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Application of Information Technology for the Preservation of Architectural Monuments

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Abstract

The preservation of historical and cultural heritage sites is a pressing issue both in global practice and in the Republic of Belarus. Typically, it involves the collection, analysis, and processing of historical data, technical condition surveys, as well as planning and execution of repairs, conservation, and restoration. However, the most effective approach is to complement classical methodologies with information modeling technologies, including laser scanning to obtain a point cloud that accurately reflects the complex geometry of a structure, and enabling the creation of a unified source of information about the object throughout its entire life cycle based on a digital information model. Using detailed examples of several architectural monuments, including those in Belarus, the authors present the results of their technical assessment employing information technologies. The obtained results can be used to create a digital repository of historical and cultural heritage sites for the purpose of effective management and preservation for future generations.

Keywords

Historical and cultural assets, Laser scanning, Photogrammetry, BIM-technology, HBIM-technology.

1 Introduction

One of the fundamental conditions for sustainable development and national security of the Republic of Belarus is the preservation of its historical and cultural heritage, including monuments of architecture, town planning, archeology. The main document for their registration is the National Register of Historical and Cultural Values of the Republic of Belarus (gosspisok.gov.by). Currently, it contains more than 5.6 thousand objects, including more than 1.8 thousand architectural monuments (Hodor, 2023). In order to popularize the historical and cultural heritage, develop tourism and strengthen the prestige in the international arena, Belarus is actively engaged in the preservation and restoration of architectural heritage. This is an important social task, a promising direction for solving of which is the use of modern information technologies that have proved themselves throughout the world.

2 The issue theory

4.1 Inspection of the technical condition of the object

Regular inspections of the object' condition help to promptly identify risks, as well as improve the conditions of its operation. Classical approaches to the inspection and documentation of information about the object include determining the historical and architectural value of the object and assessing its technical condition. To develop scientific and design documentation for the implementation of repair and restoration work, complete and factual information is required, which includes: historical background of the object, location of the object, assessment of historical, scientific, cultural or other significance, information about the owner and user, additional information about events and personalities associated with the object, archival and bibliographic sources and technical condition. A peculiarity of architectural monuments is the frequent absence of any documents and drawings, as well as difficulties in measuring the geometric parameters of tumbledown buildings manually. In this regard, their inspections using standard geodetic survey methods are often irrational or impossible. In this case, laser scanning and photogrammetry methods is used, and the elements are presented in a frame of the article.

4.2 Laser scanning and photogrammetry

The principle of operation of laser 3D scanners is that a directed laser beam is reflected from the surface of an object, forming a cloud of points. Each point has its own coordinates X, Y, Z in space. The corresponding software defines them and creates a ready-made three-dimensional digital model based on the received data (Alekseev et al, 2020, Shamarina et al, 2020).

Scanning occurs from several stations to obtain complete information about the geometric shape of objects, because a complex object is often not visible from one observation point. To combine scans made from different stations, the stitching process is used. The result is stitched point clouds and 3D models with a high degree of detailed elaboration (spatial resolution - up to several millimeters). Photogrammetry is based on a mathematical algorithm that calculates the position of points in space by assessing their mutual arrangement from a large number of photographs, depending on the illumination and depth of resolution in different pictures (Kozin, 2018). The uniqueness of this method is that the results of acceptable quality can be obtained even with a regular smartphone.

During the photo processing process, an extended point cloud is created, which can be used to create a polygonal mesh. At the last stage, the resolution is calculated and the correspondence of pixels to the polygons of the resulting mesh is determined to set the color. To implement this technology, unmanned aerial vehicles are used which allows aerial photography of the object. The use of laser scanning and photogrammetry for historical and cultural heritage sites allows for the following advantages:

- As a result of the implementation of this technology, a huge array of data about the object is obtained, which allows to recreate its geometric model, and, if necessary, informational one;
- High accuracy of the obtained models (up to several millimeters);
- High speed of data acquisition;
- Possibility of taking measurements in hard-to-reach places, maximum accurate recording of complex geometry, defects and damage;
- All data is obtained immediately in digital form;

- Surveying is carried out remotely, which significantly increases the safety of the work;
- Currently, most design programmes have the ability to download and use point clouds for subsequent modeling and tracking of collisions during construction work.

However, there is also a significant drawback of this method, which is that the obtained point clouds contain a huge amount of data, which significantly complicates direct work with them (López et al, 2018).

Therefore, the next step should be the implementation of the "Scan to BIM" technology, which is the process of reverse designing of space or an object from the real world. It envisages obtaining geometric and visual data using laser scanning or photogrammetry technologies, and then converting them into a digital information model.

An intermediate stage on the way of solving this problem is the "Reality capture" technology, which allows to create 3D models based on photographs or laser scans, characterized by a high degree of detail elaboration and accuracy. It allows you to save the coloration, texture of surfaces, as well as geographic reference. Special software is used to import and convert a point cloud, for example, Autodesk Recap. Later on, a 3D model in rcp format can be loaded into various software for information modeling. In addition to a geometric model, such programs can create an information model by adding the necessary attribute information available in the design and any other documentation. Therefore, such a model can later be used to obtain all the necessary working documentation (drawings of plans, sections, facades, units, interiors), as well as for photorealistic visualization, animation and augmented reality. A point cloud can also be converted into a polygonal 3D model, which may be used for 3D printing and prototyping.

4.3 Creation of a digital information model

Despite the fact that BIM (Building Information Modelling) technologies are already widely used worldwide in the new construction sector, BIM of historical and cultural heritage sites is a relatively new area of scientific research. BIM technology in the global sense consists of creating a single source of information about an object throughout its entire life cycle, which, as a rule, must contain a digital information model. The definition in stanbdards GOSTR 57563- 2017/ ISO/TS 12911:2012 is the following:

"An information model is an object-oriented parametric three-dimensional model that digitally represents the physical, functional and other characteristics of an object (or its individual parts) as a system of information-rich elements" (Standartinform, Moscow, 2017).

A digital information model of an architectural monument consists of:

- documents and data in the form of a geometric model (presented in the BIM software environment in the form of visualizations, graphs and sheets);
- non-geometric information (materials, outside view, condition, information on the object commercial value, management and maintenance data, environmental, structural, mechanical characteristics, as well as information on the cultural, historical and architectural value of the object);
- related documents and data (archival drawings, photographs, written sources, records or any other type of digital or digitized data, operation and maintenance manuals, reports on the inspection of the condition of the object, etc.).

The elaboration of a digital information model of historical and cultural heritage sites is associated with the recreation of various complex architectural and decorative elements that are not included in standard templates and libraries of well-known software packages (Mais, 2024). In the case of significant destruction of elements, their recreation is associated with additional research of archival historical documents, which requires significant amount of time and effort. Besides, design and decorative solutions, as well as the functional purpose of the object, can change over time, which should also be taken into consideration by the digital information model, for which the staging of elements can be used. In this regard, a new HBIM (Historic Building Information Modelling) solution, which contains specialized databases of historical architectural elements, was worked out (Kamaruzaman, 2019 and Lovell et al 2023). HBIM is the basis for collaborative work processes and the exchange of coordinated databases in an interdisciplinary team, which makes this technology ideal for heritage conservation purposes, management and research tasks throughout the life cycle of objects

(Tobiáš, 2016). In this case, a digital information model can be created with the help of various software and then uploaded onto various platforms for managing the life cycle of a building in the form of an open standard for IFC data interchange. The common data environment allows specialists from various fields to have access to all the information about the object and, accordingly, make the most informed and effective collective decisions on managing the object. Such an approach can become a platform for cooperation between architects, historians, archaeologists, engineers, technical specialists, owners, authorities, and tourism industry specialists, which will contribute to popularizing architectural monuments (Piaia et al, 2020).

To create a common data environment, both well-known solutions for designed buildings and structures (e.g., Pilot-BIM, Savchikov, 2024) Autodesk Navisworks and unique specialized solutions for historical and cultural heritage sites (e.g., the interactive Inception platform presented by Piaia et al, 2020) can be effectively used.

Thus, a digital fund of historical and cultural heritage sites can be created for the purpose of effective management, maintaining the fund in a satisfactory condition, and calculating the required material costs.

It should be noted that the implementation of BIM in relation to historical and cultural heritage sites requires the development of specialized standards and guidelines that should take into account special problems of specific unique projects (Argasiński et al, 2023).

4.4 World experience in applying information technology to historical and cultural heritage sites

Currently, the use of BIM technologies in the field of architectural heritage conservation is most developed in Great Britain, which is caused by government policy which defines the requirements for the use of information modeling in construction. One may point out the reconstruction of the A1(M) Leeming to Barton motorway (A1L2B), where with the help of BIM model was simulated the impact on archaeological sites around Forth Bridge during the widening of the existing road; the repairs of Edinburgh Waverley railway station, mainly the ticket office; the restoration of Woodseat Hall in Staffordshire and the Oriental Club at Stratford House in London, etc. (Brajan et al, 2019).

One of the most striking examples of the use of BIM technologies for the preservation of historical and cultural heritage is the restoration of Notre-Dame de Paris, which was damaged by a fire that occurred in 2019. For this purpose, Autodesk created an information model of Notre-Dame de Paris in the Revit software package. An accurate recreation of the model of the cathedral building became possible thanks to the fact that in 2010, with the support of a European documentary film about art, laser scanning of Notre-Dame de Paris was carried out using a Leica Geosystems laser scanner (Sandron et al, 2013). The BIM model of the cathedral was used not only to accurately recreate the structural elements, but also to plan logistics on the construction site, as well as adopt safety measures. Besides, it is planned to use the BIM model at the stage of operation and maintenance, associated with Internet of Things (IoT) sensors to ensure fire safety in future.

In Europe, laser scanning and photogrammetry have become standard tools for heritage documentation. In Italy, the “Scan-to-BIM” approach was applied to the Colosseum and the Pompeii archaeological site, enabling the creation of highly detailed models for conservation monitoring and virtual anastylosis of fragmented structures. The Italian Central Institute for Cataloguing and Documentation (ICCD) has issued national guidelines that integrate 3D surveying into the regular condition assessment of monuments. In Spain, the restoration of the Romanesque church of Santa María de Naranco (Oviedo) employed terrestrial laser scanning combined with historic BIM to map deformations caused by structural settling. Spanish researchers have also developed open-source workflows for converting point clouds into parametric HBIM elements, reducing the manual modeling effort for complex vaults and columns.

China has made significant progress in digitizing its vast heritage, including the Forbidden City and the Great Wall. The Palace Museum in Beijing uses a combination of drone-based photogrammetry and terrestrial scanning to create multi-resolution models that support both restoration and tourism management. Similarly, in Japan, laser scanning of the wooden temple complex of Hōryū-ji (Nara Prefecture) has enabled the precise recording of traditional joinery techniques, facilitating future replacements using original methods.

In the United States, the National Park Service has adopted 3D laser scanning for monuments such as the Statue of Liberty and Mount Rushmore. The scans are used not only for deterioration analysis but also for generating emergency response models in case of natural disasters or terrorist attacks.

Furthermore, the “Heritage Documentation Programs” (HABS/HAER/HALS) now require digital point-cloud deliverables alongside traditional drawings. The Russian Federation, much attention is paid to the preservation of wooden architecture objects using laser scanning, photogrammetry and information modeling technologies. The most famous are the studies of V.V. Talapov, including those in collaboration with A.Yu. Mainicheva in the creation of "smart wooden architecture monuments" (Anna Yu et al, 2023). Despite these widespread applications, common challenges remain: lack of standardized metadata schemas for heritage BIM, high computational cost for processing dense point clouds, and the need for interdisciplinary collaboration between engineers, historians, and conservators. International organizations such as ICOMOS and ICCROM have recently launched working groups to address these gaps, publishing preliminary guidelines for the use of HBIM in world heritage sites (Varenik et al, 2023).

3 Materials and Methods

The following research methods were used in the work:

- Collection, systematization and analysis of data on historical and cultural heritage sites of the Republic of Belarus.
- Visual inspection of the technical condition of building structures of historical buildings in accordance with СН 1.04.01-2020 "Technical condition of buildings and structures" (Minstrojarhitektury, Minsk, 2020) and СП 1.04.02-2022 "General provisions for the inspection of buildings and structures" (Minstrojarhitektury, Minsk, 2020).
- Laser scanning of historical buildings with the help of Leica BLK360 3D laser scanner.
- Digital information modelling of architectural monuments.

4 Results

Preservation of the cultural heritage of the Republic of Belarus is directly related to the protection of architectural monuments. This process includes historical and archaeological research, inspection of the technical condition of the object, planning and implementation of repairs, conservation and restoration. The most effective way to do this is to use modern information technologies, namely 3D laser scanning, photogrammetry, information modeling, which have proved themselves well all over the world. Thus, the plan for inspecting an architectural monument may include the following stages:

- Collection, systematization, and analysis of data on the historical and cultural heritage sites of the Republic of Belarus.
- Inspection of the technical condition of the historical building structures.
- Creation of a 3D model (polygonal, solid) for the possibility of subsequent modeling of the object.
- Creation of a digital information model of the object.
- Supplementing the digital information model with the results of the technical inspection.
- Application of the common data environment for the effective management of an architectural monument at the stages of repair, conservation, restoration.

The industry laboratory "Research Center for Innovations in Construction" and the Department of Building Structures of the Educational Institution "Brest State Technical University", which are represented by the authors of the article, make their contribution to the preservation of the historical and cultural values of Belarus. Thus, the authors have carried out inspections of a number of architectural monuments, both in the traditional way and using laser 3D scanning and information modeling technology. The results of the studies are described below.

4.1 Building of the former Bernardine Monastery on the territory of the Brest Fortress

This architectural monument is included in the National Register of Historical and Cultural Values of the Republic of Belarus and belongs to category "1". The surviving part of the building was built in 1680 as a Bernardine catholic church in the Baroque style with a sculpture of Christ in an arched niche above the entrance. The building was crowned with a four-tiered tower with a belfry. Sculptures of

saints were installed in seven altars. In 1780, the building was reconstructed. On the eve of the Great Patriotic War, these buildings housed Brest military hospital No. 2396. At the time of the survey, only the walls of the first floor with ceilings, basement ceilings, basement walls, and foundations remained in the building. The walls of the second floor were partially preserved (Shuryn, et al, 2023). Fig. 1 shows a general view and the results of the object laser.

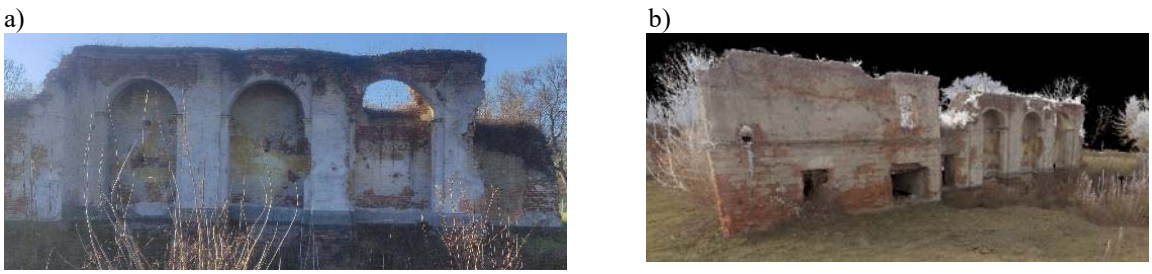


Fig. 1 General view (a) and laser scanning results (b) of the Bernardine Monastery.

The external and internal walls, arched vaults and ceilings are made of solid red fired brick M75 on lime-sand mortar M15. In some sections, due to the re-planning of internal walls and partitions in the 18th and 19th centuries, the masonry is made of other M75 brand bricks on M25 mortar. The ceilings of the 1st floor and above the basement are made mainly in the form of cross vaults. It should be noted that in order to perceive the thrust arising in the masonry of the brick vaults, iron ties made of forged steel of rectangular cross-section bxh = (22…24)x(40…44) were used in the spring arches supporting them (Fig. 2). The ties are installed above the level of the arch heels, and their ends are embedded in the masonry of the load-bearing walls with external anchoring (the cotter pin is brought out beyond the wall of the building). The specified ties take only part of the theoretical full thrust, i.e. they do not independently guarantee the immobility of the arch heels. As internal (additional) connections, the ties prevent the outward deformation of the side sections of the vaults and the sagging of their locking part.In the 20ies-30ies of the 20th century, as a result of re-planning, some of the floors were made in the form of ceramic hollow stone, reinforced with strip steel installed in mortar joints. It was established that as a result of long-term temperature and humidity effects on the structures of walls, floors and foundations (due to the lack of a roof), the following defects and damages are present: cracks in the masonry with an opening width of up to 30 mm; local collapses and destruction of the masonry;destruction of brickwork above window and door openings; thawing of brickwork to a depth of up to 250 mm; bio-destruction of the masonry by the root system of trees; bricks falling out of wedge-shaped lintels and their partial destruction and– destruction of the external layer facing of the brickwork. Part of the brick vaults of the first floor collapsed, thereby overloading the ceiling above the basement and the foundations.

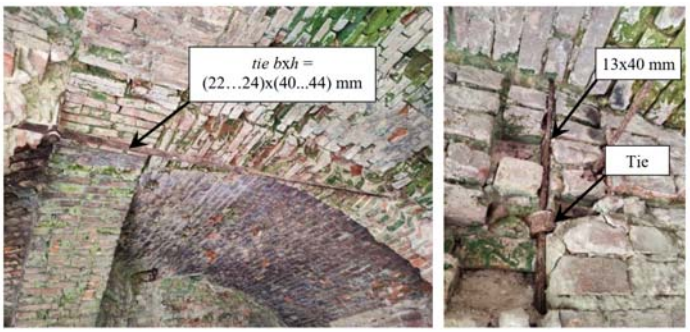


Fig. 2 Reinforcement of a collapsed spring arch with an iron tie (a) and anchoring of the tie in a brick wall (b) [20].

As a result, excessive sagging appeared in the ceiling above the basement (exhaustion of the group of operational suitability), which is fraught with their collapse (Shuryn et al, 2023).

4.2 The chapel-burial vault of the Tollochko kin in the village of BolshayaRakovitsa, Brest region

It is included in the National Register of Historical and Cultural Values of the Republic of Belarus and has category "3" - values of regional significance. The chapel-burial vault was built in the neo-Gothic style in 1910 by the last owner of the Rakovitsa estate, Theodore Tollochko (1876-1946). Initially, it was part of the estate complex located in the village of Rakovitsa, but has not survived to this day. In the 60ies of the last century, an attempt was made to destroy the chapel-burial vault, as a result of

which its upper part with a spire was partially damaged. Already nowadays, the dean of the catholic church in Kamenets, Jan Vasilevsky, and the niece of Stanislav Tollochko, Sofia Tollochko, repaired the chapel-burial vault (Gladyshchuk et al, 2019). As a result of the survey, it was established that the overwhelming majority of damage and destruction is associated with the impact of precipitation in the autumn-winter and winter-spring periods and temperature fluctuations from positive to negative values. It is during these periods that the main damage to the elements and structures of the chapel occurs. This is especially clearly seen in the area of the tower-chapel, where there is no roof at all and temperature and humidity effects have the most aggressive impact on the structures. It is also necessary to note one feature: the material from which the walls of the building are made. This is cement-sand brick, made by the unfiring method, which has a greater suction capacity, compared to ceramic brick. It is this that leads to destructive processes in the above-mentioned calendar periods and, as a result, surface destruction (defrosting) of the brickwork. This same factor, among other things, influenced the partial collapse of the gables on the roof and is a threat of collapse for the remaining part. In addition to the already mentioned lack of a roof over the chapel tower, in the roof over the main part of the building there are two holes in the ridge, through which precipitation gets inside the building, which led to bio-damage (rotting) of the wooden floorboards. It should be noted that there is no organized drainage of water from the roof of the building. Since most of the slope of the soil surface is directed towards the walls of the building, the water which gets under the foundation base, changes the physical and mechanical characteristics of the soil. This, in turn, leads to uneven foundation tearing and damage in various areas in the form of vertical cracks and local separation from the lower part of the walls. Figure. 3 shows the results of laser scanning of the chapel exterior and the interior, while the resulting point cloud was transformed into a fairly accurate and detailed polygonal model using specialized software (Fig. 6).



Fig. 3 Left- Results of laser scanning of the exterior and right interior of the chapel-tomb of the Tollochko kin.

The resulting point cloud was transformed into a fairly accurate and detailed polygonal model using specialized software (Fig. 4).

Based on the point cloud, a digital information model was also created, which represents a single source of information about the object. At the same time, using archival photographs (Fig. 5, a), the geometry of the destroyed architectural elements was restored in the information model (Fig. 5, b).



Fig. 4 Polygonal model of the chapel-burial vault of the Tollochko kin.

a) b)



Fig. 5. Archival photographs of the chapel-burial vault [22] (a) and digital information model (b)

The next step was to saturate the information model with the inspection results. The authors have developed a system of conventional designations of defects and damage and corresponding parametric families that can contain both geometric characteristics and other important attributive information. Besides, with the help of special plugins, the types of defects and damages are linked to the corresponding photographs obtained as a result of the inspection. In this case, a dialogue box is created that displays a detailed description of the damage, its extent and associated risks, as well as recommendations for its elimination (Fig. 6).

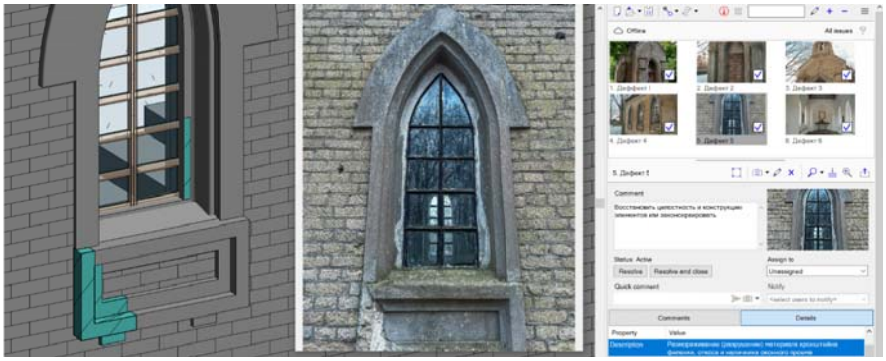


Fig. 6 Display of survey results on the digital information model of the chapel-burial vault of the Tollochko kin.

5 Discussion and conclusion

The use of modern information modeling technologies in the field of historical and cultural heritage represents a new and promising direction in applied scientific research, opening broad possibilities for the preservation, analysis, and effective management of architectural monuments. Based on a digital information model of a building, a database can be created that enables the effective management of all phases of its life cycle. The international case studies described above demonstrate that there is no single documentation technique or modeling approach that would suit all types of monuments. Wooden architecture (such as that found in Russia and Japan) requires a different level of detail and a different approach to deformable materials than stone vaults (for example, in France or Spain) or structures made of mixed materials (as illustrated by examples from Belarus). The methodology used by the authors combines laser scanning and photogrammetry to document the structure using HBIM and to catalog site-specific defects. This is in line with best practices worldwide. Neither HBIM nor BIM are perfect or highly detailed 3D models—nor is that their purpose—but they provide a good overview of the system's architecture, the condition of the structure, and its maintenance. Additional information is assigned to individual building elements, and it is precisely this information that transforms a standard model into a true information system. At the same time, a detailed 3D model can be part of the entire system as an associated element; its informative value is indisputable. Its integration with HBIM is therefore desirable and will be the subject of further research. The creation of a national digital archive in Belarus could benefit from adopting existing open standards (e.g., IFC for cultural heritage, CIDOC CRM for historical data) and from drawing lessons from the European "Time Machine" project or China's National Cultural Heritage Database.

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