

**GeoTerrace-2023-030****Rapid Fixation and Digitization for Cultural Heritage Preservation in Conflict Zones**

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**SUMMARY**

This study addresses the pressing need for expeditious architectural digitization in the midst of the ongoing conflict in Ukraine, where traditional methods are hindered by high rates of destruction and damage. The proposed methodology combines terrestrial laser scanning, digital photogrammetry, and linear-angle geodetic measurements to streamline the process of data acquisition, providing an effective solution for preserving architectural heritage. Emphasis is placed on prioritizing data acquisition over 3D modeling, recognizing it as the critical step for ensuring the accurate preservation of architectural monuments for future restoration endeavours. Results demonstrate the methodology's efficiency, showcasing significant time savings in data acquisition and processing across multiple projects, thus affirming its suitability for urgent digitization efforts. This approach not only addresses the immediate need for preserving cultural heritage amidst conflict but also lays the groundwork for comprehensive 3D modeling and restoration once the situation stabilizes, affirming its relevance and impact.

*Keywords:* digital twins, 3d modelling, terrestrial laser scanning, digital photogrammetry, linear-angle geodetic measurements

## Introduction

The fire that caused the almost complete destruction of the Notre Dame de Paris Cathedral (Paris, France) showed the relevance and importance of creating architectural digital twins. There are quite a few definitions of the term digital twin, first proposed in 2010 by NASA (Shafto et al., 2010), but the most universal is "A live digital coupling of the state of a physical asset or process to a virtual representation with a functional output" proposed by Catapult in 2021. In general, architectural digital twins refers to virtual copies or simulations of physical buildings, monuments, infrastructure, or spaces. Such digital twins are a powerful tool for improving the efficiency, sustainability, and performance of buildings and urban spaces. They enable a more data-driven and collaborative approach to architectural design and construction. But the main advantage is that even in the case of complete destruction, an architectural object that has a digital twin is preserved for future generations in digital form and can be accurately restored at any time. After Russia's full-scale invasion of Ukraine (on February 24, 2022) and the daily shelling of Ukrainian cities, the issue of digitizing architectural monuments has become extremely relevant. As of 13 September 2023, UNESCO has verified damage to 289 sites since 24 February 2022 – 120 religious' sites, 27 museums, 109 buildings of historical and/or artistic interest, 19 monuments, 13 libraries, 1 archive (UNESCO, 2023). The best option for such digitization is, of course, to create an architectural digital twin. However, military operations, as well as the rate of destruction and damage to architectural monuments, make it impossible to use classical approaches to creating an architectural digital twin. In this regard, there is a need to develop operational (fast) methods for fixing and digitizing architectural monuments in Ukraine.

## Data

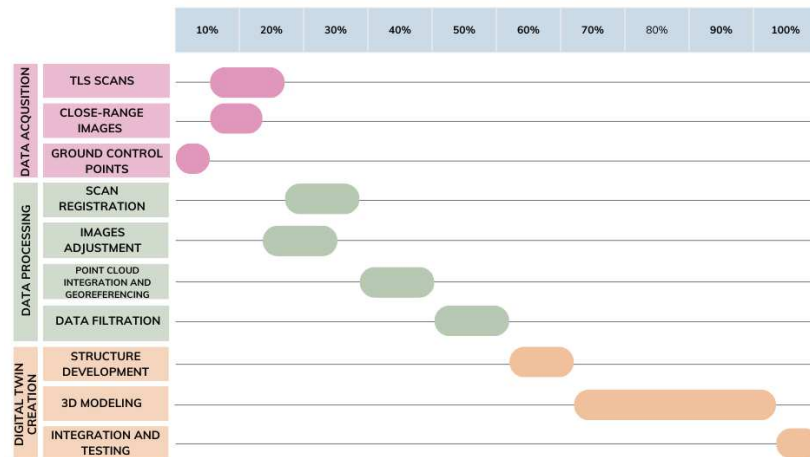
The initial data for the study were four projects to create architectural digital twins carried out by the Institute of Geodesy of Lviv Polytechnic National University (Ukraine) before and after Russia's full-scale invasion of Ukraine:

- 1) Mirror Hall of Lviv Opera and Ballet Theater – field surveys were carried out in April 2021 and included terrestrial laser scanning (23 stations), close-range photogrammetry (560 images), and ground control point measurements (12 ground control points). Technical characteristics of the object: length – 34 m; width – 7 m; height 8 m, area 239 sq.m.
- 2) Theater Hall of Lviv Opera and Ballet Theater – field surveys were carried out as part of the AURA project (Bertocci, Lumini & Cioli in 2022, Lumini & Cioli in 2022 and Schauer et al. in 2022) in June 2021 and included terrestrial laser scanning (237 stations), close-range photogrammetry (2850 images), and ground control point measurements (24 ground control points). Technical characteristics of the object: length – 25 m; width – 18 m; height 15 m, area 355 sq.m.
- 3) Main Hall of Lviv Polytechnic National University – field surveys were carried in May 2022 and included terrestrial laser scanning (20 stations), close-range photogrammetry (480 images), and ground control point measurements (16 ground control points). Technical characteristics of the object: length – 22 m; width – 13 m; height 13 m, area 286 sq.m.
- 4) Historical Library Lviv Polytechnic National University – field surveys were carried in May 2022 and included terrestrial laser scanning (35 stations), close-range photogrammetry (720 images), and ground control point measurements (14 ground control points). Technical characteristics of the object: length – 21 m; width – 9 m; height 6 m, area 189 sq.m.

All scans were performed with a Leica ScanStation C10 terrestrial laser scanner, images were taken with a Canon EOS 5D Mark III digital camera with the Canon EF 24mm f/2.8 IS lens, and the coordinates of the ground control point were determined with a Leica TCR 405 total station.

## Method

The methodology of the work involves analyzing the process of creating four architectural digital twins carried out by the Institute of Geodesy in 2021 and 2022, as well as formulating operational (fast) methods for fixing and digitizing architectural monuments in Ukraine based on the results of the analysis. Since the main issue that arises in the creation of architectural digital twins during Russia's full-scale invasion of Ukraine is the high rate of destruction and damage, the main criterion that we decided to analyze is the duration of the work. Figure 1 shows a diagram of the time required to complete the main stages of building an architectural digital twin.



**Figure 1.** Duration of main stages of architectural digital twin creation

Analyzing the results presented (see figure 1), it can be noted that the time required to complete three stages differs. For example, data acquisition takes approximately 17%, data processing – 38%, and digital twin creation – 48%. If we consider the sub-stages, the least time-consuming is the ground control points measurement, and the most time-consuming is 3D modelling. Determining the time spent on 3D modelling is a rather complicated issue because it depends on the level of development (LOD). The calculations (see figure 1) are presented for LOD 350 (Construction Documentation) in accordance with ISO 19650-1:2018.

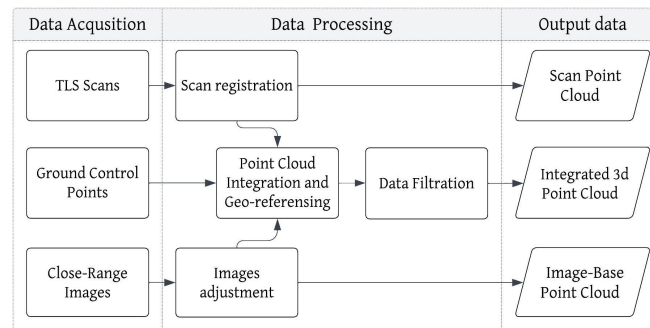
ISO 19650 is the standard that provides guidelines for managing information during the construction and operation of built assets using BIM. In this context, LOD refers to the level of development of the information within a BIM model. The following levels are offered there:

- **LOD 100 – Planning:**
  - Basic massing and location information of elements within the model.
  - Typically used for initial design and space planning.
- **LOD 200 – Conceptual Design:**
  - Generalized geometrical shapes and approximate quantities.
  - Used during conceptual design phases to evaluate the overall layout.
- **LOD 300 – Detailed Design:**
  - Specific, accurate geometrical information including size, shape, and location.
  - Used during detailed design and for coordination between disciplines.
- **LOD 350 – Construction Documentation:**
  - Additional information regarding connections, dimensions, and specifications.
  - Used for generating construction documents.
- **LOD 400 – Fabrication and Assembly:**
  - Precise details about the fabrication, assembly, and construction.
  - Used for fabrication and construction processes.
- **LOD 500 – As-Built and Operations:**
  - Detailed information about actual installed components and systems.
  - Used for facilities management and operations.

Obviously, the choice of a different LOD will lead to a change in the duration of time required to perform 3D modelling. However, the crucial part in war time conditions is a time spending for digitalisation. That's why we do not think it is advisable to waste time on 3D modelling (even the simplest one, such as LOD 100), as this work can be carried out even after Russia's full-scale invasion of Ukraine is completed. Instead, it is crucial to urgently collect information on the ground, as it will be a challenge to restore architectural monuments without this data after Russia's full-scale invasion of Ukraine. Therefore, in order to speed up the process of fixing and digitizing architectural monuments in Ukraine, we propose to conduct data acquisition only (which will speed up the process by 6 times), or, if possible, to also perform data processing (which will speed up the process by 2 times). We describe the main technological requirements for these stages in the results section.

## Results

To speed up the process of fixing and digitizing architectural monuments in Ukraine, we suggest using the methodology presented on Figure 2. This proposed methodology includes 7 separate stages, and we will try to briefly describe the main technological features of each of them.



**Figure 2. Methodology flowchart**

Data Acquisition is the most difficult stage, as it involves field measurements at the facility. To speed up the process, we suggest using a set of three types of measurements: terrestrial laser scanning, digital photogrammetry and linear-angle geodetic measurements.

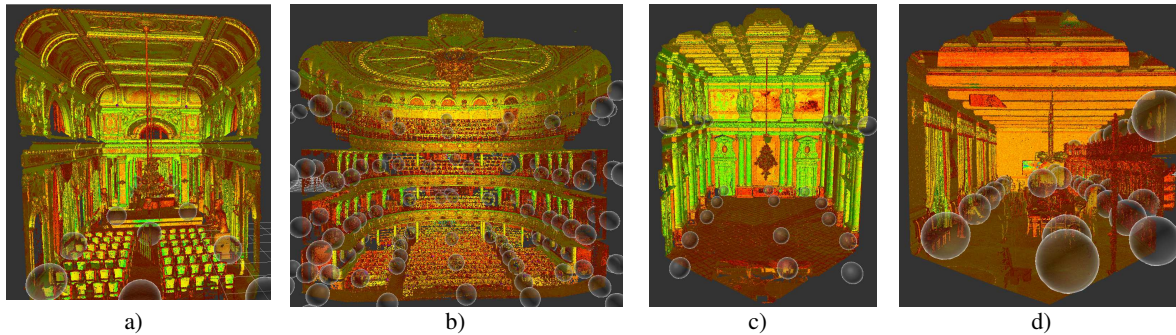
- *Terrestrial laser scanning.* The process of TLS involves capturing a large number of high-density point clouds from various viewpoints to cover the entire area of interest. The accuracy of the mutual reflection of the terrestrial laser scanning elements should be: at a distance of 1 meter – no more than 2 mm, and at a distance of 100 meters – no more than 20 mm. The presence of «dead zones» is allowed only in places where it is technically impossible to perform measurements.
- *Digital photogrammetry.* The process of digital photogrammetry consists in making photo of the special details of the object from various viewpoints to cover the entire area of interest. Digital photogrammetry is used to obtain information about an object where it is technically impossible to obtain it with a terrestrial laser scanner, as well as to obtain detailed colour information. Pictures taking process includes pictures overlapping by 60-80% as well as the use of additional lighting.
- *Linear-angle geodetic measurements.* The process of linear-angle geodetic measurements involves determining the coordinates of ground control points to georeference the point clouds. It is recommended to establish and determine the coordinates of more than 4 ground control points, evenly distributed on the site. Coordinates shall be determined in a conventional coordinate system with an accuracy of 2-3 mm in plan and height.

Data Processing. This stage is as automated as possible, including five sub-stages: scan registration, image adjustment, point cloud integration and georeferencing, and data filtration. It should be noted that only the data filtering subprocess, unlike other subprocesses, is performed almost manually.

As an example, we present the results (point clouds) obtained by using the proposed methodology for 4 different objects (Figure 3). Additionally, let's present the time spent on obtaining the point clouds presented:

- 1) Mirror Hall of Lviv Opera and Ballet Theater: a total of 15 hours were used (7 data acquisition and 8 data processing).
- 2) Theater Hall of Lviv Opera and Ballet Theater: a total of 131 hours were used (44 data acquisition and 87 data processing).
- 3) Main Hall of Lviv Polytechnic National University: a total of 14 hours were used (6 data acquisition and 7 data processing).
- 4) Historical Library of Lviv Polytechnic National University: a total of 22 hours were used (9 data acquisition and 13 data processing).

The presented results confirm that the use of this approach allows for the rapid fixation and digitization of architectural monuments for the possibility of their 3d modeling in the future, which is critically important in the current situation in Ukraine.



**Figure 3.** Prepared point cloud of a) Mirror Hall of Lviv Opera and Ballet Theater, b) Theater Hall of Lviv Opera and Ballet Theater, c) Main Hall of Lviv Polytechnic National University, d) Historical Library Lviv Polytechnic National University

## Conclusions

The conflict in Ukraine has underscored the urgency of digitizing architectural monuments. The proposed methodology, prioritizing data acquisition, proves efficient and crucial for preserving cultural heritage. This approach ensures rapid creation of digital twins, enabling future restoration efforts even after the conflict's resolution.

## Acknowledgements

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