Teka Komisji Architektury, Urbanistyki i Studiów Krajobrazowych
Oddział Polskiej Akademii Nauk w Lublinie / Politechnika Lubelska

Assessment of the technical condition of a historic building using photogrammetry and terrestrial laser scanning: the case of the Juliusz Osterwa Theatre in Lublin

ORIGINAL ARTICLE: https://doi.org/10.35784/teka.8905
Received 22.12.2025, accepted 23.12.2025, published 30.12.2025

Michał Wac
https://orcid.org/0009-0001-7640-9721
m.wac@pollub.pl

Weronika Kendzierawska-Foryś
https://orcid.org/0000-0001-8984-2164
w.kendzierawska@pollub.pl

Department of Conservation of Monuments, Faculty of Civil Engineering and Architecture, Lublin University of Technology

Abstract: This paper presents a methodology for assessing the technical condition of historic building façades, using the Juliusz Osterwa Theatre in Lublin as a case study. The approach is based on the integration of terrestrial laser scanning (TLS) data and close-range photogrammetry. The comprehensive dataset enabled the generation of a dense, metrically reliable 3D model of the building envelope as well as façade orthophotos. These products were used to prepare a detailed graphical inventory of damage, including surface cracking, cracks and fractures, corrosion, plaster losses, biological growth, and damp areas. The resulting damage maps allowed the identification of zones of advanced degradation, the prioritisation of conservation interventions, and the indication of methodological limitations and directions for further development, confirming the high utility of the proposed methodology in modern integrated diagnostics of historic buildings in urban environments.

Keywords: 3D documentation, historic façades, close-range photogrammetry, damage inventory, terrestrial laser scanning, technical condition assessment

1. Introduction

Assessing the technical condition of historic buildings façades located within dense inner-city development constitutes one of the key challenges of contemporary conservation practice. The Juliusz Osterwa Theatre in Lublin represents an example of a building with a complex form, richly developed architectural detail, and façades that have undergone multiple phases of modernisation. Its location in the city centre, exposure to atmospheric factors and traffic-related pollution, as well as the history of previous renovation works, means that the building requires precise and well-documented diagnostics as a basis for rational planning of further conservation interventions.

Traditional methods based on visual inspections and two-dimensional drawing and photographic documentation prove insufficient, both in terms of the level of detail and the possibility of objective comparison of the state of preservation over time. In this context, the present study addresses the application of integrated photogrammetric and terrestrial laser scanning (TLS) for the assessment of the technical condition of the theatre façades. The comprehensive dataset enabled the acquisition of a dense, metrically reliable point cloud and a 3D mesh model of the building, in which the high geometric accuracy of TLS was combined with high-resolution textures obtained from terrestrial and UAV photogrammetry. On this basis, façade orthophotos at a constant scale were generated and used for a detailed graphical inventory of defined damage categories, including networks of surface cracking, cracks and fractures, zones of chemical corrosion of steel elements, plaster losses with exposure of the structural substrate, as well as biological growth and damp areas. The resulting damage maps made it possible not only to identify zones of advanced degradation but also to interpret the mechanisms of deterioration spatially, in relation to the building geometry, the arrangement of openings, corners, and architectural detail.

The rationale for undertaking this research lies in the need to introduce diagnostic procedures into conservation practice that combine the inventory-related advantages of modern measurement techniques with the possibility of a formalised, multi-criteria assessment of the technical condition of façades. The presented hybrid methodology, verified on the example of a representative historic building, demonstrates that the integration of TLS and photogrammetry enables a transition from descriptive and drawing-based documentation to digital 3D models. These models can be used as bases for damage annotation, prioritisation of renovation needs, monitoring of degradation processes, and, in the longer term, integration with BIM/HBIM environments. At the same time, the analysis of limitations and sources of inaccuracy—such as urban constraints, radiometric properties of surfaces, and the partly subjective nature of interpretation—indicates directions for further research focused on the automation of selected forms of damage detection and the standardisation of documentation procedures. Consequently, the subject addressed in this study is of both scientific and practical relevance, responding to the growing demand for tools supporting the rational management of architectural heritage.

2. Object of the research

The object of the research presented in this paper is the Juliusz Osterwa Theatre. It is located in the city centre of Lublin, at the intersection of Gabriela Narutowicza, Peowiaków, and Kapucyńska streets (Fig. 1).

Figure 1. **Location of the building on the map of Lublin.** *Source: System informacji przestrzennej [2] (accessed 2025 Nov)*

Constructed between 1884 and 1886 according to the winning competition design by architect Karol Kozłowski, the building represents an eclectic architectural style (Fig. 2). From the beginning of its existence, the structure has served a theatrical function, except for the period of the First World War, when it was temporarily converted into a military hospital.

Figure 2. Winning competition design of the Theatre – front façade. *Source: [5] (accessed 2025 Nov)*

Figure 3. Current view of the front façade. *Source: Authors*

The building mass (Fig. 3) consists of three interconnected parts shaped in accordance with the course of the surrounding streets, with later extensions located on the northern side. The building is partially below ground and covered with gable roofs. The individual segments share the same overall height but differ in the number of storeys (2, 4, or 5), reflecting their varied functional uses.

The two-storey, five-axis front façade features lateral pseudo-risalits and rich classical detailing, with central arcaded portals and elaborately designed windows and *portefenêtres* on the upper floor. The façade is crowned by a cornice with modillions, a frieze bearing the date "1886," and attics adorned with aediculae and vases. The interior retains a representative entrance hall as well as a richly ornamented stucco decoration of the auditorium, balconies, and boxes.

The building is listed in the register of historic monuments under No. A/263, dated 10 March 1967 [1]. The structure has undergone several renovation campaigns, with the most recent works related to the external walls carried out in 2003 [4].

3. Methodology

The primary objective of the data acquisition was to obtain a model of the external façades of the Juliusz Osterwa Theatre in Lublin that is as complete as possible and metrically reliable, enabling a detailed analysis of damage and the formulation of an assessment of the building's technical condition. An integrated approach combining close-range photogrammetry and terrestrial laser scanning (TLS) was applied. Both techniques were used in parallel, adopting a common reference system based on a network of control points in the form of self-adhesive markers placed on the façades. These points were simultaneously visible in the photogrammetric images and in the TLS point clouds, which enabled precise integration of the datasets and reduced registration errors.

3.1. Photogrammetry

Close-range photogrammetry is currently one of the most commonly used methods for acquiring spatial data in the form of 3D models, based on standard digital photographs. The fundamental principle of photogrammetry is the precise reconstruction of an object's geometry from a set of images. A properly prepared photographic dataset should include information on the internal camera parameters, such as sensor resolution, lens focal length, lens distortions, and additional metadata, including the approximate location where each photograph was taken. These data form the basis for subsequent camera model calibration and optical distortion correction.

Equally important is the method of photographic data acquisition. In order for reconstruction algorithms to correctly reproduce the object's geometry, the images must exhibit appropriate coverage geometry, meaning that individual frames should overlap by approximately 30–70%. Images acquired from varied directions and heights significantly increase the number of detectable feature points that can be used to match successive photographs, thereby enabling an effective spatial reconstruction.

As part of the photogrammetric survey, a comprehensive photographic documentation was carried out, covering all accessible façades of the theatre, both from ground level and from above using a UAV. The images were recorded with a high-resolution digital camera equipped with a fixed-focal-length lens to reduce geometric distortions, as well as a UAV with GPS positioning. In total, approximately 5,000 photographs were acquired (Fig. 4), including both general views and close-up images of architectural details.

After acquisition and optional preliminary processing of the images, such as contrast enhancement or noise reduction, the dataset was analysed using specialised photogrammetric software. In this case, RealityCapture software was employed. The first processing stage involved the detection and description of feature points (e.g. using SIFT, SURF, or ORB) for each image. For every photograph, a database of descriptors was created, enabling the subsequent identification of corresponding points across different images.

Subsequently, the software matched common features between pairs of images. This process is computationally intensive, as the number of comparisons increases with the size of the photographic dataset. To reduce processing time, the algorithms may utilise additional metadata, such as the image acquisition date or the GPS coordinates of the camera. This allows the set of potential image pairs to be narrowed, significantly accelerating the analysis.

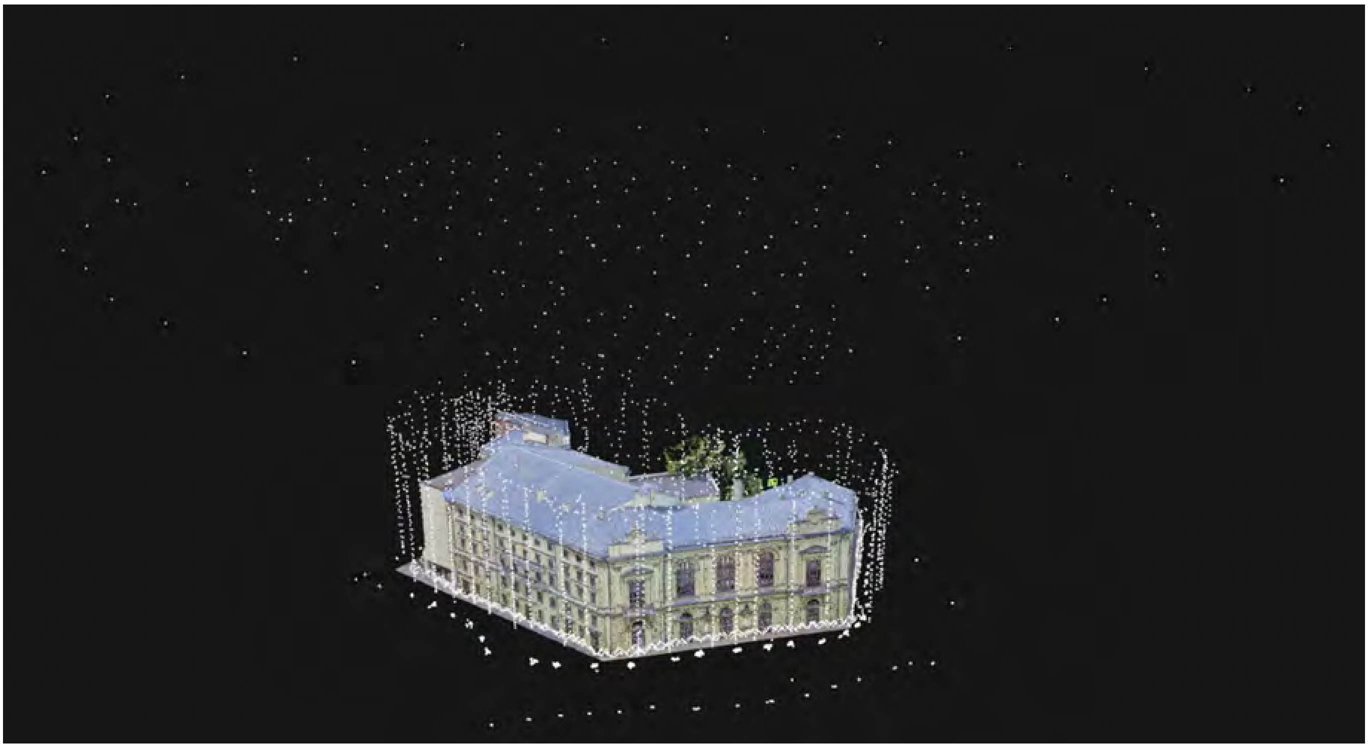

Figure 4. Photogrammetric point cloud with camera positions. *Source: Authors*

After establishing the mutual relationships between the detected feature points, the software determined the external orientation of the images, corrected optical distortions, and reconstructed the initial geometric structure of the object. A prerequisite for computing the spatial position of a point is its registration on at least two images. The result of this stage is a sparse point cloud containing a set of 3D coordinates along with radiometric information.

The next stage involved the generation of a dense point cloud using Multi-View Stereo (MVS) methods, which significantly increase data density and improve the level of detail of the reconstructed object. Based on this dataset, a triangular mesh was created through point triangulation. The final step consisted of texturing the model by mapping colour information from the original images onto the mesh surface, resulting in a realistic representation of the historic building.

3.2. Terrestrial Laser Scanning (TLS)

Terrestrial laser scanning (TLS) is one of the most advanced methods of active spatial data acquisition and is currently regarded as the most accurate implementation of LiDAR technology in engineering and conservation applications. This technique employs a high-precision laser rangefinder that records the spatial position of points based on distance measurements and the emission angles of the laser beam.

In TLS instruments, the distance L is measured using either the time-of-flight principle or the phase-shift measurement method. A movable mirror or scanning head directs the laser beam in a controlled manner, performing scanning in both vertical and horizontal planes. For each recorded reflected signal, the instrument determines a set of measurement parameters, including the distance L, the directional angles α and β, the return intensity, or other radiometric parameters. Based on the known geometric parameters of the beam and the measured distance, the scanner computes the spatial coordinates of point P in the instrument coordinate system (Fig. 5). In subsequent processing, the data are registered and georeferenced, allowing their transformation into a global or project-specific local coordinate system.

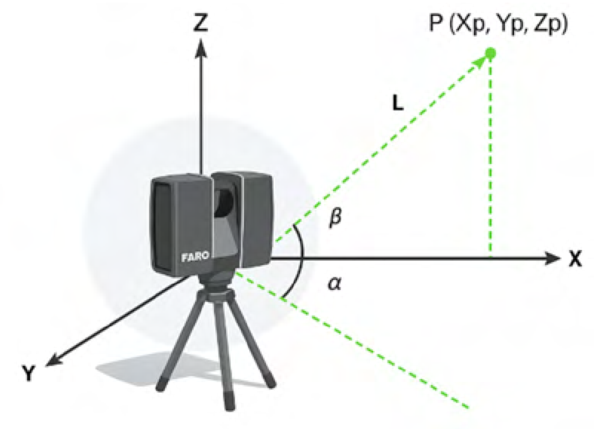

Figure 5. **Principle of operation of the laser scanner.** *Source: Authors*

Figure 6. **Photograph from the laser scanning process on the site.** *Source: Authors*

Modern stationary laser scanners (Fig. 6) integrate additional sensors, including an inertial measurement unit (IMU), a magnetic compass, a GNSS receiver, and RGB cameras or panoramic camera systems, which enables automatic synchronisation and colourisation of the point cloud. Acquisition rates reaching several million points per second, combined with variable angular resolution, allow the collection of extremely high-density data, often exceeding several hundred points per square metre. Measurement accuracy on the order of 2–6 mm, and in high-precision instruments even below 2 mm, makes this technology particularly suitable for applications requiring a high level of geometric detail, such as structural diagnostics, architectural surveying, conservation documentation, and deformation monitoring.

Table 1. **Parameters of the laser scanner used.** *Source: manufacturer's datasheet*

Parameter	Value
Measurement range	0.6–70 m for surfaces with high reflectivity (approx. 90%, e.g. white target)
Distance accuracy	distance error approx. ±1 mm (under typical conditions, after warm-up, according to FocusS series specifications)
Scanning speed	Up to 976,000 points/s
Field of view	approx. 300° vertical, 360° horizontal (full rotation)
Angular accuracy	approx. 19″ (arcsec) in both vertical and horizontal directions
Camera / images	integrated colour camera up to approx. 165 Mpix (HDR 2×/3×/5×)
Laser class	Class 1, wavelength ~1550 nm (eye-safe under normal operation)
Additional sensors	built-in GPS/compass, height sensor, dual-axis compensator, accuracy approx. 0.019°

A key stage in the processing of TLS data is multi-station registration, which is performed using reference targets (spheres, coded targets) or point cloud matching methods, in particular the Iterative Closest Point (ICP) algorithm.

Figure 7. Layout of laser scanner stations. *Source: Authors*

Figure 8. Photograph of a control point. *Source: Authors*

The scanner stations (Fig. 7) were linked using a network of reference targets and adhesive markers placed on stable façade elements, such as corners, sections of window surrounds, and cornice segments (Fig. 8). These points were used both for multi-station registration and for subsequent integration with the photogrammetric model. The registration process was carried out in software dedicated to the operation of the instrument, resulting in a single, unified point cloud representing the entire building.

In the next stage, the point cloud was subjected to filtering and preliminary cleaning. Points corresponding to moving objects (vehicles, pedestrians) were primarily removed, as well as measurement noise such as isolated reflections from glass surfaces or strong reflections from metal elements. The cleaned point cloud was then reduced to a density level that preserved essential geometric details while ensuring an acceptable file size and efficient further processing.

The TLS model prepared in this way served as the reference geometry in the process of integration with the photogrammetric model. A unified coordinate system and a common network of control points enabled direct comparison, merging, and joint use of the datasets in subsequent analyses, including the generation of raster base maps for damage inventory.

3.3. Limitations

The applied hybrid approach significantly reduced the typical shortcomings of individual measurement techniques; however, it does not eliminate all sources of inaccuracy. In the case of terrestrial laser scanning, the main limiting factors included occlusions resulting from dense inner-city development, street traffic, and the presence of temporary elements such as advertisements and parked vehicles. The upper parts of the façades, as well as elements located above the rooflines of neighbouring buildings, required a compromise between scanning density and acquisition time, which could locally reduce point density. Data quality was additionally affected by laser beam reflections on highly reflective surfaces, particularly glazing, which necessitated subsequent filtering during data processing.

In photogrammetry, the primary limitation was related to the radiometric properties of the documented surfaces. Uniformly coloured, smooth plaster areas and extensive surfaces painted in a single colour generated a limited number of distinctive features, which hindered stable image matching and geometric reconstruction. Strongly shaded areas and highly glossy surfaces, where light reflections occurred, also proved problematic. In such zones, the photogrammetric model exhibited lower levels of detail or local data gaps.

Despite these limitations, the combined TLS and photogrammetric dataset ensured continuous coverage of all façades and a resolution sufficient for detailed mapping of surface damage. The hybrid methodology thus enabled both a reliable reconstruction of the building geometry and the preparation of high-quality graphical base materials, which form the basis for the analyses presented in the subsequent sections of this paper.

4. Results

The outcome of the conducted work was the development of an integrated three-dimensional model of the external façades of the Juliusz Osterwa Theatre in Lublin, based on the combined use of photogrammetric and TLS data. The integration of both techniques enabled the creation of a continuous geometric representation of the building in the form of a dense point cloud and a mesh model with high-quality textures, allowing for detailed identification and mapping of surface damage to plaster layers and architectural details.

4.1. Geometric Model and Processing Parameters

The integrated point cloud covering all accessible façades was characterised by high spatial density, enabling a clear representation of both the main architectural divisions and fine-detail elements. Based on this dataset, a continuous mesh model of the building was generated, with a surface composed of approximately 380 million triangular elements. Such a high level of detail allowed for a reliable representation of the complex building geometry as well as local irregularities resulting from deformations and previous repair works.

Model texturing was carried out using the complete set of photogrammetric images. This resulted in a realistic reproduction of surface colour and texture, enabling visual identification of discolouration, streaking, soiling, and other traces of material degradation. The quality of the textures proved sufficient for their further use as base materials in manual and semi-automatic damage mapping at the scale of architectural detail. Below, two example façade models are presented: the front façade (Fig. 9) and a side façade (Fig. 10).

Figure 9. Point cloud of the front (south-eastern) façade. *Source: Authors*

Figure 10. Point cloud of the southern façade. *Source: Authors*

4.2. Façade Orthophotos and Analytical Base Materials

Based on the 3D model, orthophoto representations of the individual façades were generated (Figs. 11 and 12), forming a set of two-dimensional base materials in orthogonal projections. Each base covered the full height of the façade while maintaining metric accuracy and a constant scale, which enabled direct geometric analysis as well as the graphical inventory of damage.

Figure 11. Orthophoto of the southern façade. *Source: Authors*

Figure 12. Orthophoto of the south-eastern façade. *Source: Authors*

4.3. Graphical Inventory of Façade Damage

A detailed graphical inventory of damage was carried out on the orthophotos of the individual façades (Figs. 13 and 14). For the purposes of the study, a set of damage categories corresponding to the applied cartographic legend was defined, including:

- surface cracking;
- cracks and fractures;
- corrosion of elements;
- plaster losses / exposure of the structural substrate;
- biological corrosion / damp areas.

Each category was marked on the inventory drawings using a distinct graphical symbol, which enabled both qualitative and quantitative analysis of the spatial distribution of damage. The mapping results revealed a clear differentiation in the state of preservation between the individual façades. The highest concentration of damage was recorded:

- in the plinth zone, where dampness and associated biological corrosion as well as plaster losses predominated;
- in areas of architectural detail (cornices, window surrounds, attics), which are particularly exposed to rainfall and temperature fluctuations and where numerous instances of surface cracking, cracks, and corrosion of metal elements were observed;

- in corner zones and around openings, where oblique and vertical cracks and fractures accumulated, potentially related to structural behaviour or previous repair interventions.

Figure 13. Graphical inventory of damage on the front (south-eastern) façade. *Source: Authors*

Figure 14. Graphical inventory of damage on the southern façade. *Source: Authors*

A comparison of the results obtained for the two façades analysed in detail showed that the façade more exposed to direct atmospheric influences and traffic-related pollution is characterised by more advanced degradation of the plaster layer, a higher proportion of plaster losses, and more intensive biological corrosion. In contrast, the less exposed façades exhibit a lower degree of damage while retaining a relatively better condition of the architectural detail.

4.4. Summary of Results

The conducted study demonstrated that an integrated 3D model based on the combination of TLS and photogrammetric data enables both a highly detailed representation of façade geometry and the preparation of high-quality raster base materials for damage inventory. The developed orthophotos and cartographic drawings allowed for the unambiguous identification of the main forms of degradation and the determination of zones of their concentration, providing a basis for further assessment of the building's technical condition and for planning conservation measures. The applied approach confirmed the usefulness of photogrammetric methods and laser scanning as tools supporting decision-making processes related to the maintenance and protection of historic façades.

5. Discussion

The presented results allow an assessment of the quality of the obtained 3D model and the developed damage maps, but also for a broader reflection on the usefulness of the applied hybrid method in conservation practice. In this section, the research outcomes are compared with experiences reported in the literature and with traditional approaches, highlighting both the strengths of combining photogrammetry and laser scanning as well as its limitations and potential sources of uncertainty. The discussion also addresses the implications of the obtained results for the planning of interventions on historic façades and outlines possible directions for further development of the methodology.

5.1. Assessment of the Applicability of the Photogrammetry–TLS Hybrid Method

The applied hybrid approach confirmed the high suitability of combining photogrammetry and terrestrial laser scanning for the diagnostics of façades of a historic building with complex geometry. TLS provided a reliable geometric representation of the theatre's massing, including elements that are difficult to access and located at significant heights. Photogrammetry, owing to dense image coverage and high radiometric resolution, enabled the acquisition of textures of a quality sufficient for the unambiguous identification of fine forms of degradation.

The key outcome of integrating both techniques was the creation of a coherent 3D model in which comprehensive geometric information was linked with high-quality surface imagery. This made it possible to move from a purely documentary stage to an analytical stage, encompassing detailed damage inventory and spatial interpretation. In conservation practice, this represents a significant added value compared to the use of individual methods, as it allows simultaneous interpretation of information related to the form, scale, and contextual occurrence of damage.

5.2. Reference to Traditional Approaches and the Literature

Compared to classical methods of façade condition assessment based on on-site visual inspections and two-dimensional photographic and drawing documentation, the presented approach allows for a significant increase in the level of detail and objectivity of the results. The 3D model and façade orthophotos eliminate the problem of perspective distortions and enable damage analysis at a constant scale, regardless of the observation distance. In addition, the possibility of revisiting the same parts of the model at any time allows for verification of conclusions and comparison of different interpretations.

The literature on heritage documentation indicates that photogrammetry and TLS are increasingly being applied as tools supporting conservation works. The presented case study fits within this research trend, extending it through the consistent use of geometric and radiometric data to create a systematic, multi-criteria damage map. In contrast to many studies focused solely on the inventory aspect, this work emphasises the integration of documentation with technical condition assessment and the identification of zones critical to the safety and durability of the building.

5.3. Method Limitations and Sources of Uncertainty

The analysis of the results also indicates a number of limitations that must be taken into account when interpreting the model and the developed damage maps. In the case of TLS, the most significant issues are occlusions resulting from urban constraints, such as narrow streets, adjacent buildings, and temporary infrastructure, which limit the possibilities for flexible scanner placement. This leads to local data gaps and necessitates a reduction in scanning density in order to maintain a reasonable acquisition time. Additional sources of inaccuracy include optical effects associated with laser beam reflections from glass and highly reflective surfaces.

In photogrammetry, the main challenge remains extensive, uniformly coloured plaster surfaces, which generate a limited number of distinctive features and hinder the automatic image matching process. When combined with shaded areas and zones with strong reflections, this results in a local reduction in texture quality or the occurrence of areas with limited radiometric reliability.

A further important source of uncertainty is the manual stage of damage mapping. Although the use of orthophotos at a constant scale minimises dimensional errors, the interpretation of the type and extent of damage remains to some degree subjective and dependent on the experience of the operator. In the future, it appears justified to develop procedures for automatic or semi-automatic classification of selected forms of degradation, while maintaining expert control over the final interpretation.

5.4. Implications for Conservation Practice and Heritage Management

Despite the identified limitations, the obtained results demonstrate that a hybrid photogrammetric–laser scanning model can serve as an effective tool supporting the planning and execution of interventions on historic façades. The developed damage maps enable the prioritisation of conservation needs by indicating zones with the highest degree of degradation and potentially the greatest risk to user safety.

For building managers and designers of renovation works, the ability to link information on the type of damage with its precise location and structural context is particularly important. The 3D model allows the analysis of crack and fracture patterns in relation to the arrangement of openings, corners, changes in building geometry, or material junctions, which facilitates the identification of mechanisms responsible for the observed degradation. Moreover, the digital record of the façade condition at a given point in time provides a reference for future measurement campaigns, enabling monitoring of deterioration processes and assessment of the effectiveness of repair measures.

5.5. Perspectives for Further Research

Presented results indicate the need for further development of integrated methods for documentation and technical condition analysis of historic buildings. In the authors' opinion, the following directions appear justified in subsequent stages of research:

- extending the analysis by linking identified damage with the results of material testing as well as moisture and salt content measurements;
- developing procedures for automatic or semi-automatic detection of selected forms of degradation based on texture and colour features of photogrammetric textures;
- integrating the resulting model with BIM/HBIM environments in order to link geometric and material information with archival documentation, renovation design, and building maintenance plans;
- conducting comparative analyses for other buildings of different scales and structural characteristics, which would allow for a better determination of the applicability range of the proposed method.

The application of the described procedure to the Juliusz Osterwa Theatre in Lublin demonstrates that modern measurement techniques, when properly integrated and oriented towards conservation needs, can significantly improve the quality and reliability of technical condition assessments of historic buildings, thereby supporting decision-making processes related to their protection and use.

6. Conclusions

The aim of this study was to develop and verify a methodology for assessing the technical condition of the façades of a historic building, using the Juliusz Osterwa Theatre in Lublin as a case study, based on integrated photogrammetric data and terrestrial laser scanning. The conducted measurement campaign and subsequent processing resulted in a detailed 3D model of the building and a set of façade orthophotos, which formed the basis for a graphical inventory of damage.

The key conclusions drawn from the study can be summarised as follows:

1. The integration of TLS and photogrammetric data enabled the generation of a dense, metrically reliable point cloud and a highly detailed mesh model, while maintaining very high texture quality. The integrated model provided continuous coverage of all accessible façades and a reliable representation of both geometry and surface variability.
2. The generated façade orthophotos proved to be an effective tool for graphical inventory. The constant scale and elimination of perspective distortions enabled precise damage mapping and unambiguous determination of the extent and location of deterioration.
3. The defined system of damage categories allowed for the organisation and systematisation of the observed forms of degradation. The developed damage maps revealed a clear concentration of adverse phenomena in the plinth zone, in areas of architectural detail, and in corner zones and areas around openings.
4. The applied methodology provided information useful from the perspective of conservation practice. The ability to link the type of damage with its precise spatial location facilitates the prioritisation of renovation needs, the identification of critical zones, and the planning of the scope and sequence of repair measures. The digital 3D model and accompanying materials can also be used as a reference for future inspections and comparative measurement campaigns.

5. The identified limitations of the method result mainly from urban constraints, the radiometric properties of the documented surfaces, and, to some extent, the necessity of manual damage interpretation. These limitations do not undermine the usefulness of the hybrid approach but indicate areas requiring further refinement.

In conclusion, the presented methodology combining photogrammetry and terrestrial laser scanning proved to be an effective tool supporting the assessment of the technical condition of the façades of the Juliusz Osterwa Theatre. The obtained results confirm that modern measurement techniques, when properly integrated and oriented towards conservation needs, can significantly improve the accuracy and reliability of diagnostics and thus support rational planning of conservation actions for historic buildings.

References

[1] Kotowska D, oprac. *Karta ewidencyjna zabytków architektury i budownictwa* [dokument archiwalny]. Lublin: Archiwum Zakładowe WOZ w Lublinie; 1982. Nr 13448.

[2] System informacji przestrzennej [Internet]. Lublin: lublin.eu; Accessed 2025 Nov. Available from: https://lublin.eu/lublin/sipl.

[3] Ośrodek „Brama Grodzka – Teatr NN". *Teatr im. Juliusza Osterwy w Lublinie – historia budynku* [Internet]. Accessed 2025 Nov. Available from: https://teatrnn.pl/leksykon/artykuly/teatr-im-juliusza-osterwy-w-lublinie-historia-budynku.

[4] Narodowy Instytut Dziedzictwa (NID), Sikora-Terlecka A, oprac. *Lublin – budynek Teatru im. Juliusza Osterwy* [Internet]. Accessed 2025 Nov. Available from: https://zabytek.pl/pl/obiekty/lublin-budynek-teatru-im-juliusza-osterwy.

[5] Martynowski FK. Teatr w Lublinie. Projekta konkursowe. W: *Kłosy. Czasopismo ilustrowane tygodniowe* [Internet]. 1883;(931). Accessed 2025 Nov. Available from: http://polona.pl/item/7942722/0.

[6] Alshawabkeh Y, Baik A, Miky Y. Integration of laser scanner and photogrammetry for heritage BIM enhancement. *ISPRS International Journal of Geo-Information*. 2021;10(5):316. doi:10.3390/ijgi10050316.

[7] Altuntas C. Integration of point clouds originated from laser scanner and photogrammetric images for visualisation of complex details of historical buildings. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2015;XL-5/W4:431–435. doi:10.5194/isprsarchives-XL-5-W4-431-2015.

[8] Altuntas C, Yildiz F, Scaioni M. Laser scanning and data integration for three-dimensional digital recording of complex historical structures: the case of Mevlana Museum. *ISPRS International Journal of Geo-Information*. 2016;5(2):18. doi:10.3390/ijgi5020018.

[9] Carnevali L, et al. Close-range mini-UAVs photogrammetry for architecture survey. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2018;XLII-2:217–224. doi:10.5194/isprs-archives-XLII-2-217-2018.

[10] Chatzistamatis S, et al. Photogrammetry in architectural education: deploying aerial and terrestrial means. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2023;XLVIII-1/W2-2023:261–267. doi:10.5194/isprs-archives-XLVIII-1-W2-2023-261-2023.

[11] Elkhrachy I. 3D structure from 2D dimensional images using structure from motion algorithms. *Sustainability*. 2022;14(9):5399. doi:10.3390/su14095399.

[12] Fryskowska A. Accuracy assessment of point clouds georeferencing in surveying and documentation of historical complexes. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2017;XLII-5/W1:161–165. doi:10.5194/isprs-archives-XLII-5-W1-161-2017.

[13] Haddad NA. From ground surveying to 3D laser scanner: a review of techniques used for spatial documentation of historic sites. *Journal of King Saud University – Engineering Sciences*. 2011;23(2):109–118. doi:10.1016/j.jksues.2011.03.001.

[14] Karagianni A. Terrestrial laser scanning in building documentation. *Civil Engineering and Architecture*. 2017;5(6):215–221. doi:10.13189/cea.2017.050603.

[15] Lah L, et al. Detailed cultural heritage recording produced with traditional methods and laser scanning. *Geodetski vestnik*. 2023;67(4):442–458. doi:10.15292/geodetski-vestnik.2023.04.442-458.

[16] Liu J, et al. Static terrestrial laser scanning (TLS) for heritage building information modeling (HBIM): a systematic review. *Virtual Worlds*. 2023;2(2):90–114. doi:10.3390/virtualworlds2020006.

[17] Luhmann T, et al. Combination of terrestrial laser scanning, UAV and close-range photogrammetry for 3D reconstruction of complex churches in Georgia. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2019;XLII-2/W11:753–761. doi:10.5194/isprs-archives-XLII-2-W11-753-2019.

[18] Luis J, et al. Integration of laser scanning and imagery for photorealistic 3D architectural documentation. In: Wang C-C, editor. *Laser Scanning: Theory and Applications*. InTech; 2011. doi:10.5772/14534.

[19] Markiewicz JS, Zawieska D. Terrestrial scanning or digital images in inventory of monumental objects? Case study. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2014;XL-5:395–400. doi:10.5194/isprsarchives-XL-5-395-2014.

[20] Mateus L, et al. Terrestrial laser scanning and digital photogrammetry for heritage conservation: case study of the historical walls of Lagos, Portugal. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2019;XLII-2/W11:843–847. doi:10.5194/isprs-archives-XLII-2-W11-843-2019.

[21] Murtiyoso A, et al. Acquisition and processing protocols for UAV images: 3D modeling of historical buildings using photogrammetry. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2017;IV-2/W2:163–170. doi:10.5194/isprs-annals-IV-2-W2-163-2017.

[22] Pepe M, Alfio VS, Costantino D. UAV platforms and the SfM-MVS approach in the 3D surveys and modelling: a review in the cultural heritage field. *Applied Sciences*. 2022;12(24):12886. doi:10.3390/app122412886.

[23] Prasidya AS, et al. Three-dimensional digital documentation for the conservation of the Prambanan Temple Cluster using guided multi-sensor techniques. *Heritage*. 2025;8(1):32. doi:10.3390/heritage8010032.

[24] Salagean-Mohora I, Anghel AA, Frigura-Iliasa FM. Photogrammetry as a digital tool for joining heritage documentation in architectural education and professional practice. *Buildings*. 2023;13(2):319. doi:10.3390/buildings13020319.

[25] Szostak B, Wac M. The use of digital technologies in assessing the technical condition of historic structures. *Budownictwo i Architektura*. 2024;23(4):151–172. doi:10.35784/bud-arch.6669.

[26] Temizer T, et al. 3D documentation of a historical monument using terrestrial laser scanning: case study Byzantine water cistern, Istanbul. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2013;XL-5/W2:623–628. doi:10.5194/isprsarchives-XL-5-W2-623-2013.

[27] Vacca G, Dessi A. Geomatics supporting knowledge of cultural heritage aimed at recovery and restoration. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2022;XLIII-B2-2022:909–915. doi:10.5194/isprs-archives-XLIII-B2-2022-909-2022.

[28] Valença J. Systems based on photogrammetry to evaluation of built heritage: tentative guidelines and control parameters. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2014;XL-5:607–613. doi:10.5194/isprsarchives-XL-5-607-2014.

[29] Xing Y, Yang S, Fahy C, Harwood T, Shell J. Capturing the past, shaping the future: a scoping review of photogrammetry in cultural building heritage. *Electronics*. 2025;14(18):3666. doi:10.3390/electronics14183666.

[30] Yang X, Qiu B, Tian Z. Research on the application method of historical building protection under the integration of multiple technologies. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2022;XLIII-B2-2022:923–928. doi:10.5194/isprs-archives-XLIII-B2-2022-923-2022.

[31] Zabrzeska-Gąsiorek B, Szewczyk J. Photogrammetric inventory of monuments in the aspect of laser scanning. *Archives of Photogrammetry, Cartography and Remote Sensing*. 2023:125. doi:10.14681/apcrs-2023-006.

[32] Zachos A, Anagnostopoulos C-N. Using TLS, UAV, and MR methodologies for 3D modelling and historical recreation of religious heritage monuments. *Journal on Computing and Cultural Heritage*. 2024;17(4):1–23. doi:10.1145/3679021.