THE USE OF LASER SCANNING TECHNOLOGY FOR THE RESTORATION OF HISTORICAL BUILDINGS

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Abstract: *The restoration of historical monuments presents significant challenges, requiring a combination of precision and non-intrusive techniques to preserve their architectural integrity. This paper explores the use of Terrestrial and Aerial Laser Scanning for the renovation of the Republican Stadium, a historical structure built between 1950-1951 in Chișinău, Republic of Moldova. The application of modern methods, such as scanning with the Leica BLK360 and DJI Phantom 4 RTK, along with advanced software like Leica Cyclone Register 360 and AgisoftMetashape, enabled the highly accurate capture of data regarding the structure and decorative details of the stadium. The integration of this data into a complex three-dimensional system facilitated the creation of a detailed digital model, essential for preserving the original architectural elements and planning restoration interventions. Moreover, the transformation of point clouds into textured 3D meshes enabled the creation of realistic visualizations for analysis, restoration planning, and virtual exploration. This study highlights the significant potential of combining terrestrial and aerial scanning technologies for the conservation of cultural heritage, demonstrating how non-intrusive methods can offer both accuracy and the preservation of original features in the restoration of historical buildings.*

Keywords: *3D laser scanning technology; point clouds; georeferencing; historic buildings; restoration; 3D models*

1. Introduction

Laser scanning technology offers an accurate method for documenting both the interior and exterior features of buildings, including intricate architectural details. This data proves invaluable for design professionals involved in the complex planning and design phases of historic preservation projects. By enabling the creation of realistic 3D models and computer-aided design representations of historic structures, this technology supports more efficient and cost-effective execution of projects, whether they involve restoration, rehabilitation or reconstruction.3D laser scanning serves as a valuable tool for architects and builders, delivering highly accurate measurements essential for optimizing renovation projects. Additionally, this technology significantly accelerates the measurement process, completing it up to 75% faster than conventional surveying techniques.[1], [2] 3D laser scanning technologies, including terrestrial laser scanning (TLS) and Aerial Laser Scanning (ALS), provide high precision and efficiency by capturing extensive measurement data in short periods, making them essential tools in historic preservation projects. In the context of historic preservation, these technologies are used for various applications such as site analysis, structural assessments, and material-deterioration studies. Furthermore, they support the creation of detailed as-built drawings and facilitate the accurate documentation of historic districts and monuments, ensuring comprehensive analysis and preservation.[3]

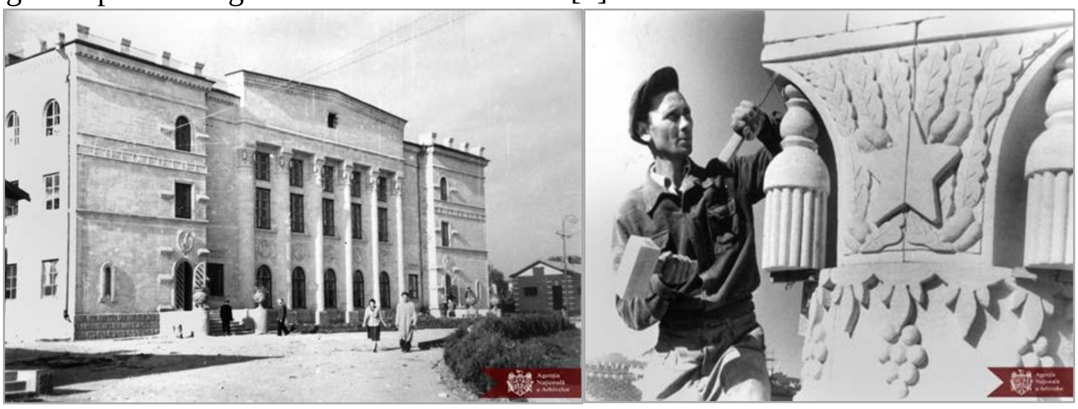
The present study focuses on combining TLS and ALS technologies for the analysis and restoration of architectural buildings with a complex history. Despite their historical significance, these structures have suffered decades of neglect and structural degradation, requiring urgent restoration measures. To address these challenges, a comprehensive approach was undertaken, utilizing cutting-edge technologies to document their current condition and facilitate their restoration.

2. Materials and methods

2.1. Studied object

In this paper, the Republican Stadium in Chișinău, Republic of Moldova, a remarkable example of mid-20th-century architecture built between 1950 and 1951, was chosen as the subject of study. At that time, the sports fields, the gymnasts' village, and the pavilion had not yet been built, and the defects of the stadium's eastern stand had not been addressed. Between 1955 and 1957, reconstruction work was carried out on the stadium, expanding the stands and adding various facilities (Figure 1 a, b). In 1974, the stadium was rebuilt again, reaching a capacity of 21,580 seats. [4]

The Republican Stadium was demolished in 2007, and the site remained unused and neglected for an extended period. In July 2024, the Government of the Republic of Moldova approved the sale of the former stadium’s land to the United States government for the purpose of constructing the new headquarters of the U.S. Embassy in Chișinău. As part of this agreement, the United States committed to renovating and restoring the stadium’s historic gates and transforming part of the site into a public park accessible to citizens, along with other green spaces designated for cultural events. [5]



a) b)

Figure 1. Republican Stadium:a)The administrative building of the stadium, 1955;b)Stonemason Stogrin Alexei during the stadium's reconstruction work, 1957[4]

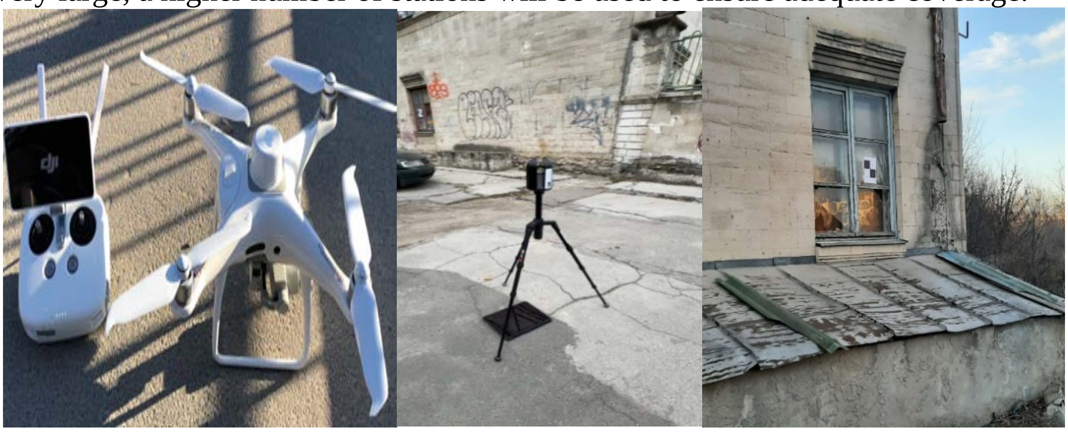
In the process of renovating the stadium gates and the administrative building (Figure 2 a, b) [6], [7], the use of laser scanning technologies proved to be essential, providing precise data for the conservation and restoration of their structural and decorative elements. Terrestrial laser scanning (TLS) with the Leica BLK 360 [8] and aerial scanning with the Phathom 4 RTK drone [9] were used as observation technologies. The collected data were processed using Leica Cyclone Register 360 (BLK Edition) software [10], AgisoftMetashape software [11], and data processing with Leica Cyclone 3DR software [12], through which various useful information for achieving the proposed objectives can be managed and visualized. By integrating these advanced technologies and specialized software, a detailed and accurate documentation of the architectural monument was obtained, allowing the generation of a complex three-dimensional model, essential for analysis, conservation, and future interventions on the studied object. This combined approach demonstrates the efficiency and versatility of modern solutions in implementing georeferencing and digital modeling projects.

a) b)

Figure 2. Republican Stadium: a) Location of the study object[6]; b) Entrance gate to the ruins of the stadium[7]

2.2. Data acquisition

In the architectural monument renovation project, data collection through laser scanning, using aerial devices (DJI Phantom 4 RTK) (Figure 3 a) and terrestrial devices (Leica BLK 360) (Figure 3 b), allowed for the creation of a high-resolution point cloud, essential for generating a detailed 3D model necessary for the precise conservation and restoration of historical details. By gathering information about the object to be scanned and the surrounding surfaces, optimal scanning positions and corresponding targets were determined (Figure 3 b, c). The scanning of the object can vary depending on its size, if the object is very large, a higher number of stations will be used to ensure adequate coverage.



a) b) c)

Figure 3. Data acquisition: a) DJI Phantom 4 RTK drone; b) Terrestrial laser scanning with Leica BLK 360 of the administrative building; c) Materialized marker

To ensure complete coverage of the monument, 24 stations were established, resulting in a double coverage of over 50% (Figure 4 b, c).

For the georeferencing of the object, two points with known coordinates, determined using the GNSS receiver CHCNAV I50, were materialized. These points were used for the georeferencing of the object in the national coordinate system MOLDREF99, and the Baltic altitude system specific to the Chișinău municipality was applied for determining the altitudes of the points [13]. Based on these materialized points, a closed traverse was performed using the Leica Viva TS16 total station (Figure 4 a) to determine and fix markers with known coordinates on the walls of the architectural monument.

a) b) c)

Figure 4. a) Leica Viva TS16 total station; b) Terrestrial laser scanning of the entrance gate to the stadium; c) Scanning stations

Before starting the scanning process with the Leica BLK360, automatic calibration was performed. For the DJI Phantom 4 RTK, calibration involved simultaneous rotations in both vertical and horizontal directions, followed by a full 360° rotation, according to the instructions in the control panel.

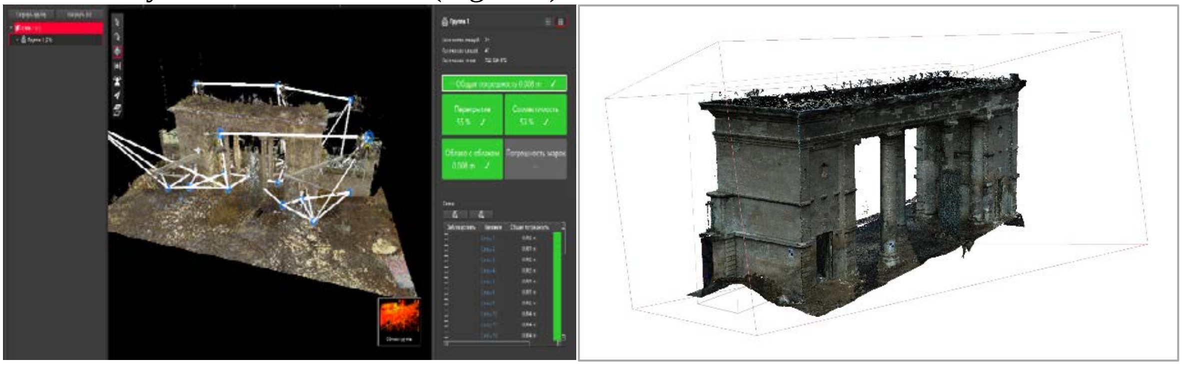
As a method of data acquisition, the terrestrial laser scanner's station points were strategically positioned to ensure the scanner's visibility of the common targets used in the measurement process. Data processing was carried out in several stages, using both the contact points determined from the main control network and the targets fixed on the building facades.

2.3. Data processing

After the scans are completed, the processing phase begins, in which a point cloud, created by displaying the x, y, and z coordinates of points on the surface, will be represented based on the selected resolution and the scanning technique used during field data collection. Software such as Leica Cyclone REGISTER 360 (BLK Edition) for terrestrial laser scanning and AgiSoftMetashape for aerial scanning were used for visualizing the scans and performing numerous processing and post-processing operations on the scanned projects. In this stage of processing, the registration process occurs, which involves transforming the individual point cloud files, obtained from each scan, into a common coordinate system, resulting in a single 3D point cloud. After completing this process, the combined point clouds provide a measurable 3D representation of the scanned object, structure, or site (Figure 5 a, b) [3].

In this section, we also have the option to perform several actions, such as optimization, modeling, editing, detecting scanned errors, and deleting erroneous points.

Additionally, we have access to the georeferencing option for the job using the national coordinate system MOLDREF 99 (Figure 6) [14].



a) b)

Figure 5. 3D representation of the stadium entrance gate: a) Leica Cyclone REGISTER 360; b) AgiSoftMetashape

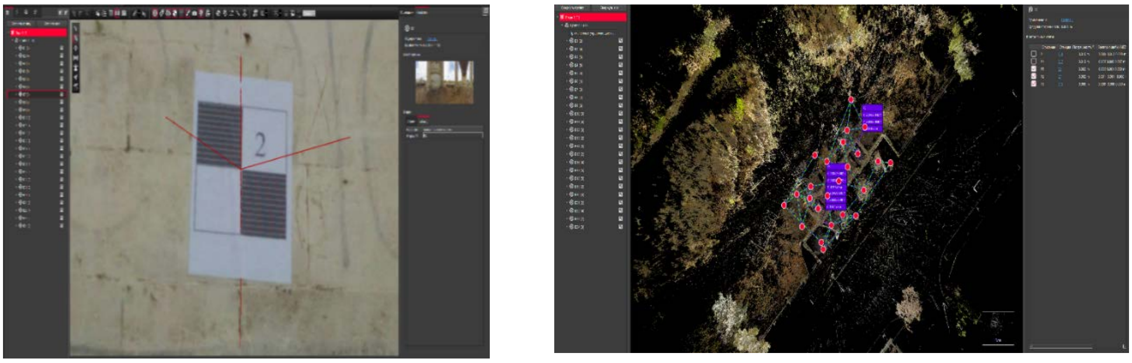
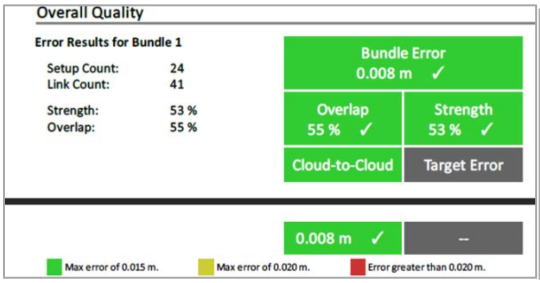


Figure 6. Georeferencing the project in the MOLDREF 99 coordinate system

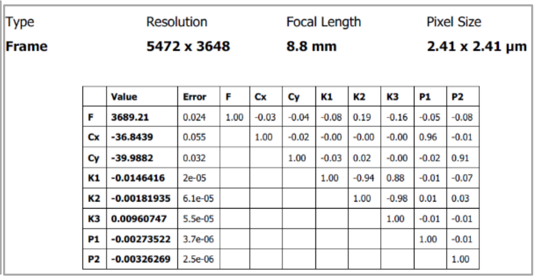
In the post-processing stage, data cleaning and analysis are performed, as the laser scanner tends to record the movement of people on the construction site or collect additional, unnecessary points. Cleaning the point cloud becomes essential to facilitate access and visibility of the most relevant elements for the specific project. This process serves as valuable support for conservation architects during the documentation and design stages. [3]

After completing all editing, modeling, creation, and deletion operations for objects that should not be scanned, we can perform the final optimization of all data and generate an assessment report. The accuracy of the results can be evaluated through the performance of the classifiers, which can be analyzed by generating a coverage report of the scanned object, created with the help of the point cloud. [15], [16]

In Figure 7a, we can observe an evaluation of the precision of the terrestrial laser scanning performed with the Leica BLK 360 (BLK Edition) laser scanner, while in Figure 7b, the evaluation report of the airborne scanning precision conducted with the DJI Phantom 4 RTK drone is presented. These evaluations not only allow for the verification of the quality and accuracy of the collected data but also enable the adjustment of scanning parameters to improve results in future projects, ensuring that the generated 3D models are as precise and useful as possible in the restoration process of historic buildings.



a)



Type	Resolution	Focal Length	Pixel Size
Frame	5472 x 3648	8.8 mm	2.41 x 2.41 μm

	Value	Error	F	Cx	Cy	K1	K2	K3	P1	P2
F	3689.21	0.024	1.00	-0.03	-0.04	-0.08	0.19	-0.16	-0.05	-0.08
Cx	-36.8439	0.055		1.00	-0.02	-0.00	-0.00	-0.00	0.96	-0.01
Cy	-39.9882	0.032			1.00	-0.03	0.02	-0.00	-0.02	0.91
K1	-0.0146416	2e-05				1.00	-0.94	0.88	-0.01	-0.07
K2	-0.00181935	6.1e-05					1.00	-0.98	0.01	0.03
K3	0.00960747	5.5e-05						1.00	-0.01	-0.01
P1	-0.00273522	3.7e-06							1.00	-0.01
P2	-0.00326269	2.5e-06								1.00

b)

Figure 7. Precision Evaluation: a) Terrestrial Laser Scanning; b) Airborne Laser Scanning

After obtaining and cleaning the point clouds, the next step is the analysis and interpretation of the data into drawings and 3D models. This remains a challenging and time-consuming task, as it involves tracing each element of a building, but it allows for the creation of precise and detailed models of structures. This facilitates the restoration and conservation process of historical monuments, as well as their integration into larger architectural projects. These models will not only document the architectural details of the stadium but also serve as a foundation for identifying structural issues and planning targeted restoration interventions.

3. Results and discussions

In the process of documenting buildings and restoring historical monuments, a precise understanding of their geometry is essential. This work aims to achieve this goal by creating a three-dimensional digital model of the Republican Stadium. The digital model obtained through point cloud processing represents a simplified reconstruction based on the data collected in the field. The purpose of this model is to provide as accurate a graphical representation as possible of the scanned object, allowing for the extraction of all essential information for this historical building.

3.1 3D Data Modeling

To create an exact 3D model of the monument, the data must be correctly registered, meaning it should be processed and aligned in a common space, so that it faithfully reflects the structural reality of the monument (Figure 8).

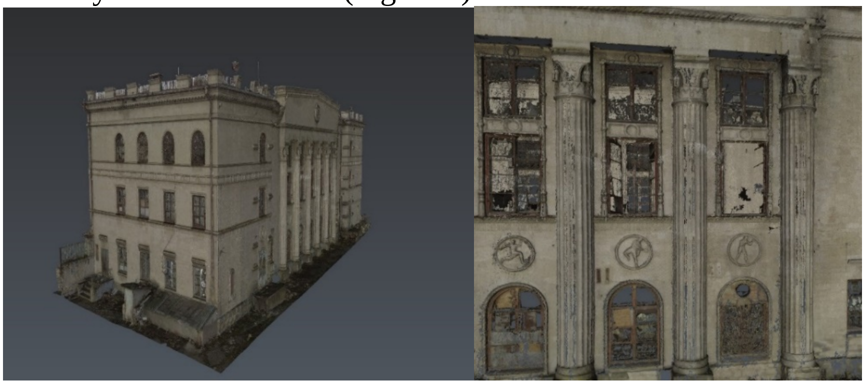


Figure 8. 3D model of the administrative block with architectural elements (front view)

After obtaining the 3D model, the next step is the restoration and design phase, in which historical and architectural information is integrated to develop an intervention plan

(Figure 9). This may include the reconstruction of deteriorated parts of the monument, the restoration of ornamental elements, or even the modification of areas that have undergone major degradation. For these processes, ArchiCAD software is used for modeling and documenting architectural interventions, ensuring a precise integration of historical and structural details.

a) b)

Figure 9. Administrative Block: a) Architectural element design; b) 3D visualization

The 3D modeling of the stadium's entrance gate after processing the terrestrial and aerial laser scanning is presented in Figure 10.

a) b)

Figure 10. Stadium Entrance Gate: a) 3D model through terrestrial laser scanning; b) 3D model through airborne laser scanning

Through terrestrial or airborne laser scanning, no direct contact with the monument is made, which means there is no risk of causing damage. The recorded data allows the creation of a digital copy of the monument, which can be studied and manipulated without interfering with the physical structure. This information can be used to understand the exact shape and dimensions of the monument before restoration work begins.

3.2 Textured polygonal mesh 3D modeling (3D MESH)

The transformation of a point cloud into a mesh (polygonal grid) brings multiple benefits in the renovation of architectural monuments. The mesh represents a continuous and easy-to-interpret form of the structure, facilitating the visualization of details and enabling geometric analysis, sections, or precise technical details. Moreover, this 3D model can be integrated into software applications for simulations, restoration plans, and structural analysis, aiding in more accurate intervention planning. Figure 11 presents the 3D MESH model of the stadium's entrance gate.

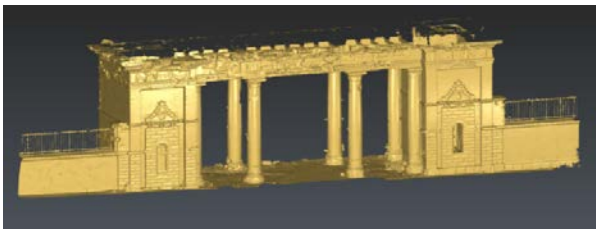
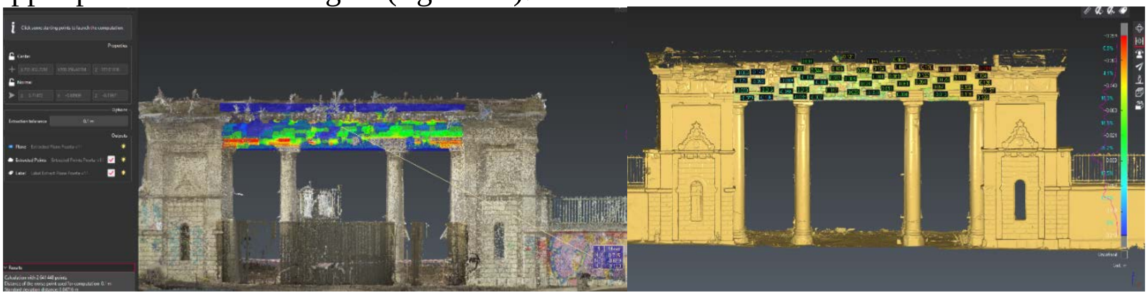


Figure 11. 3D Model - MESH

3.3Evaluation of the architectural structure

Cyclone 3DR is an advanced software used to determine the verticality and planarity of an object in a simple and efficient manner, facilitating the calculation of deviations through specific functions. It also allows for the extraction of lines from 3D objects using specialized algorithms, where the definition of a geometric axis is necessary for deviation analysis.

In this case, a portion of the point cloud was extracted to determine the deviations in the upper part of the stadium gate (figure 12).



a) b)

Figure 12. Entrance Gate: a) Extraction of the plane; b) 3D-MESH visualization

Finally, by using the software tools and following the appropriate steps, precise results regarding the recorded deviations will be obtained. Thus, with the help of the color range, areas that require intervention for restoring the existing portion or, in certain cases, replacing it can be identified (Figure 13).

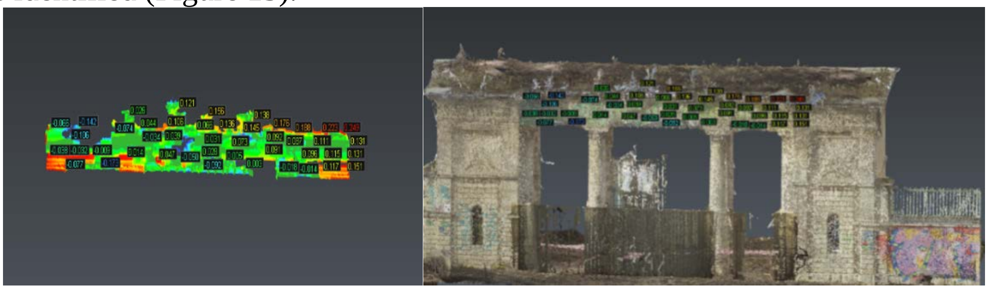
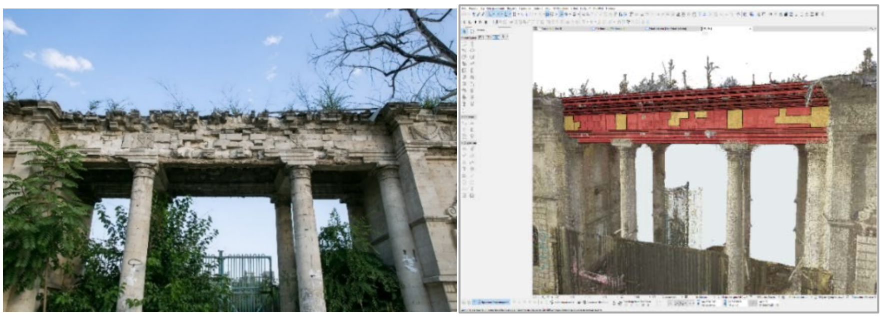


Figure 13. Deviations of the upper wall of the stadium entrance gate

Based on the 3D model and historical information, a database has been created that includes precise details about each element of the building (facades, decorative elements, supporting structures). In our case, an evaluation of the elements that need to be restored, conserved, or reconstructed was carried out, considering the principles of heritage conservation (Figures 14, 15). Detailed plans for each intervention are developed, including sections, construction details, selection of materials, and restoration methods, integrated with modern solutions for improving comfort. The final plan must be approved by the competent authorities, according to regulations regarding the protection of cultural heritage. After obtaining the necessary permits, the interventions are implemented, including the actual restoration, reconstruction of destroyed elements, and integration of modern technologies, ensuring the protection of heritage for the future and more efficient restoration planning through the use of 3D models.



a) b)

Figure 14. a) Ruined elements; b) Facade analysis for restoration

Figure 15.Design of destroyed elements

4. Conclusions

In the renovation process of the Republican Stadium in Chișinău, the use of advanced terrestrial and aerial laser scanning technologies demonstrated the efficiency and added value in documenting, analyzing, and restoring an architectural monument with a complex history. The application of modern methods, such as scanning with the Leica BLK360 and DJI Phantom 4 RTK, alongside high-performance software like Leica Cyclone Register 360 and Agisoft Metashape, enabled the precise capture of data regarding the structure and decorative details of the stadium. The integration of this data into a complex three-dimensional system facilitated the creation of a detailed digital model, essential for preserving original architectural elements and for planning future interventions. Additionally, georeferencing methods and the establishment of optimal scanning positions ensured the accuracy of results, while the use of 3D mesh models guaranteed efficient data interpretation and precise planning of works. This modern technological approach not only demonstrated the capacity to meet the specific requirements of the project but also highlighted the importance of using contactless technologies for the preservation of cultural heritage. The digital modeling allowed for the simulation of various restoration solutions, ensuring compatibility with the historical values of the monument.

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