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Historical virtual reconstruction of Przemyśl Fortress forts using geodetic methods: the case of I/4 Maruszka Las Fort in Ukraine

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SUMMARY

For the historical virtual reconstruction of the I/4 Maruszka Las Fort, a comprehensive approach was applied, which included a combination of field observations (terrestrial laser scanning and digital photogrammetry) as well as historical data analysis. A key aspect was the accurate and detailed reproduction of the shape and size of all architectural and structural elements of the fort including preserved and damaged. An integrated approach and the use of specialised software allowed us to integrate the collected data into a three-dimensional solid model of the I/4 Maruszka Las Fort. The creation of such a model is important for the preservation of this object, as well as its promotion. The presented study demonstrates a wide range of possibilities for the use of modern technologies, especially geodetic ones, for the study of different historical sites.

Keywords: historical virtual reconstruction, Przemyśl Fortress, I/4 Maruszka Las Fort, digital twin

Introduction

The Przemyśl Fortress (Figure 1) is a powerful complex of defensive structures around the city of Przemyśl (Poland, then the Austro-Hungarian Empire), one of 200 large fortifications in Europe at the turn of the XIX and XX centuries (Watson, 2019). It was the third largest fortress after Antwerp (Belgium) and Verdun (France) (Rożański, 1983). The fortress was constructed in the XIX century, although work on improving the fortifications continued until the beginning of the First World War. The outer ring of the fortress was 45 km long and consisted of 17 main forts. In addition, 14 permanent gun stations, 2 permanent trench lines and 2 permanent infantry bases were built. The internal defence system consisted of 21 defensive forts.

Figure 1. *Przemyśl Fortress*

A small part of the buildings of the Przemyśl Fortress is located on Ukrainian territory. These are the outskirts of the village of Popovychi, from which the state border with Poland is a few hundred metres away. There are only 6 forts on the Ukrainian side (Bandylo, 2020):

- I/1 Łysiczka (49°45'54.7"N, 22°54'49.1"E) – built in 1897–1903. It had an irregular shape. The front approaches to the fort were protected by a moat in the form of a trench. In the centre were two-storey brick barracks with steel-concrete floors. In the middle, the barracks were connected to the main two-storeyed storage. The flank complex contained an armoured artillery battery, an artillery casemate and an observation tower.
- I/2 Byków (49°45'38.3"N, 22°55'10.1"E) – built in 1895–1900. Its shape resembled a semicircle with a bastion. It had two completed open flank artillery batteries. There was a dry moat in front of the fort and batteries. In the centre was the casemate building, which combined the functions of a combat unit and barracks. It housed four armoured gun turrets. Between them, along the axis of the fort, there was an observation tower.
- I/3 Pleszowice (49°45'17.2"N, 22°54'59.1"E) – built in 1882–1886. It had the form of trapezoids. The moat was protected by three caponiers. In the centre were concrete barracks. The left wing had a staircase leading to higher levels. Near the staircase was a lift shaft for lifting ammunition. There was a similar lift on the right side of the barracks. The main entrance was located along the axial line of the fort. A wide staircase was attached to the right wing, leading to the fighting positions on the rampart.
- I/4 Maruszka Las (49°44'52.2"N, 22°54'21.4"E) – built in 1882–1886. It was almost similar in form and purpose to I/3 Pleszowice.
- I/5 Popowice (49°44'37.4"N, 22°54'19.4"E) – built in 1895–1900. Its shape resembled a semicircle with a bastion in the rear part of the fortification. In the centre was a two-storey barracks and defence building. The central part of the building served as a barracks, and the side parts housed armoured batteries, each with two turrets with guns. There was an observation tower along the axis.
- I/6 Dziewięczyce (49°44'43.5"N, 22°53'48.7"E) – was rebuilt in 1897–1900 on the basis of an earlier defensive structure of 1882–1886. It had an irregular shape and included four main

complexes: a rear casemate, a middle one, a counter-skarp caponier, and a flank complex (an armoured battery with two guns in towers connected to the artillery casemate). To the right was an open artillery battery.

On 21 March 1915, before the surrender of the Przemyśl garrison, as a result of a long siege to destroy the weapons stockpile, the forts, warehouses and other facilities of the Przemyśl fortress were blown up (including the listed facilities on the territory of Ukraine) (Błoński, 2008). In 1968, the damaged and destroyed facilities of the Przemyśl Fortress located on the territory of Poland were declared a monument of defensive architecture and included in the National Protection Programme. In Ukraine, however, the forts of the Przemyśl fortress are little known and require appropriate research and preservation measures.

In the framework of this study, it was decided to conduct a historical virtual reconstruction of one of the 6 objects of the Przemyśl Fortress (on the territory of Ukraine). Historical virtual reconstruction is creating a digital twin of a historical object that reproduces its shape and dimensions in a certain historical period and is characterized by accuracy and reliability. This approach combines modern modelling technologies, field observations, and analysis of historical documents, drawings, maps and photographs. Among the above objects, the I/4 Maruszka Las Fort was chosen for the study. The choice was made due to the fairly good state of preservation of a part of the site, its optimal size for historical virtual reconstruction, and relatively good accessibility to the site.

Method

The research methodology included (Repekhovych, 2024):

- Construction of a three-dimensional point cloud of the preserved elements of the I/4 Maruszka Las Fort based on field observations (Savchyn et. al., 2023).
- Construction of a three-dimensional solid model of the preserved elements of the I/4 Maruszka Las Fort based on modelling (simplification) of the point cloud.
- Complementing the built three-dimensional solid model of the preserved elements of the I/4 Maruszka Las Fort by modelling the destroyed elements based on the analysis of historical data.

Data

The input data used for the historical virtual reconstruction of the I/4 Maruszka Las Fort included historical data as well as field observations. Among the historical data, it is worth highlighting the scheme (Figure 2) published by Idzikowski (2001). This scheme further provides information on the shape of the fort, as well as an understanding of the extent of damage and preservation of the site.

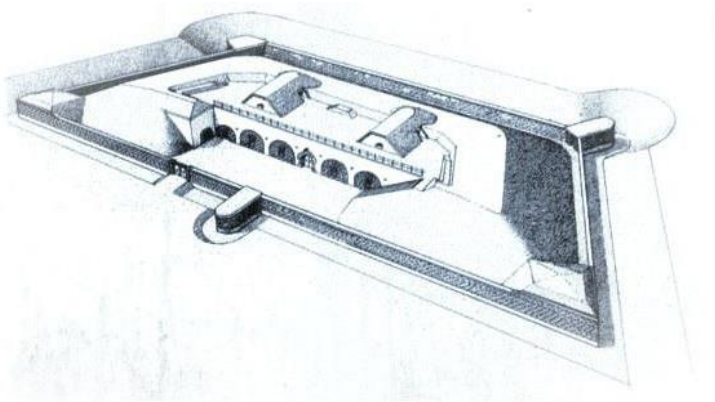

Figure 2. *Scheme of the I/4 Maruszka Las Fort (Idzikowski, 2001)*

The field observations included a terrestrial laser scanning of the preserved elements of the I/4 Maruszka Las Fort from 18 scanning stations using a Leica ScanStation C10 terrestrial laser scanner, as well as digital photography of the site using a Canon EOS 5D Mark III digital camera with a Canon EF 24mm f/2.8 IS lens.

The current view of the I/4 Maruszka Las Fort, as well as a three-dimensional point cloud of the preserved elements of the fort obtained from terrestrial laser scanning processing are shown in Figures 3 and 4, respectively.

Figure 3. *The current view of the I/4 Maruszka Las Fort*

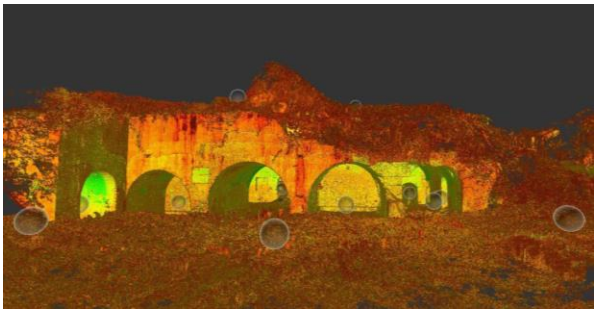

Figure 4. *Three-dimensional point cloud of the preserved elements of the I/4 Maruszka Las Fort*

It is important to note that all the data in this study was processed using specialised software: Leica Cyclone 3DR (for scan registration), Autodesk ReCap (for point cloud filtering), Autodesk Revit (for modelling).

Results

Within the framework of this study, the modelling was carried out using Building Information Modelling (BIM) technology in metric units, on a 1:1 scale. At the first stage, a three-dimensional solid model of the preserved elements of the I/4 Maruszka Las Fort was created (Figure 5).

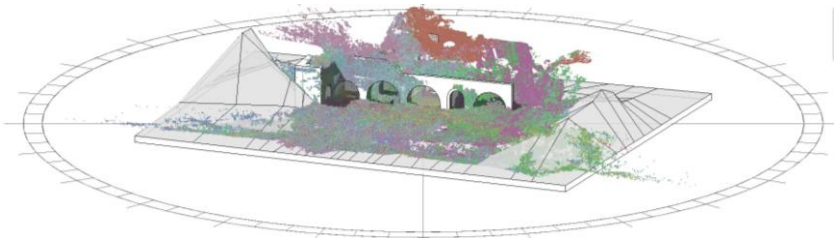

Figure 5. *Three-dimensional solid model of the preserved elements of the I/4 Maruszka Las Fort*

The modelling (simplification) was based on the manual classification of the preserved elements of the fort that were fixed on the point cloud. The classification was performed within the level of development (LOD) – LOD300. In accordance with ISO19650-1:2018, LOD300 provides for the display of specific, accurate geometrical information including size, shape, and location.

At the next stage, the obtained parameters of the preserved elements of the I/4 Maruszka Las Fort in combination with historical data were used for modelling the destroyed elements of the fort. As a result, three-dimensional solid model of the I/4 Maruszka Las Fort was created (Figure 6).

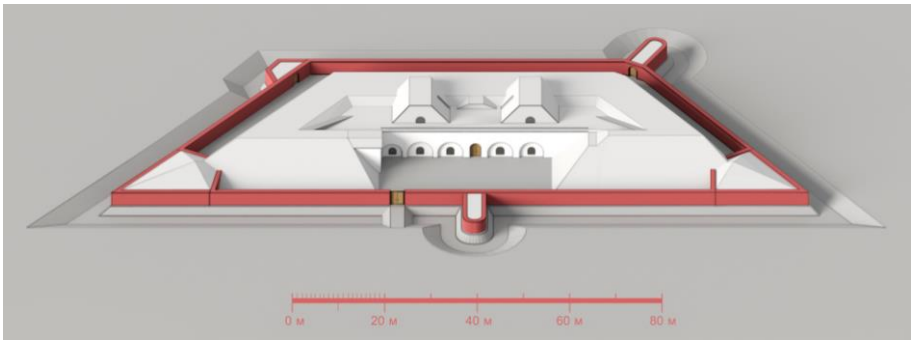

Figure 6. *The three-dimensional solid model of the I/4 Maruszka Las Fort*

The built three-dimensional model is a digital twin of the I/4 Maruszka Las Fort, which is a source of information about the exact shape and dimensions of the object.

Conclusions

The paper presents a set of studies for the historical virtual reconstruction of the I/4 Maruszka Las Fort, which is one of the elements of the Przemyśl Fortress. The three-dimensional solid model of the I/4 Maruszka Las Fort created as part of the research is not only a means of preserving the historical object, but also opens up new opportunities for educational and scientific research, as well as for promoting historical heritage among the public. This work is an example of how modern technology can be used to preserve historical heritage. A promising area for further research is to conduct GPR surveys to obtain information on the condition of the elements of I/4 Maruszka Las Fort that are under the soil layer. It is also promising to continue similar studies at other Przemyśl Fortresses located in Ukraine.

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