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Original Article

The use of digital technologies in assessing the technical condition of historic structures

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Abstract: This article explores the use of modern digital technologies, such as 3D scanning and photogrammetry, in assessing the technical condition of historic structures. It compares traditional and digital inventory methods, emphasising the advantages of the latter in the precise and rapid acquisition of spatial data. Three types of laser scanning are described – simplified, handheld, and stationary – along with their applications in monument documentation. Case studies are presented where digital technologies were applied to the analysis and conservation of structures such as the ruins of Melsztyn Castle, Czersk Castle, the historic brickworks in Izbica, and the Juliusz Osterwa Theatre in Lublin. The findings demonstrate that these technologies enhance inventory accuracy, enable the detection of damage invisible to the naked eye, and save time and resources. Challenges related to processing large volumes of data and the need for specialised knowledge and standards are also discussed. In conclusion, the application of digital technologies in cultural heritage protection offers significant benefits and is invaluable for preserving monuments for future generations.

Keywords: digital technologies, 3D scanning, photogrammetry, technical condition assessment, historic structures, digital inventory, monument conservation, 3D models

1. Introduction

Modern digital technologies play an increasingly significant role in the protection of cultural heritage, particularly in assessing the technical condition of historic structures. Advanced methods such as 3D scanning and photogrammetry enable precise documentation of monuments and their conservation without interfering with their structures [3,10,13].

This work discusses the latest advancements in the application of 3D scanning and photogrammetry in evaluating the technical condition of monuments, as well as the challenges encountered in their use. Notable cases include the use of these technologies for the protection and conservation of monuments such as the 3D documentation of the Clock Tower in Tirana and the archaeological site of Amrit in Syria [24]. The article outlines the benefits of employing these technologies, including the ability to create digital 3D models for conservation, scientific research, and educational purposes.

3D scanning technologies have been widely applied in assessing the technical condition of historic structures. Point clouds are used to prepare an inventory drawings of structural damages in heritage buildings, such as those in the Kłodzko Fortress [6]. Point cloud segmentation algorithms, based on edge detection and supervoxel topology, enable accurate analysis and classification of architectural elements, which are crucial for further conservation efforts [22].

Another significant achievement is the application of laser scanning technology in the virtual spatial reconstruction of historic buildings. Techniques such as the Radial Basis Function (RBF) method improve the accuracy of repairs and reduce the processing time of point cloud data, leading to precise virtual reconstructions [2].

Despite their numerous advantages, conservators face challenges related to processing the large volumes of data generated by 3D scanning. This process requires advanced software as well as substantial time and financial investment [15]. Additionally, there is a pressing need to develop new standards for storing and sharing data to ensure the long-term availability and usability of 3D models [12].

Furthermore, point clouds are a valuable tool in the precise analysis and optimization of existing structures for compliance with accessibility standards and the accommodation of individuals with disabilities [11].

The use of digital technology in heritage protection also requires adapting point clouds to meet specific conservation needs, such as material analysis or the assessment of degradation in historic building elements [4]. Moreover, creating accurate inventories based on point cloud data can be time-consuming and often requires manual or semi-automatic techniques, increasing the complexity of the process. This was demonstrated in the case of the historic building Ye Olde Trip to Jerusalem [1].

The use of digital technologies, such as photogrammetry and Terrestrial Laser Scanning (TLS), significantly enhances the assessment of the technical condition of historic buildings. TLS enables the creation of precise point clouds, facilitating the inventory of complex structures, particularly in hard-to-reach areas [20]. This is especially useful for automating the documentation and evaluation of historic buildings. In the case of ruins, TLS allows for the precise documentation of complex and damaged elements, which is challenging to achieve with traditional methods [7]. These technologies enhance conservation and diagnostic activities, revolutionising the management of architectural heritage.

The aim of this publication is to present selected digital technologies used in the documentation and assessment of the technical condition of historic structures, along with their practical application in examples such as the Castle in Czersk, the ruins of Melsztyn Castle, the historic brickworks in Izbica, and the Juliusz Osterwa Theatre in Lublin.

2. Digital and traditional inventory methods

Technology plays an increasingly significant role in modern life, driving the development of numerous industries, including construction. Today, a variety of methods exist for acquiring spatial data of entire areas, construction objects, or machine components, differing primarily in efficiency and accuracy.

This study focuses on the most widely used methods, aiming to describe, compare, and evaluate their usefulness in the field of monument conservation.

Photogrammetry was selected as the representative technology for optical methods, while laser scanning was categorised into simplified, handheld, and stationary types, reflecting the diversity of laser scanning equipment available on the market (fig. 1).

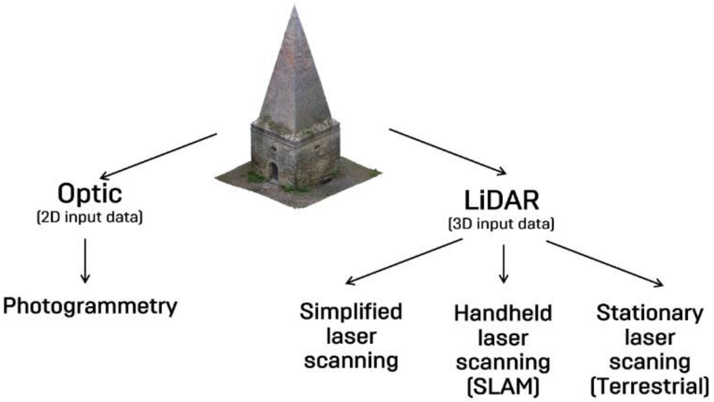

Fig. 1. Classification and types of selected digital methods LiDAR (Light Detection and Ranging) is a technology that measures distances by calculating the time interval between the emission and reception of a laser signal beam [5]

2.1. Traditional method of conducting building inventories

Before discussing digital methods, it is essential to review how geometric information about building structures has traditionally been obtained (fig. 2).

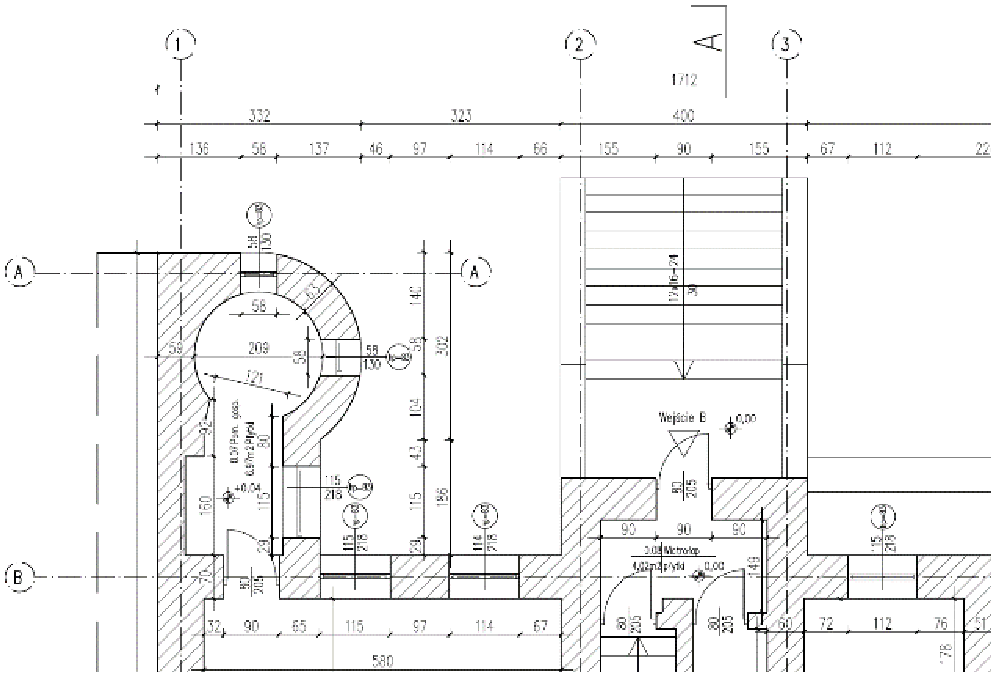

Fig. 2. Example of a building inventory drawing created using the traditional method

The traditional approach to conducting building inventories involves manually measuring distances between specific points in a structure using tools such as rulers, measuring tapes, or laser rangefinders. The measurements are recorded on a sketch, typically drawn by hand during on-site visits, which is later converted into a standard technical drawing [23].

When performing inventory measurements, it is necessary to collect all dimensions – both overall and detailed. For floor plans, measurements should be taken as close to the floor or ground level as possible. These measurements should include the full dimensions of each element along with the placement of all its architectural features [23].

This method is susceptible to numerous potential measurement errors due to factors such as the complexity and large size of objects, the monotonous nature of the work, and communication issues among the measurement personnel. In cases where the layout of a building's rooms lacks orthogonality, a significantly larger number of measurements is required. The accumulation of these errors can lead to substantial discrepancies between the actual state of the structure and the resulting inventory documentation.

2.2. Photogrammetry

The first digital method discussed in this study is photogrammetry. This technique has been known since the 1950s, where it was primarily applied in geodesy. However, it was not until the 1990s that computer algorithms enabled its use in industries beyond geodesy [16].

Photogrammetry involves obtaining spatial information from a database of standard photographic images. For accurate results, each photo in the database must include information about key parameters related to its capture, such as (fig. 3):

- The sensor size of the camera used,
- The focal length of the lens,
- The intended resolution of the photograph,
- The degree of digital zoom applied, and
- The approximate geographic coordinates of where the photo was taken.

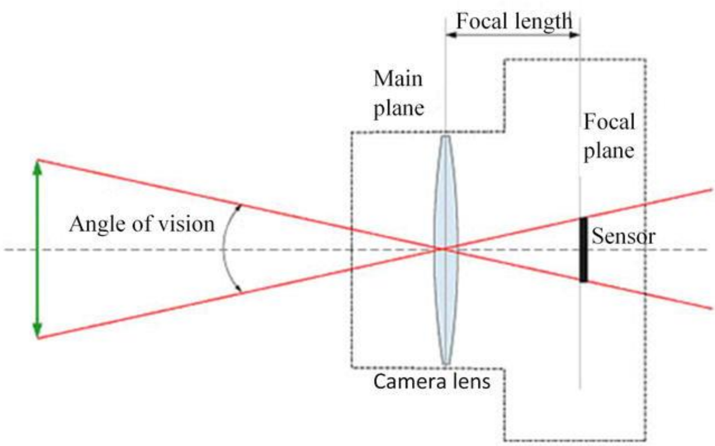

Fig. 3. Diagram illustrating the camera operation used to extract individual parameters [22]

If the photo database contains such information for each image, it can be effectively used in the photogrammetry method.

Another crucial factor is the technique used to capture the photos, which should be tailored based on an understanding of how the photogrammetry process works. Depending on the characteristics of the model being created, the photos should have an overlap of 30% to 70% (fig. 4). The perspectives should be as varied as possible to ensure comprehensive coverage. The number of photos should be adjusted according to the desired level of detail in the final model; the more photographs provided, the higher the resolution of the resulting model.

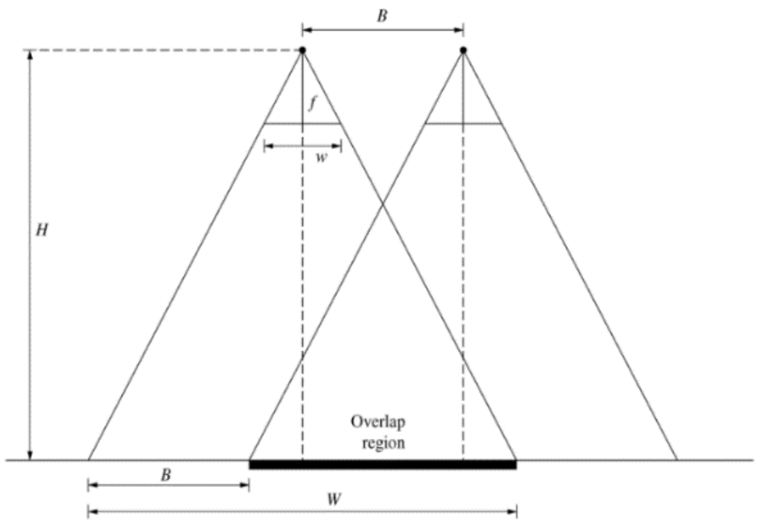

Fig. 4. Overlap between the captured photos [14]

To maximise the potential of the method, the entire photo database can be processed to enhance and highlight all the details of the photographed object.

Applying proper principles during photo capture and optimising the images in photo editing software can significantly accelerate the subsequent model creation process.

Once a database of photos is compiled using the appropriate techniques and includes the technical and optical parameters of their acquisition, as well as any necessary processing, the data can be used in specialised software for photogrammetric analysis.

In the initial stage, the software analyses each photo and generates a unique database for it, detailing the number and properties of all characteristic points identified in the image. Once all input images contain these individual data sets, the next stage involves their comparison. This requires the algorithm to compare every characteristic point extracted from each photo with all others. Consequently, the computational power and time required to create the model increase exponentially with the amount of input data. This effect can be mitigated by providing the algorithm with light hints, such as approximate geographic coordinates or the date and time each photo was taken, embedded as structured metadata (fig. 5). Such hints offer preliminary information about which photos were captured in proximity, streamlining the comparison process.

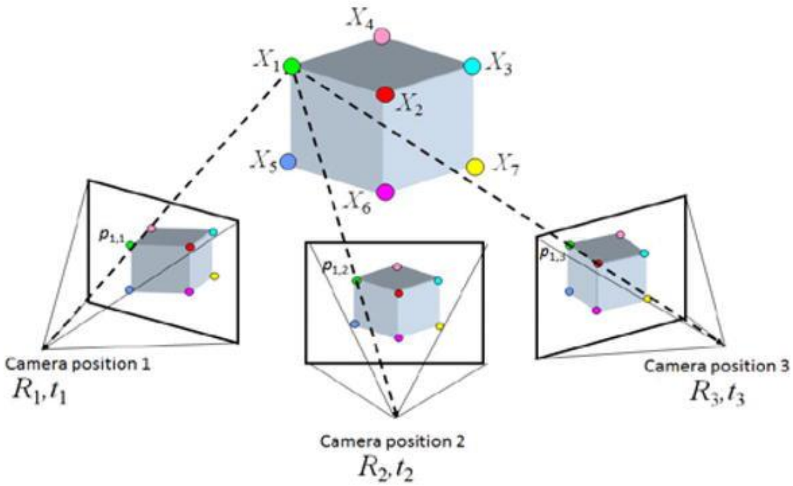

Fig. 5. Process of positioning points in space [22]

If the algorithm identifies similarities in the features assigned to points, it proceeds to determine the spatial position of each point by correcting the optical distortions that occurred during photography, using information contained in the preliminary data. A key requirement for positioning a point in space is its identification in at least two photos. Once this process is completed, the result is a generated point cloud of the created model. This point cloud is essentially a database containing the spatial coordinates of each point along with its assigned colour (fig. 6).

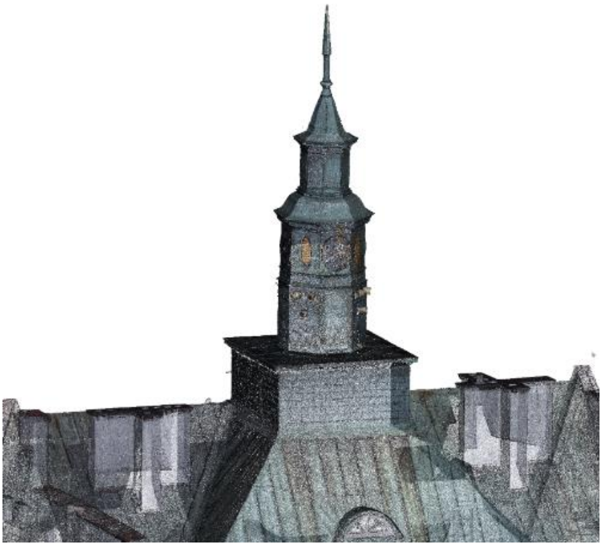

Fig. 6. Point cloud obtained through the photogrammetry method

The calculated point cloud is then processed through triangulation, a method that connects sets of three points with triangular planes to form a mesh, thereby transforming the point cloud into a 3D model (fig. 7).

Fig. 7. Model created from the point cloud

The final process is texturing the model. The software re-analyses the input photographs, extracts relevant fragments, and overlays them onto the raw mesh of the created model (fig. 8).

Fig. 8. Model with applied textures

The photogrammetry process also has certain limitations due to the method's operational characteristics. A primary challenge is the mapping of smooth, reflective surfaces with uniform colours. The algorithm may fail to extract characteristic points from such surfaces or may misinterpret them, resulting in dead zones within the point cloud structure or incorrect alignment of subsequent photos during analysis [27].

2.3. Simplified laser scanning

Simplified laser scanning is a form of scanning that utilises LiDAR technology. This method involves a moving laser beam to acquire spatial information about a measured point in relation to the spatial position of the scanning device.

Fig. 9. Visualization of the operation of simplified laser scanning [31]

The method described in this section serves primarily as an auxiliary tool in laser technology to determine the relative positions between scanning stations during virtual tours.

The result is a fully interactive virtual tour of the scanned space, featuring spherical photographs integrated within the generated model. The model itself is based on a simplified and automatically adjusted point cloud produced by the device, with texturing applied using the spherical photographs.

When conducting such scanning, several challenges may arise:

- The scanner's short laser beam range, approximately 4 metres, makes it unsuitable for scanning exteriors or large interior spaces.
- The method encounters significant difficulties in merging scans performed in narrow passages.
- Proper lighting of the scanned spaces is essential for successful application.
- The scanner's low accuracy and limited range necessitate a much larger number of stations to achieve a detailed representation of the scanned object.

2.4. Handheld laser scanning

Handheld laser scanning is another method that utilises LiDAR technology. What sets this method apart from others is the absence of fixed scanning stations; instead, the path along which the scanning device moves during measurements serves as the reference (fig. 10).

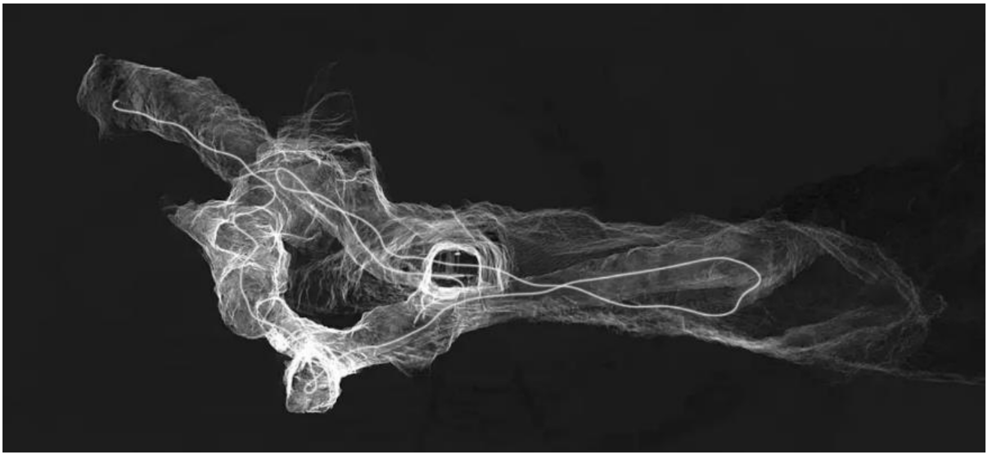

Fig. 10. Example of handheld laser scanning with a defined path [29]

The primary purpose of this method is to create a point cloud, as the models generated from it generally exhibit low accuracy. The scanner operates with a measurement efficiency of approximately 300,000 points per second [29], determining their positions relative to its current location, with a range of up to 100 metres [29]. It is equipped with apparatus to track its position in space, enabling continuous scanning by collecting new information about subsequent points relative to its changing location.

The scanner functions as a tool for capturing the geometric data of scanned objects, with the colours of the points determined based on the reflection intensity of individual materials. However, it can also be equipped with a camera, whose images can be used for simplified colouring of the points.

This method presents certain challenges:

- Replacing scanning stations with a continuous path introduces significant noise and errors into the point cloud, particularly from reflective surfaces, which can often penetrate the actual structures of the scan. These errors are difficult to isolate during subsequent processing.
- While scans are completed much faster and cover a large area of the building in a single pass—an advantage of the method—improper execution or incorrect settings can result in significant discrepancies between the actual state of the object and the generated point cloud. In comparison, scans conducted using fixed stations make it easier during processing to identify and address incorrectly generated scans.

2.5. Stationary laser scanning

Stationary laser scanning is the final digital method for acquiring spatial information and represents the most efficient and accurate application of LiDAR technology. In this method, the scanner's moving laser beam rotates around its horizontal axis, measuring the distance "S" to a point in space. By knowing the exact angle of beam emission, its direction, and the measured distance, the device calculates the position of point "P" in space using its coordinates "Xp" "Yp" and "Zp" (fig. 11, fig. 12).

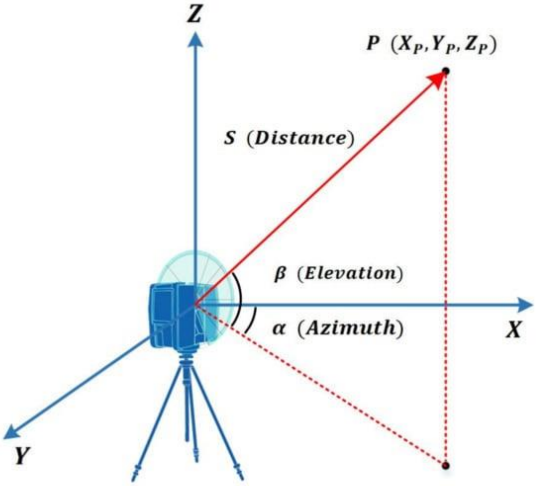

Fig. 11. Diagram of the operation of a stationary laser scanner [19]

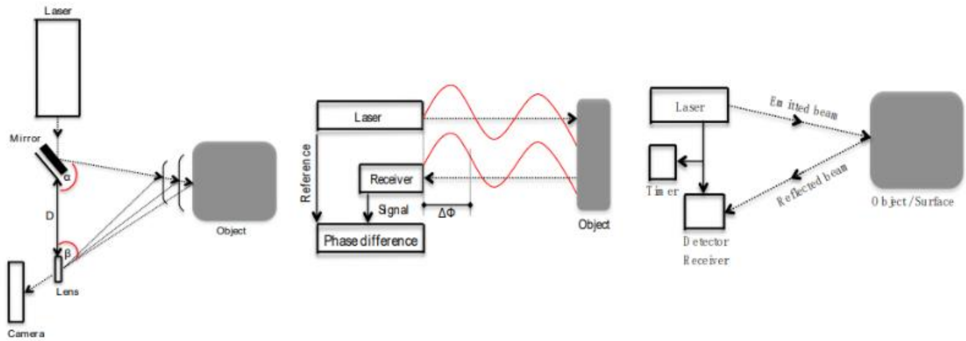

Fig. 12. Diagram of LiDAR technology operation [19]

The result obtained using this method is a high-density point cloud, providing an excellent foundation for creating a spatial model. The scanner operates with a measurement efficiency of 1,000,000 to 2,000,000 points per second [30], and its individual stations represent sets of points visible from a single scanner perspective. Depending on the device model, the measurement range can extend up to 350 metres [30].

The raw data from the scanner consist of separate point clouds from each station. During digital processing, the software identifies geometric similarities between scans and aligns them to produce a complete point cloud.

The alignment process can be enhanced by using specific targets placed within the scanner's visibility range. These targets, manually or automatically identified by the software, serve as hints for the algorithm, indicating common features between stations. This approach significantly improves the final point cloud's accuracy in relation to reality [15].

The scanner also captures high-resolution spherical photographs, which help identify stations within the software and are used to colourise the collected spatial points.

When using this method, several considerations should be noted:

- Calibration and Maintenance: The scanner's high efficiency and accuracy require careful attention to its calibration and regular maintenance.

- Line of Sight Limitations: The scanner records only what is visible from its perspective. To capture an object in its entirety without blind spots, a large number of scanning stations is necessary.
- Reflective Surfaces: Reflective surfaces can cause the laser beam to bounce back incorrectly, resulting in erroneous distance readings. Areas with reflective surfaces should undergo additional processing to refine individual stations.

2.6. Summary

In summary, digital methods such as 3D scanning have significantly improved the process of inventorying building structures, particularly in the context of monument conservation. Unlike traditional methods, which rely on manual measurements, are time-consuming, and prone to numerous errors, 3D scanning offers far greater efficiency and precision [9].

Technologies like photogrammetry and various forms of laser scanning (simplified, handheld, and stationary) enable the rapid and accurate acquisition of vast amounts of spatial data. These technologies make it possible to create detailed 3D models of structures, significantly reducing work time and minimising the risk of measurement errors. 3D scanning allows even the most complex structures to be reproduced with high accuracy, a feat that is challenging to achieve using traditional methods [22].

Additionally, the ability to process and analyse data in a digital environment opens up new opportunities for documenting and conserving historical objects. This capability facilitates the planning of conservation efforts and contributes to the improved preservation of cultural heritage.

3. Case study

Tools such as laser scanning and photogrammetry are transforming the processes of building inventories and technical condition assessments, particularly for structures of historical significance. These advanced technologies not only enable the precise digital reproduction of objects but also allow for detailed structural and material analyses. They facilitate the rapid and accurate acquisition of large volumes of data, improving the efficiency and quality of conservation and renovation efforts.

Benefits and capabilities of digital technologies in assessing technical condition:

- Precise geometric reproduction of objects: Accurate 3D models enable detailed examination of a structure’s geometry without physical interference.
- Rapid data acquisition: Significantly reduces the time required for inventory compared to traditional methods.
- Minimisation of measurement errors: Automation of the measurement process reduces the likelihood of human error.
- Analysis of deformations and structural damages: Detects cracks, deformations, detachments, and other structural anomalies.
- Documentation of technical condition: Generates detailed maps and plans to support conservation planning.
- Monitoring changes over time: Enables comparisons of models created at different intervals, allowing the tracking of degradation or evaluating the effectiveness of repairs.

- Access to hard-to-reach places: Allows scanning of difficult-to-access areas without invasive techniques such as scaffolding.
- Integration with other systems: Facilitates data integration with BIM (Building Information Modelling) and GIS (Geographic Information Systems).
- Support in educational and promotional processes: Utilises 3D models for educational, tourist, or promotional purposes, promoting cultural heritage awareness.

Capabilities achieved in the field of technical condition assessment:

- Identification and localisation of damages: Precisely determines the locations of cracks, fissures, detachments, corrosion, and other defects.
- Geometry and deformation analysis: Detects deviations from standard geometry, potentially indicating structural issues like foundation settlement.
- Material condition assessment: Evaluates material surfaces for corrosion, biological growth, moisture, or salt deposits.
- Planning conservation interventions: Provides precise data to develop repair plans and select appropriate methods and materials.
- Archival documentation creation: Preserves accurate records of an object's condition, particularly important for structures prone to rapid degradation.
- Support in structural analyses: Supplies data for numerical simulations and strength assessments.
- Enhanced communication among specialists: Facilitates information sharing between engineers, architects, and conservators through detailed models and reports.

In the following sections, specific case studies will be presented, showcasing the application of digital technologies in assessing the technical condition of historical structures, such as the ruins of Melsztyn Castle, the Castle in Czersk, the historic brickworks in Izbica, and the Juliusz Osterwa Theatre in Lublin. These examples will illustrate how the outlined benefits and capabilities have been applied in practice, demonstrating the effectiveness and utility of methods like laser scanning and photogrammetry in monument conservation efforts.

3.1. Ruins of the Melsztyn Castle

The first site analysed for the application of digital technologies is the ruins of Melsztyn Castle. Due to the challenging, overgrown surroundings and densely forested area (fot. 1, fot. 2) traditional documentation and assessment methods proved inadequate. The use of modern tools enabled the following:

- Precise mapping of terrain topography: By separating vegetation from the ground during point cloud processing, an accurate terrain model was created (fig. 13).
- Accurate identification of ruin locations: This allowed for detailed structural analysis and the planning of protective measures.
- Generation of surface layouts of the ruins: This aided in identifying the specific areas included in the study.

Fot. 1. Photographic representation of the hill

Fig. 13. Point cloud of the hill

The main advantage of using modern digital technologies was the ability to analyse the precise topography of the terrain surrounding the object by separating vegetation from the ground during point cloud processing (fig. 14).

Fot. 2. Photographic representation of the terrain topography

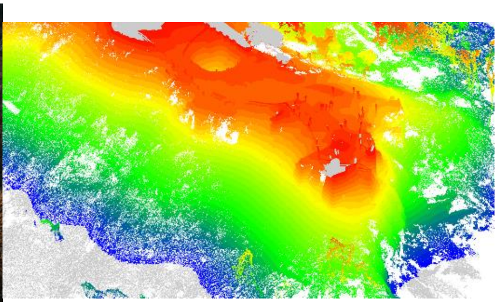

Fig. 14. Hypsometry of the terrain's topography

Additionally, cross-sections were generated on the surfaces of the identified castle ruins (fig. 15).

Fig. 15. Cross-section of the point cloud on the surface of the castle ruins

The ruins of Melsztyn Castle, surrounded by dense vegetation and challenging terrain, presented significant difficulties for traditional inventory methods due to limited accessibility and safety concerns. Digital technologies, such as LiDAR laser scanning and drone-based photogrammetry, were employed to accurately map the structure and its surroundings, effectively separating vegetation from structural elements. This approach resulted in the creation of a detailed 3D model of the ruins and an accurate terrain elevation map, enabling the identification of structural damage and the planning of conservation works. These technologies provided time and resource efficiency, enhanced safety, and produced enduring documentation of the site's condition [18].

The example of Melsztyn Castle demonstrates how advanced digital technologies can effectively address the limitations of traditional methods and support the preservation of cultural heritage (table 1).

Table 1. Use case parameters

Technologies used	Photogrammetry and laser scanning
On-site time	6 hours
Amount of collected data	Approx. 2,000 photos and 20 scanning stations
Processing time	16 hours
Scanned area	9,500 m^2
Accuracy	~5 cm

3.2. Castle in Czersk

Another example of the application of digital technologies in assessing the technical condition of historical structures is the Castle in Czersk (fig. 16). In this case, modern tools enabled the creation of precise elevation views, allowing for detailed architectural analysis of the building. Additionally, these technologies were employed to examine the delamination of the wall crowns and facing layers, which is essential for evaluating structural stability and planning conservation efforts. Through the use of digital methods, hidden damages and material degradation, often overlooked with traditional techniques, could be identified. The case study of the Castle in Czersk highlights how advanced technological tools can support the diagnosis and preservation of cultural heritage.

Digital technologies facilitated:

- Obtaining precise elevation views: Enabling detailed architectural and historical analysis of the structure.
- Examination of delamination in wall crowns and facing layers: Detecting areas where the facing layer deviates from the wall plane, critical for assessing structural stability.
- Generation of deformation maps: Assisting in the planning of necessary repair works

Fig. 16. View of the point cloud of Czersk Castle

The point cloud was analysed geometrically by colouring points based on their specified coordinates. Subsequently, maps were created to identify areas where the facing layer of the wall deviates from its plane (fig. 17, fig. 18).

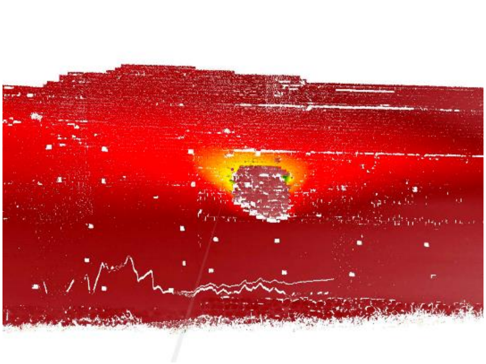

Fig. 17. Hypsometry of the wall face

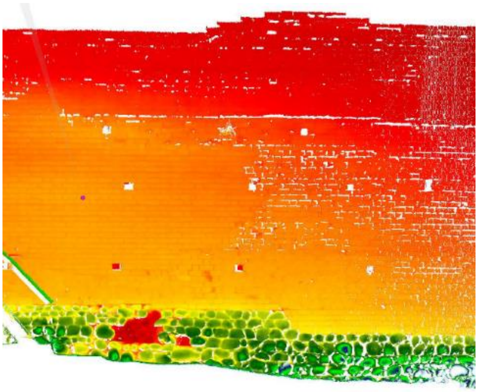

Fig. 18. Hypsometry of the wall face

The Castle in Czersk, with its complex geometry and hard-to-reach areas, posed challenges for accurate inventory using traditional methods. The use of digital technologies, such as stationary laser scanning and photogrammetry, facilitated precise mapping of the structure and the creation of a detailed 3D model. This approach revealed hidden damages, including delamination of the wall's facing layer and micro-cracks, enabling effective conservation planning. The collected data also allowed for the analysis of environmental factors and the preservation of unique architectural details for research and educational purposes. The integration of these technologies enhanced work safety, saved time and resources, and contributed to the improved preservation of cultural heritage (table 2).

Table 2. Use case parameters

Technologies used	Photogrammetry and laser scanning
On-site time	4 hours
Amount of collected data	Approx. 1,800 photos and 20 scanning stations
Processing time	12 hours
Scanned area	8,300 m^2
Accuracy	~5 cm

3.3. Historic Brickworks in Izbica

The historic brickworks in Izbica is another example of the application of digital technologies (fig. 19). In this case, modern tools facilitated the generation of precise surface analysis maps for the ceilings and structural trusses of the hall. This enabled the accurate identification of deformations, damages, and weaknesses in the building's structure, which is essential for planning conservation and renovation works. The case study of the brickworks in Izbica demonstrates how digital technologies can support the assessment of the technical condition of complex industrial structures, aiding their preservation and adaptation for modern purposes.

The application of digital technologies at the historic brickworks in Izbica enabled:

- Generation of accurate surface analysis maps of the ceilings: Deformations and potential structural weaknesses were identified.
- Analysis of the geometry of the hall's structural trusses: Anomalies in the structural arrangement were detected, facilitating the evaluation of the object's load-bearing capacity and safety.
- Easy localisation of areas requiring intervention: Hypsometric maps indicated areas of increased risk.

Fig. 19. View of the point cloud of the historic brickworks

By analysing the upper surface of the industrial ceiling, the geometry of the trusses, and generating hypsometric maps, it becomes possible to easily and clearly identify areas exhibiting anomalies relative to the whole (fig. 20, fig. 21).

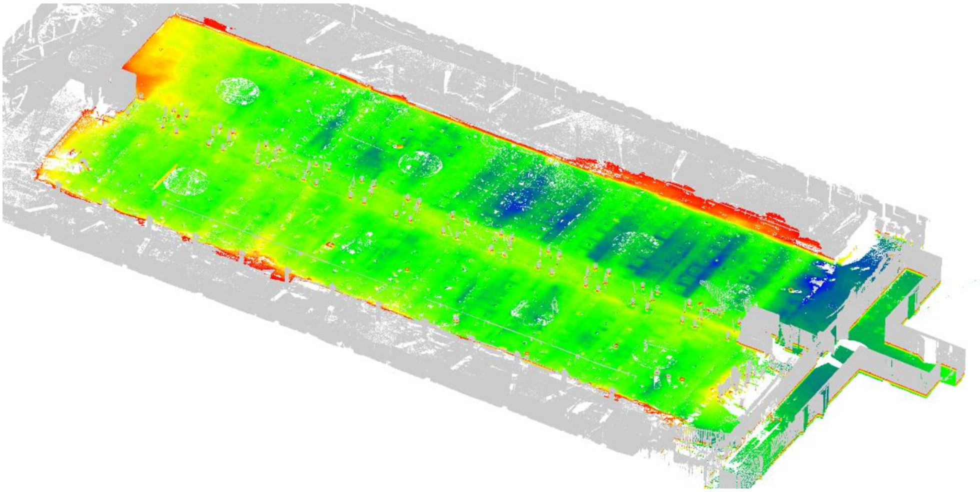

Fig. 20. Hypsometry of the industrial ceiling surface

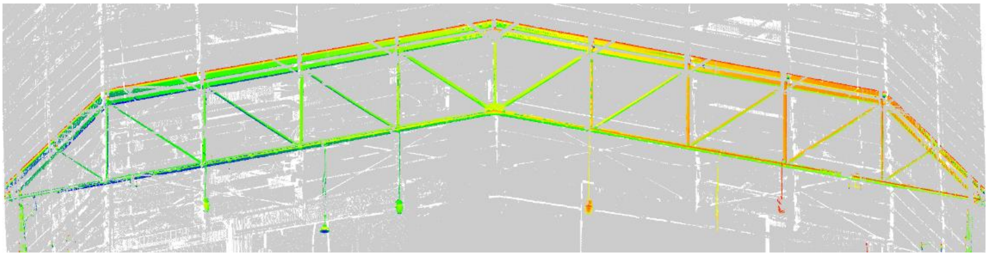

Fig. 21. Analysis of the geometry of the steel truss in the production hall

The historic brickworks in Izbica, an early 19th-century industrial complex, features a complex steel-masonry construction that posed challenges for traditional technical condition assessments. The use of stationary laser scanning and photogrammetry allowed for precise mapping of the construction geometry, including ceilings and trusses, and facilitated the detection of deformations, deflections, and corrosion. Accurate hypsometric maps were generated to identify areas prone to overload and damage, enabling effective planning of conservation and renovation works. This technology enhanced work safety by eliminating the need for hazardous measurements at heights and contributed to time and resource savings. The brickworks in Izbica exemplifies how modern digital technologies can effectively support the assessment of complex industrial structures and contribute to the preservation of cultural heritage (table 3).

Table 3. Use case parameters

Technologies used	Photogrammetry and laser scanning
On-site time	4 hours
Amount of collected data	Approx. 1,500 photos and 30 scanning stations
Processing time	10 hours
Scanned area	8,800 m^2
Accuracy	~5 mm

3.4. Juliusz Osterwa Theatre in Lublin

The final object included in this study is the Juliusz Osterwa Theatre in Lublin. By combining laser scanning and photogrammetry, highly accurate elevation drawings of the building were generated (fig. 22, fig. 23). This advanced approach facilitated the creation of detailed graphic inventories documenting various types of damage to the elevations. The precise documentation of the façades' technical condition enabled a comprehensive analysis of material degradation and the planning of effective conservation measures [28]. The case study of the Juliusz Osterwa Theatre demonstrates how integrating modern digital technologies can greatly enhance the process of diagnosing and preserving historical architectural structures.

The combination of laser scanning and photogrammetry enabled:

- Generating highly accurate elevation drawings: Detailed architectural documentation was produced.
- Developing graphic inventories of damage: Various types of damage on the elevations were precisely identified and marked.

Fig. 22. View of the 3D model of the theatre

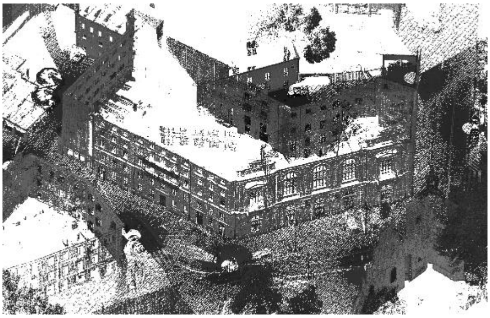

Fig. 23. View of the point cloud of the theatre

Generating cross-sections with very high resolution enabled the precise identification and marking of damages on the elevations. The following types of damage were identified:

- Surface cracks,
- Scratches and fissures,
- Corrosion of steel elements,
- Losses of plaster / Exposure of structural material,
- Biological corrosion and efflorescence,
- Moisture,
- Salt deposits.

The Juliusz Osterwa Theatre in Lublin, a historic building with richly decorated façades, presented challenges for traditional inventory methods due to its intricate architectural details and hard-to-reach elements. The use of laser scanning and photogrammetry enabled the precise mapping of all façade elements and the creation of detailed 3D models. This approach allowed for the accurate identification and categorization of façade damages, including cracks, scratches, corrosion, and moisture, facilitating the planning of effective conservation measures (fig. 24). These technologies improved efficiency and safety by eliminating the need for hazardous measurements at heights and reducing the time required for inventory. The case of the theatre in Lublin illustrates how modern digital technologies can greatly enhance the diagnosis and preservation of historical architectural structures (table 4).

Fig. 24. Graphic inventory of the theatre façade damages

Table 4. Use case parameters

Technologies used	Photogrammetry and laser scanning
On-site time	8 hours
Amount of collected data	Approx. 6,000 photos and 50 scanning stations
Processing time	35 hours
Scanned area	4,000 m^2
Accuracy	~5 mm

4. Summary and conclusions

The article explores the application of modern digital technologies, such as 3D scanning and photogrammetry, in assessing the technical condition of historical structures. It compares traditional and digital inventory methods, emphasising the advantages of the latter in acquiring spatial data with precision and speed. Three types of laser scanning are outlined: simplified, handheld, and stationary, along with their specific uses in monument documentation. The importance of integrating point cloud data with HBIM models is highlighted, as this integration supports conservation processes and facilitates the planning of restoration works.

The article includes case studies demonstrating the use of digital technologies for the analysis and conservation of sites such as the ruins of Melsztyn Castle, the Castle in Czersk, the historic brickworks in Izbica, and the Juliusz Osterwa Theatre in Lublin. These examples illustrate how digital methods improve inventory accuracy, allow for the detection of damages invisible to the naked eye, and save both time and resources. Challenges related to processing large volumes of data and the necessity for specialised expertise and standards are also addressed. In conclusion, the use of digital technologies in cultural heritage preservation offers substantial benefits and is invaluable for safeguarding monuments for future generations. Additionally, point clouds generated through other works can assist civil engineers in accurately assessing technical conditions and the extent of destruction.

The key conclusions influencing a more precise and comprehensive assessment of the technical condition of historic objects are as follows:

- Increased accuracy and efficiency: Digital technologies greatly enhance the precision and speed of inventorying historical objects compared to traditional methods.
- Detection and analysis of damages: 3D scanning and photogrammetry enable the identification of even minor damages and deformations, crucial for maintaining the structural integrity of monuments.
- Time and resource savings: Automated measurement processes reduce the time and costs associated with inventorying and planning conservation works.
- Enhanced safety: Remote analysis of objects minimises risks to personnel by eliminating the need for physical access to hazardous or hard-to-reach locations.
- Durable documentation: Digital 3D models provide long-lasting and accurate records of an object's condition, essential for future research and conservation efforts [26].
- Integration with other systems: Data can be easily incorporated into BIM and GIS systems, supporting comprehensive management of historical objects [8,14,25].
- Education and heritage promotion: Digital models can be used for educational and promotional purposes, raising awareness and encouraging social engagement in monument protection [17].
- Technological challenges: Processing large volumes of data requires advanced hardware and software, potentially increasing costs.
- Standardisation needs: Developing standards for storing and sharing 3D data is essential to ensure their long-term availability and usability.
- Adaptation to specific needs: Digital models must be customised to meet unique conservation requirements, such as material analysis or the study of historical construction techniques.

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