steel micro-piles drilled among the ruins for the creation of smaller foundations), and simultaneously ensuring structural stability and visitor safety.

The study provides a detailed analysis of the technical solutions employed by the project team, as well as the complex challenges arising from the integration of heritage conservation principles with contemporary engineering design. For a comprehensive discussion and more detailed description of this work, please refer to our previous publication [1].

The presented project also serves as an excellent example highlighting the roles that a structural engineer assumes within a given construction project [2].

2.2. Bolyai street, no. 11

The second case study presents the rehabilitation process of a historic building located in the city center of Târgu Mureș, during which the original Baroque-style roof structure was reconstructed using a modern metal framework. The study primarily focuses on the design of the roof structure and the metal access staircase. The complex, irregularly shaped roof with multiple planes required careful dimensioning and detailing before being installed on the refurbished masonry walls.

The main access staircase, made of steel plates and featuring a special structural system, required advanced computational methods for analysis and verification.

Our article [3] discusses the engineering challenges encountered during the design and execution phases, as well as their solutions: a survey conducted using 3D scanning served as a reference system for the steel structure (Figure 2); discrepancies between the masonry walls and the steel structure had to be addressed; and the irregular geometry was configured taking into account site-specific constraints.

The methods applied during the design and construction phases of the project played a crucial role in addressing the complex geometric and structural challenges. Dimensioning and detailing such a complex structure would have been practically impossible without the use of advanced digital technologies. The precise survey of the existing condition was conducted using laser scanning technology, which provided high-resolution data on the current geometric configuration of the building, as well as deviations arising during construction that significantly influenced the structural design. The resulting three-dimensional point cloud served as the basis for digital modeling and detailed design.

During the project, a BIM (Building Information Modeling) software environment was employed, enabling effective collaboration among various disciplines—such as structural engineers, architects, and mechanical engineers—within a shared

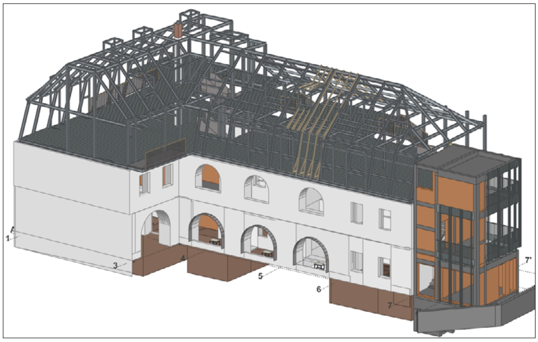

Fig. 2. *Bolyai street 11 building 3D model.*

Fig. 3. *Bolyai street 11 roof structure during construction.*

spatial model. This model contained all relevant structural, geometric, and material characteristics, and allowed for real-time coordination and the prevention of potential clashes.

A challenge was posed by the detailing of structural elements with random orientations in the absence of an accurate reference system. To solve this issue, the project team developed a custom coordinate system, to which the three-dimensional connection points of the steel structural elements were aligned. The position, orientation, and shape of the elements were verified in multiple stages using repeated laser scans, thereby ensuring the accuracy of the final model and avoiding manufacturing errors.

One of the key lessons of the methodology is that the objectives of different disciplines can sometimes reflect divergent or even conflicting considerations. The success of the project largely depended on open communication between the parties involved, multidisciplinary collaboration, and the development of compromise solutions.

2.3. Restoration of Sebesvár Castle

The third case study presents the design work related to the opening of the medieval Sebesvár castle ruins (known as Bologa in Romanian) to visitors, including the measures required to ensure safety. **Figure 4** shows the structural model prepared by Gordias Engineering Office and the current state of the bastion. During the works, the castle area was cleared of overgrown vegetation, the walls were repaired, landscaping works were carried out, the wall crown was insulated with turf bricks, access ramps were built, and the old tower was made accessible from the inside with the help of steel structural elements. The company responsible for the restoration works partially rebuilt the missing wall sections to such an extent that if we suddenly went back a few hundred years in time and an enemy army approached, the castle in its current state would be ready to withstand a siege **[4]**.

Fig. 4. *Designed and executed staircase.*

The role of steel structures in making the medieval Sebesvár castle ruins accessible to visitors is crucial from several perspectives, especially considering the complex challenges of the heritage environment. The following points summarize why steel can be considered the ideal choice in this project:

Reversibility and Minimal Intervention:
One of the fundamental principles of heritage conservation is that interventions should be reversible, meaning they should not cause irreversible changes to the original structure. Steel structures fit well with this principle, as they can be fixed point-wise with minimal intervention area and can be easily removed if necessary.

– *High Load-Bearing Capacity with Small Cross-Section*:
In the case of a ruined castle, load capacity is limited—the centuries-old walls cannot bear any arbitrary additional loads. Steel allows for strong yet lightweight and slender structures that do not overly burden the existing masonry.

– *Structural Stability on Difficult Terrain*:
Medieval castles were often built on steep, hard-to-reach locations. Steel structures can be effectively used to create temporary or permanent bridges, stairs, and walkways that minimally load the ground or ruins, while providing safe circulation for visitors.

– *Compatibility with Contemporary Interpretation*:
Modern interventions often aim to visually distinguish themselves from the original structure. The use of steel and its clean design language fit well with contemporary architectural vocabulary while not attempting to imitate the historical appearance—thus respecting the principle of authenticity.

– *Prefabrication and Rapid Assembly*:
Due to the difficult-to-access locations, it is important that structures can be prefabricated and quickly assembled on site. Steel structures perfectly meet this requirement: they can be manufactured in factories and rapidly erected with on-site work.

In summary, although on-site welding was necessary in this project, the fitting of the elements was successfully executed in an aesthetically pleasing manner, providing an enjoyable visual experience for visitors (**Figure 6**).

2.4. St. Michael's Church tower stairs

The fourth case study presents a summary of the design work for the steel stairs intended to make the tower of St. Michael's Church in Cluj-Napoca accessible to visitors. **Figure 7** shows a visualization created by the Gordias engineering office, an intermediate phase of the construction work, and the final state of the proposed staircase structure, also reflecting the difficulties encountered during execution due to the confined space and lack of access to the working areas.

During the renovation of the tower, more severe structural problems were revealed than in previous surveys. Due to the significant self-weight resulting from the 19th-century Neo-Gothic tower construction, a 20 cm settlement was observed in the medieval wall sections, which was measurable based on 3D scanning. These issues also influenced the design and construction of the new steel stair structure, as the components had to perfectly adapt to the condition of the existing walls, their irregular planes, and the level differences caused by the settlement. Due to the confined spaces, the stair structure had to be designed in elements that could be installed using only manual two-person handling. The renovation of the Saint Michael Church tower stairs and the opening of the tower to visitors contributed to strengthening the church's cultural and religious role, while ensuring the preservation of the monument and providing an enjoyable experience for visitors. The renovation of Saint Michael Church received the Europa Nostra Award (European Heritage Award) in 2024 in the category of preservation and adaptive reuse.

3. Contemporary Structural Interventions in Heritage Environments

The four case studies discussed — related to built heritage elements from different historical periods and with varying functions — showcase common principles, design strategies, and engineering responses. These cases aptly illustrate

Fig. 5. *Sebesvár castle before restauration.*

Fig. 6. *Sebesvár castle after restauration.*

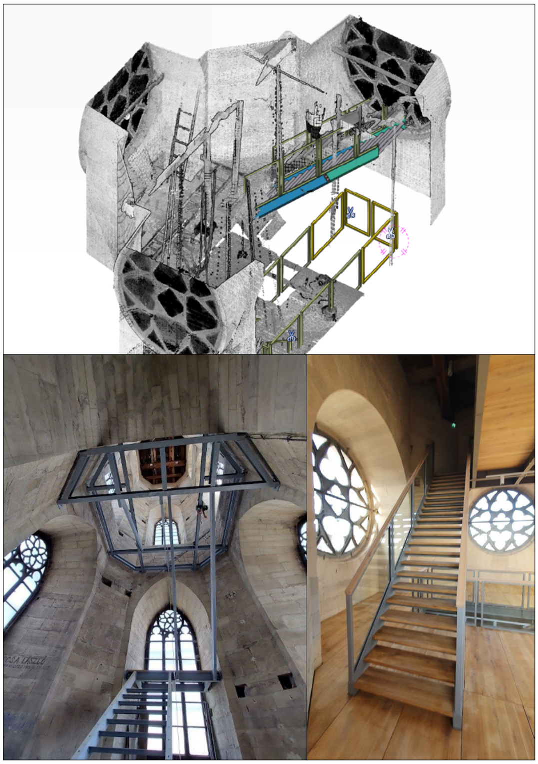

Fig. 7. *The structure of the designed and constructed stairs (intermediate and final phases).*

how contemporary structural thinking meets the ethos of heritage conservation in light of 21st-century expectations. The projects at Castrum Turda and the Sebesvár castle ruins primarily aimed at the physical protection of historic structures and making them accessible to tourists. In contrast, the reconstruction of the St. Michael's Church tower stairs and the rebuilding of the Baroque roof structure at Bolyai 11 focused on the functional renewal of existing monuments — reshaping the cultural experience and usability.

In all four projects, steel structures appear not merely as a construction technique choice but as a statement of intent: Through its slenderness and strength, steel allows for minimal intervention in the original structure. Its reversibility and distinctly contemporary appearance ensure a clear differentiation between old and new — avoiding architectural forgery. Thanks to its prefabrication and ease of assembly, steel adapts well to hard-to-reach or historically sensitive sites.

Digital surveying and design tools played a decisive role: Laser scanning and point cloud–based modelling enabled precise documentation of displaced, deformed, or irregular geometries. The use of BIM systems allowed coordination across disciplines and accurate detailed design of geometrically complex connections. In several cases (e.g., St. Michael's Church), hidden structural damages uncovered during construction required ongoing revision of the planned solutions. The detailing of connections between different materials (e.g., stone and steel) and the fine-tuning of structural load transfers demanded significant engineering innovation.

4. Conclusions

The conclusions based on the examined case studies can be summarized as follows:

4.1. Material Usage Considerations – Advantages of Steel Structures in Heritage Environments

One of the greatest challenges in making the medieval Sebesvár castle ruins accessible was how to provide safety and usability that meet modern standards in a way respectful to the historic structure. The use of steel structures proved justified and advantageous in several respects:

- *Reversibility*: Steel structures allow for removable, non-invasive solutions, thus preserving the integrity of the monument and permitting future modifications if needed.
- *Low weight – high load capacity*: Modern steel profiles enable lightweight yet statically stable constructions that do not overload the historic masonry.
- *Prefabrication and assembly*: Steel elements can be manufactured in controlled factory conditions and quickly assembled on-site with minimal work, especially beneficial in difficult-to-access ruin sites.
- *Contemporary appearance*: Steel is clearly distinguishable from the original stone and brick materials, avoiding architectural forgery and complying with the principle of anastylosis (distinguishable restoration).

4.2. Contemporary Structural Solutions in Heritage Conservation – The Role of Steel Structures in the Sebesvár Castle and Turda Castrum Projects

To ensure safe visitor circulation, steel structural interventions were necessary in several locations throughout the projects. These primarily served the following functions:

- Construction of access ramps and walkways to various parts of the castle, designed so as not to overload the existing ruins.
- Placement of viewpoints, railings, and complementary structures that enhance the visitor experience while fulfilling safety functions.
- Application of special fixing and connection techniques enabling the coordinated integration of elements made from different materials (e.g., stone and steel).
- Adaptation to terrain conditions: On sloped, rocky terrain, the flexibility of steel structures allowed for unique fittings and tailored solutions.

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