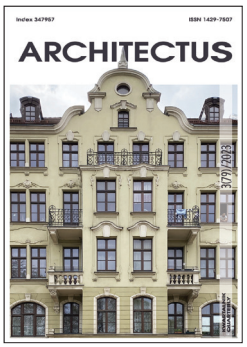

Architectus

2024
3(79)

DOI: 10.37190/arc240307

Barbara Świt-Jankowska*

Adam Mickiewicz Museum in Śmiełów – towards a contemporary museum concept using digital twin technology

Abstract

Modern demands and dynamic technological development, especially in the field of artificial intelligence (AI) and machine learning methods, require science to adapt and verify the existing methods. It also includes the fields related to the history of architecture and the cultural heritage protection. The concept of the digital twin – a virtual copy of a historic object which enables a deeper understanding of its structure and the optimization of the protection/preservation and exploitation process, is gaining popularity.

The aim of the paper was to analyse the potential of the digital twin in the context of historic museum building, where museum collections are often subject to separate protection principles. The current state of research on digital twins, as well as the challenges associated with creating HBIM documentation and the problems faced by contemporary museums, was presented. The results of research carried out in 2022–2024 on the palace in Śmiełów, a branch of the Adam Mickiewicz Museum were also presented. Traditional technical documentation served as the basis for research, conservation work and the plans of the further expansion of the museum, as well as the creation of a new digital exhibition path.

The conclusion highlights the prospects for developing the concept of a "museum in a monument" as an innovative form of presenting cultural heritage. A contemporary museum in a monument should combine tradition with modernity, and the "digital twin" can become a bridge between the past and the present, providing visitors with unique experiences.

Key words: digital twin, HBIM, heritage protection, museum in a monument

Introduction

The requirements of the modern world and extremely rapid technological development in recent years (especially in the field of artificial intelligence (AI) and machine learning methods), as well as increasing access to high-performance equipment, mean that almost every field of science must verify previous methods and adapt to the changing environment. It also applies to research in the field of history of architecture and (especially) heritage protection. The use of a virtual copy of a historic object, the so-called digital twin, in order to better understand its structure and plan the appropriate protection and exploitation process has appeared in the subject literature relatively recently, but it has aroused great interest, both among researchers, decision-makers and owners of historic monuments. The point of view most often taken by specialists concerns the analysis of the possibilities offered by the creation of a digital twin for the protection of a historic object (preserving its existing condition), conducting research and increasing the efficiency of activities aimed at its conservation or restoration. The purpose of this study is to attempt to analyse the possibilities offered by the digital twin concept in the case of a historic building housing museum collections, which are usually subject to their own principles of protection and exploitation. Additionally, in some cases, the exhibition may itself become a pretext for creating a virtual representation of reality, thus expanding the main issue to include the relations between two separate databases. Creating a digital twin in the case of a historic building that simultaneously performs museum functions allows for increasing the efficiency of planned activities which brings

* ORCID: 0000-0003-0683-7584. Faculty of Architecture, Poznan University of Technology, Poland, e-mail: barbara.swit-jankowska@put.poznan.pl

mutual benefits, both for the historic building and the exhibition. The additional introduction of advanced solutions related to virtual reality (VR) and augmented reality (AR) may contribute to increasing the cultural heritage protection and greater social acceptance of activities undertaken for this purpose.

The reason for undertaking the research topic was the establishment of cooperation between the Faculty of Architecture of the Poznan University of Technology (WA PP) and the National Museum in Poznań in 2022, concerning the inventory of the historic palace in Śmiełów, currently housing the Adam Mickiewicz Museum. Technical documentation prepared in the traditional way was to be the basis for further activities in the facility – research, conservation or restoration work and preparation of plans for the possible expansion of the museum with additional exhibition and storage space, as well as, ultimately, the creation of a new exhibition path based on digital technologies. In the subsequent years, WA PP has taken steps to prepare full digital documentation, including elements of creating a digital twin of the palace and creating a database of the facility (Historic Building Information Modelling – HBIM). This work is being continued, and its progress depends on financial capacity and access to modern software and equipment.

The article presents the current state of research on the creation of digital twin, also in the field of historic buildings, and indicates the most important aspects related to the creation of HBIM studies, as well as the challenges faced by contemporary museums. The work undertaken by WA PP at the palace in Śmiełów is also discussed. The last part presents the conclusions from the conducted research and research plans.

State of research

The integration of advanced digital technologies in heritage protection, such as digital twin or historic building information modelling (HBIM), has led to significant progress in the management, documentation and conservation of historic monuments. Interest in such approach and methods of creating virtual copies has grown rapidly in recent years: in 2016, there were only 29 scientific studies on the topic, while by 2021 there were already 2997 (Kukushkin et al. 2022). Several factors have undoubtedly contributed to this progression – a huge role has been played by rapidly developing technology and, above all, increasing access to modern inventory methods such as LIDAR, photogrammetry and TLS (Terrestrial Laser Scanning), drones or 3D scanning (point cloud). The growing interest in the virtual world is also a reflection of general trends that have dominated the modern scientific world – artificial intelligence (AI) and machine learning have raised the existing possibilities of analysing collected data to a completely new level, and allowed for easier and more pictorial (intuitive) access to the information contained therein. One sign of change in this regard may be the introduction of the concept of "digital preservation" by the World Intellectual Property Organization in 1996 and the Charter on the Preservation of the Digital Heritage published by the United Nations Educational, Scientific and Cultural Organization in 2003 (UNESCO 2003), which takes into account the use of digital technologies to preserve cultural and historical values. Digital preservation is characterized by three valuable features for heritage: it is non-invasive, relatively simple and convenient. It also allows for the preservation of the authenticity of experiences (preservation of form, structure, materials and decoration).

Digital twin

The basic concept of the digital twin model, which involves creating an exact digital replica of a physical object, was created in 2002 and remains relevant despite the passage of time and the development of technology. According to the definition developed by Michael Grieves and John Vickers, a digital twin […] *is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level* (2017, 11). Based on the definition presented above, it can be stated that there are two models of digital twins – a prototypical physical artifact (made before the construction of a given object) and a virtual equivalent of a physical product (an existing object). For the purposes of heritage protection, the latter model – a virtual equivalent of an existing building, understood as its copy – seems relevant[1]. This technology is increasingly used to create dynamic models of monuments and artifacts, enabling real-time "exploration" of the model. Calin Boje et al. (2020) emphasized that creating a digital twin allows for active protection of cultural heritage sites, e.g., by simulating the impact of various environmental conditions on their structural layout. A similar approach was presented by Marco F. Funari et al. (2021), who examined the benefits of creating a digital representation of a historic building for predicting and quickly counteracting potential construction disasters. Also of interest seems to be the combination of digital twin with IoT sensors[2] that allow for collecting data on the condition of the building in real time, which further improves the accuracy of the model and supports conservation efforts (advanced data analysis, planning of conservation actions, response to threats). This possibility seems particularly valuable when placing a museum collection in a historic building because it provides the opportunity to take a comprehensive approach to the monument and plan the exhibition at the same time.

HBIM

HBIM is a specialized form of building information modelling (BIM) adapted to the needs of historic buildings. It consists in combining the 3D model with source

[1] Some potential for heritage preservation is also provided by the first option – in the case of unbuilt objects, for which, for example, technical documentation or a detailed description has survived.

[2] Internet of Things (IoT) – the concept of connecting all elements that can transmit data (e.g., household appliances, sensors, embedded systems, sensor networks, measuring equipment) within a single network so that they can communicate, process and analyse collected data, detect or prevent failures.

data that includes: the history of the facility, the transformation of its form over time, structural details, construction technology, data on the building materials used, conservation interventions, equipment and current use. This combination allows the historical model to be enriched with visualizations presenting the variability of the building over time (Götz et al. 2023). HBIM models are valuable repositories of historical knowledge supporting the work of conservators and researchers – especially in the case of monuments where direct survey is not possible for various reasons (e.g., poor technical condition of the building, possibility of irreparable damage, need for demolition). Maurice Murphy et al. additionally emphasizes the advantages of HBIM in documenting complex architectural details and supporting renovation projects (2011), indicating that such an approach allows for better visualization and analysis of construction problems and, in the long term, facilitates making conservation decisions. An important topic often discussed in the above context is the need to integrate different methods of obtaining data on the existing object. It was confirmed by Facundo J. López et al. (2018), discussing the combination of laser scanning and photogrammetry with HBIM, and Steven Götz et al. (2023) in a detailed study showing the inventory process of a historic villa in Sorrento, during which environmental conditions (lack of access to a permanent power source, partial submergence of structural elements) influenced the need for a creative approach to combining different measurement and inventory methods.

The significant advantages of applying HBIM technology to heritage protection were also highlighted by Pierre Jouan and Pierre Hallot (2019), especially in terms of the ability to reconstruct buildings with irregular geometry while maintaining the properties, attributes and interrelations of structural objects, as well as the relationship between the physical object and digital data. According to the authors, the main goal of HBIM is to improve the efficiency of data management among various stakeholders involved in heritage protection in order to increase its effectiveness while taking a cost-effective approach to the financial resources involved in the process. Data integration in HBIM is crucial for developing mitigation programs and protection plans at each stage of the monument's life cycle. Most of current research emphasizes the need to manage the entire life cycle of historic buildings – from their documentation, through condition monitoring, to conservation and restoration projects. For this purpose, the use of digital platforms for data management and cooperation between various stakeholders involved in heritage protection is preferred. The integration of modern tools and techniques can enable more effective protection and preservation of monuments, which is particularly important in the view of growing dangers related to natural disasters and climate change (Li et al. 2023). In this context, creating digital twins can support key decisions regarding both conservation and management – exploitation of a historic building. Digital models can be used for a variety of simulations and analysis of various scenarios – from construction disasters and climate protection requirements to planning the future exhibition – both of the facility and its equipment, which can be extremely important in the case of a museum located in a historic building.

Contemporary museum in a historic building in the context of digital twin technology

The application of digital twin and HBIM technology to historic buildings housing museum exhibitions has revolutionized the approach to both the management of immovable resources (monument) and movable resources (exhibition). However, the specificity of this combination requires understanding and cooperation of both stakeholders. Here, we can refer to the title of the article by Franco Niccolucci et al. *The heritage digital twin: a bicycle made for two* (2023) – a tandem, a bicycle for two, on which riding requires close cooperation between cyclists and setting a common destination that is best for both of them. The digital museum is both an opportunity to introduce interactive and immersive experiences for visitors, as well as support in the management, monitoring and maintenance of exhibitions, especially in terms of event prediction. The inclusion of integrated information about the object and IoT sensors in this process allows for advanced analysis of various protection options and finding solutions that comprehensively address the often disparate needs of both elements (monument + collections) simultaneously. However, for this to be possible, it is necessary to take into account the bidirectional data flow – some research works on the creation of digital twins distinguish between three types of them, emphasizing precisely the issues related to the direction of data flow: the concept of the digital model (no automated data flow between physical and virtual counterparts), the digital shadow (automated one-way data flow from physical to virtual counterparts) and the "true" digital twin, which, according to Werner Kritzinger et al., is characterized by automated data flow in both directions (2018). In the case discussed in this article, only the latter version allows for full use of all the possibilities offered by the digital twin concept. It should also be remembered that a modern museum is not only buildings, collections, data and their digitization. Over two thousand years of museum history show how the purpose for which they operated has changed: from ethereal inspirations of the Muses, to a place of research on the past, centres of concentration, knowledge and education, as well as meeting places and spaces for narratives – stories about what memory has preserved. Their contemporary role oscillates between two opposing experiences from the past – storage of collections (a treasury of artifacts) and a place of meetings and social interactions combined with educational activities. By combining these two extremes, the museum becomes a space where visitors can experience diverse emotions and specific, neuronal responses (Folga-Januszewska 2022). Modern technologies, including widespread access to the Internet and museum collections on the websites of individual institutions, paradoxically increase viewers' interest in the real exhibition. Research on this phenomenon (cybermuseology) includes not only technical aspects related to the use of modern methods of collection inventory, but also discourse related to the changing needs of users, including

aspects of philosophical nature and conceptual foresight (Leshchenko 2020). An increasing number of institutions are establishing departments responsible for digital asset management, and the rapid development of this field is being discussed at conferences and in scientific publications, covering a wide range of activities: from multimedia elements complementing traditional exhibitions, to mobile tours and virtual exhibitions on websites, as well as methods of collecting information on collections and their dissemination (tablets, 3D prints, digital narratives). More and more often, artificial intelligence algorithms are being used to present the collections, allowing for an increasingly individualized visitor's program, as well as augmented reality, mobile applications, and social media interactions. It allows for the creation of a platform on which a dialogue between the museum and its guests is possible. In addition, the sense of belonging and the ability to participate in digital narratives, interact with original artifacts in augmented reality or communicate via mobile devices and digital platforms creates a new dimension of the museum – a parallel world in which digital twin technology, applied to its premises, can be particularly helpful, especially if we are dealing with a historic monument. In 2015, Danuta Folga-Januszewska wrote: *The nature of the collections does not determine popularity and is not a factor influencing the interest of recipients. The way of interpreting the collections, creating an appropriate narrative, is of fundamental importance* (Folga-Januszewska 2015, 135). It shows the importance of the way of presenting collections and the ability to hit the users' needs with the message[3]. In this context, the museum becomes a setting for individual experience of visitors, who, supported by technology, can customize the experience to their individual needs – and the place where it happens begins to play a significant role[4]. The trend can be observed primarily during the creation of new facilities, in which the space closely interacts with the exhibition and becomes its part, increasing its attractiveness (e.g. the Warsaw Uprising Museum, the Museum of the Second World War in Gdańsk or the Silesian Museum in Katowice). However, this approach is inherently almost impossible if we are dealing with an existing building – often a monument per se. In such a situation, the possibility of creating a parallel, virtual model of the museum can, on the one hand, allow to change the way of display in augmented reality, and, on the other hand, can help to find an optimal solution that does not negatively affect the historic fabric of the building and harmonizes with the needs of artifacts. Combining the needs of both approaches allows for greater integration of the collections with the place where they are presented and enhances the attractiveness of the museum. It should be noted at this point that usually the elements of an exhibition are digitized: individual artifacts, documents, etc. – less frequently the places where they are exhibited. An intermediate version can be created by the so-called virtual tour, based on the technology of combining 360-degree panoramas – an example of such a solution is, among others, the Louvre (Musée du Louvre "Virtual tour"), the Vatican Museum (Musei Vaticani "Virtual tours"), but a similar possibility is also provided by the National Museum in Poznań, branch in Śmiełów (National Museum in Poznań, Śmiełów "Virtual tour"). The above solution allows to get acquainted with the structure of the building only to a limited extent – depending on the number of photos and the intentions of the creator. Making a full digital model (point cloud, photogrammetry, etc.) is definitely more labour – and cost-intensive, but its advantage is full freedom in exploring the object. This type of work is usually performed for a historic building, often requiring virtual reconstruction (Götz et al. 2023). In the case of museum objects, we usually deal with buildings in relatively good technical condition, but the possibility of combining a digital model with gaming software opens up entirely new possibilities of exploration (Campanaro, Landeschi 2022). The combination of a digital model (in this case a Roman villa) with eye-tracking technology (VR) allowed to record the body position, head and eyeballs movements of virtual "guests" which can be useful in a museum facility, for example, when planning a new exhibition. Considering that 3D scanning technologies, photogrammetry and LIDAR are becoming more and more common and available, it can be expected that the use of digital twin for this type of application will increase. In view of the above, WA PP started cooperation with the National Museum in Poznań, aimed at creating a digital model of the Adam Mickiewicz Museum in Śmiełów (a branch of the National Museum in Poznań) and exploring the possibilities and potential of various inventory methods, as well as determining their potential for planning further expansion of the museum and the virtual tour path.

Adam Mickiewicz Museum, Palace in Śmiełów

The palace in Śmiełów was built around 1797 on the order of Andrzej Gorzeński, regent of Poznań municipal government. He commissioned the construction to a well-known Warsaw architect, Stanisław Zawadzki, who created a classicist palace with two quarter-circular galleries connected to the side in the Palladian style – a motif characteristic of the residential architecture of Greater Poland (Wielkopolska region) at that time (Fig. 1). The residence in Śmiełów, surrounded by a picturesque landscape park, forms a viewing axis with the complex of the classicist church in Brzóstków. The stucco work in the palace interiors was done by Michał Ceptowski, and the wall paintings by two brothers: Antoni and Franciszek Smuglewicz. Despite visible stylistic references to other realizations of this type, e.g., in Racot or Sierniki, the palace in Śmiełów is distinguished by original solutions in the decoration of the façade of the main body of the palace, as well as in the interior design – the lack of connection of the living

[3] An excellent example of this approach is the series on the history of the servant Stefcia, carried out by the Zamoyski Museum on their social media. The series was created to bring the realities of servant life in the 19th and 20th centuries closer. Joanna Adamek is responsible for the script and direction; the actors are: Aneta Ćmiek and Michał Rudnicki (Muzeum Zamoyskich "A series of short films…").

[4] An example of this approach is the Groninger Museum in the Netherlands – created by Frans Haks and Alessandro and Francesco Mendini, opened in 1986.

Fig. 1. Palace in Śmiełów – front elevation, 2022 (photo by B. Świt-Jankowska)

Il. 1. Pałac w Śmiełowie – elewacja frontowa, 2022 (fot. B. Świt-Jankowska)

room (occupying the middle of the garden path) with the entrance part. In the years 1886–1939, the Chełkowski family resided in Śmiełów and on the initiative of the last owner, the body of the palace was expanded. One-storey annexes were added to the side elevations of the main body, the resulting rooms were connected to the older part by doors in accordance with the existing enfilade. A second, lower terrace, filled with earth and flowers, was also added on the garden side. After World War II, the palace, together with the farm, devastated and deprived of equipment, was taken over by the State Treasury and used by the local PGR (State Agricultural Farm). In its rooms, primary school and apartments for teachers were located. The need to adapt the interiors to new needs resulted in bricking up of several openings and painting over the stucco as well as its partial destruction (zabytek.pl "Zespół pałacowo-parkowy w Śmiełowie").

In the following years, the palace underwent partial renovations (e.g., changing the roof tiles, partial replacement of the rotten roof truss), and the preserved polychromes (1955, 1967), the façade of the building (1956) and the parquets (1956/1957) were also subject to conservation. In 1972, the building, in a condition requiring immediate protection of the its structure, was officially taken over by the National Museum in Poznań. Conservation work carried out in the following years allowed the palace in Śmiełów to slowly regain its former glory. The exhibition contains valuable collections related to the poet Adam Mickiewicz and his stay in Śmiełów in August and September 1831. Additionally, there are also memorabilia related to Juliusz Słowacki, Cyprian Kamil Norwid and the Chełkowski family (zabytek.pl "Zespół pałacowo-parkowy w Śmiełowie").

In 2022, the Department of History, Theory and Heritage Protection, headed by prof. dr hab. inż. arch. Piotr Marciniak, undertook to carry out an inventory of the palace. Measurement work using traditional methods (rangefinders, tape measures, laser and water levels, photographic inventory) was carried out partly as part of field inventory classes (RA 2021-22, 2nd cycle studies, 1st semester, field of study: architecture).

During the preparation of technical documentation, there were many problems related to the determination of the correct geometry of individual parts of the palace, which modern technology was harnessed to solve. LIDAR technology made it possible to perform scans of problematic areas (Fig. 2), both from the interior and exterior. BIMba Scientific Club under the supervision of Borys Siewczyński made a photogrammetric inventory of the front part of the palace. Unfortunately, due to the large amount of greenery adjacent directly to the walls of the outbuildings, it was difficult to make a full photogrammetry of the palace body. The missing data was partially completed in the autumn-winter season.

The collected information and the technical documentation previously prepared in 2023–2024 academic year were used to create two digital versions of the building structure in Sketchup and Archicad, respectively. The work on

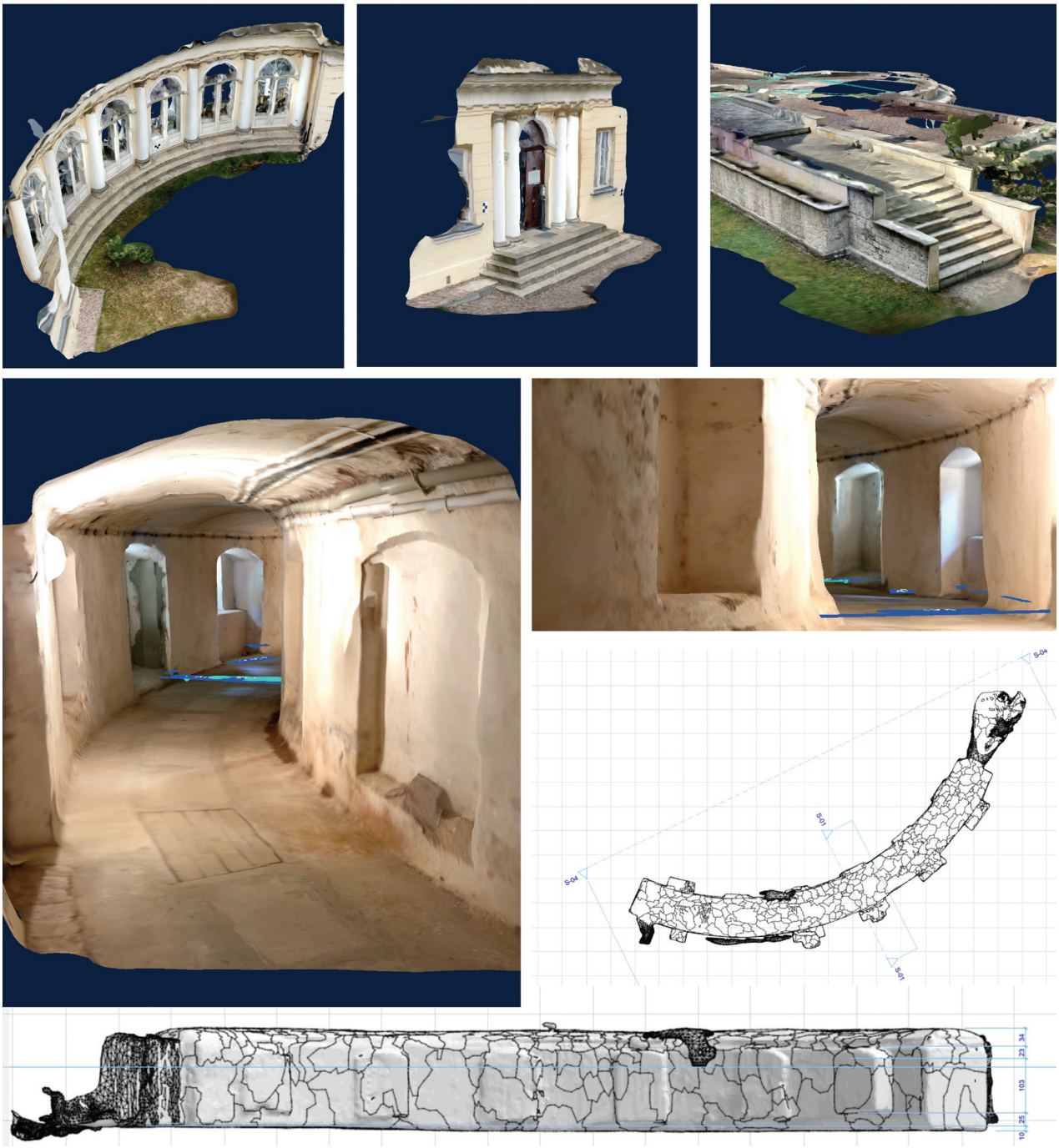

Fig. 2. The effects of using LIDAR technology during the measurement inventory of the palace in Śmiełów (elaborated by B. Świt-Jankowska)

Il. 2. Efekty wykorzystania technologii LIDAR podczas wykonywania inwentaryzacji pomiarowej pałacu w Śmiełowie (oprac. B. Świt-Jankowska)

the creation of the digital twins was conducted as part of the conservation design classes (2nd cycle studies, the faculty of architecture, 2nd semester), in three student groups. In addition to making digital models, students also familiarized themselves with the collected historical information and conducted their own source research and analyses of the entire palace complex. In consultation with the head of the museum, Dr. Emilian Prałat, a functional program was created to expand the exhibition and to adapt the historic palace building for contemporary needs (with particular emphasis on the new educational and storage base and accessibility for people with disabilities). The proposals for the reconstruction projects were presented during a joint review of the works on 25.02.2024 and then forwarded to the National Museum for further presentation and use.

In the summer semester of 2023/2024, as part of the research studio classes (2nd cycle of studies, faculty of architecture), there was a science camp the aim of which was to perform in-depth architectural research on the effectiveness of partitions and the degree of moisture in the building structure, 3D scanning of the basement level and the front of the building (Fig. 3). Based on the collected materials, a model of the basement interiors was made, which will ultimately allow for the effective design of a new part

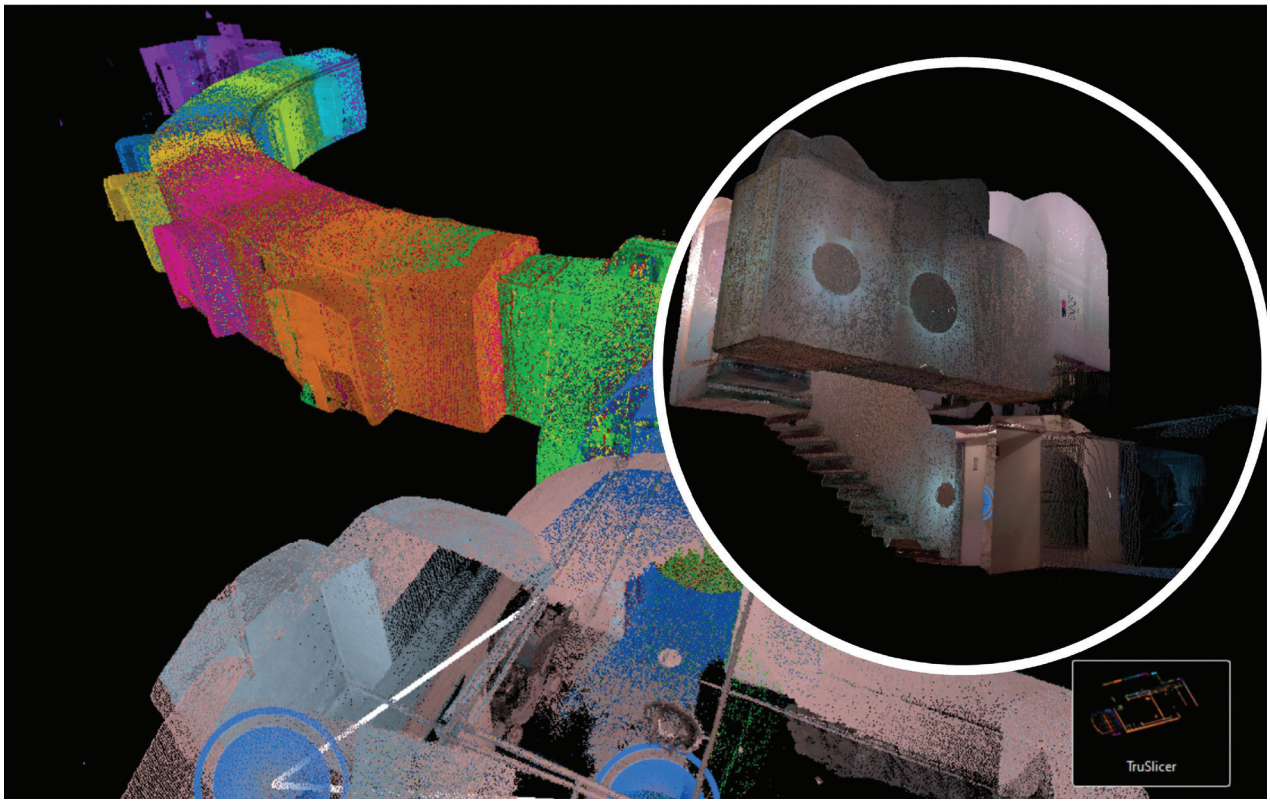

Fig. 3. Point cloud – basements of the palace in Śmiełów. Cyclone REGISTER 360 (elaborated by B. Świt-Jankowska)

Il. 3. Chmura punktów – piwnice pałacu w Śmiełowie. Cyclone REGISTER 360 (oprac. B. Świt-Jankowska)

of the exhibition, using modern technologies such as AI or VR. The aim of the actions taken is to create a full digital representation of the palace in Śmiełów, which will allow for the connection of digital data with the historical database and will support the operation of the building as well as the organization of the exhibition placed in it.

Conclusions

Taking measurements using traditional methods (tape measure, laser rangefinder, laser level/water scale) is associated with many problems resulting primarily from the large number of tasks during work (the time spent in the building) as well as the need for properly interpretation of the obtained data and its multiple verification. The use of the triangle method to determine the geometry of individual rooms requires, on the one hand, high accuracy and experience from employees, as well as creativity when overcoming difficulties (existing permanent development, large-size exhibits or lack of access to certain rooms). At the same time, traditional measurements are subject to a high risk of making small errors due to, for example, improper stretching of the tape measure or non-parallel laser measurement – which means that when determining the geometry of the building in the CAD system, it is necessary to make certain generalizations and adjustments. Traditional construction drawings (plans, sections, elevations) do not always allow for a perfect representation of the complex building structure, especially with regard to vaults, arches, staircases, subtle differences in floor levels, roof trusses or basement layouts. It can be difficult to maintain the legibility of drawings with a very large amount of additional information. The solution adopted during the work was to divide the key information and split it into two versions of the drawings (room dimensioning separately, information on vaults and heights separately), which obviously increased the volume of documentation. In the case of the parts of the building with simpler geometry, traditional methods proved to be quite effective at a relatively low cost. More demanding sections (semicircular galleries) required a different approach. Traditional methods of delineating triangles from the inside and outside of the building led to contradictory conclusions. The use of LIDAR technology allowed the optimum solution to be found more quickly.

When carrying out the inventory based on laser scanning (LEICA scanner, BLK360, Cyclone REGISTER 360 software), data acquisition (point cloud) took considerably less time than traditional measurements, the data was more accurate, but the result (basement model) required additional processing with specialized software (additional cost and work time) and removal of unnecessary information (labour input), and in addition, the size of obtained material was very large, which generated problems with storage, dissemination and use of the collected data. A significant gain was information that could would not have been possible to obtain by traditional means (installation course, minor differences in floor heights, detailed representation of irregularities in foundation walls, etc.). An additional problem that unexpectedly occurred during measurement work was the range – the BLK360 scanner connects to

the tablet via its own Wi-Fi network, but the thickness of the walls in the palace's basements repeatedly interrupted the connection, requiring the devices to be paired again.

The experience gained from the inventory work carried out at the palace in Śmiełów indicate the need for an interdisciplinary approach to the issue of data acquisition, interpretation and recording. Creating a fully functional digital twin of a historic building requires a lot of work, financial resources and skills, and above all – proper coordination of various methods and selecting optimal solutions, adequate to current needs and possibilities, including aspects such as: access to a power source, network coverage, Internet access, elements that hinder data collection (greenery, lack of access, existing buildings, rubbish). Proper coordination of various activities allows obtaining the necessary data, and their combination gives a broad and complete picture of the historic building, which can be used in various fields – from historical analysis and planning of conservation activities to various concepts of room arrangement and the use of the model as an element of augmented reality. At the same time, it should be remembered that creating a perfect representation, even the help of advanced technology, is usually impossible and unnecessary. However, after completing this process, the information and digital representations, even imperfect ones, significantly accelerate the decision-making process and provide an excellent platform for discussion for various stakeholders. The measurement work and digital models of the palace in Śmiełów significantly influenced the pace and level of the subsequent conceptual and design work.

Summary

The implementation of digital twin and HBIM in historic buildings with museum functions brings significant benefits, both in terms of heritage protection and museum management. Modern technologies improve the efficiency of conservation, but also enrich the visitors' experience and promote cultural education. The high price of their implementation in the long term can be balanced by the benefits resulting from the possibility of non-invasive testing of various renovation scenarios and exhibition changes as well as the selection of the best possible solution, also in economic terms. It is also of great importance for heritage conservation to be able to respond early to emerging threats and to take into account the needs of the heritage site, often treated as less valuable than the artefact collections housed within it, in the process of using the museum facility.

Digital twin in the case of historically valuable monuments allows for the expansion of their protection possibilities and appropriate planning of activities, including interventions related to the related to climate protection requirements or the need to adapt the building to modern requirements. The use of modern technologies in historic buildings housing museums increases the efficiency of the facility maintenance and exhibition management. The installation of IoT sensors provides an opportunity to collect data and monitor both the historic structure of the building and the exhibits in real time, which allows for a quick response to potential threats or structural or environmental problems. Additionally, the use of learning algorithms and artificial intelligence provides an opportunity to select optimal solutions, taking into account the differences between the needs of the collections and the monument. Appropriate control of parameters such as humidity, temperature or lighting allows for dynamic adaptation to a given situation and ensuring appropriate protection. However, it should be taken into account that the implementation of the above technologies (purchase of IoT sensors, 3D scanning, professional software or qualified employees) is usually associated with high initial costs, and the creation process, from data collection to modelling and integration, can be very time-consuming. This is particularly important due to the fact of the constant underinvestment in culture in Poland and the frequent need to make decisions in a relatively short time. Additionally, maintaining a 3D model at an appropriate level of complexity and its operation require advanced technical skills, which may require personnel changes or training and including their costs in the museum's budget. Another issue worth considering before implementation is the compatibility of new solutions with existing ones as well as the integration of data from different platforms and the need to store large amounts of data, as well as dependence on specific technological solutions which is especially important in the context of long-term maintenance and availability of software and software components.

The ability to simulate various scenarios for both renovation and exhibition allows for better cost prediction, prevention of unnecessary damage (both to the collection and the monument) and obtaining acceptance for the proposed changes by advisory groups (the board, conservator, decision-makers, sponsors). In addition, appropriate arrangement of exhibitions and access to information as well as its interactive nature increase attractiveness and better respond to the contemporary needs of users. Dynamic 3D models enriched with historical, architectural and material data are in themselves a valuable research resource and can complement the museum's existing didactic offer – especially that the use of modern technologies makes the knowledge which is usually difficult to understand available also to non-professionals. This approach facilitates research and education. It also promotes understanding and respect for cultural heritage in society. Digital twins can also be used to create interactive, immersive experiences for visitors. They can be combined with digital copies of the collected artifacts in order to explore the collections in the virtual world (for example, through the use of VR technology), making the space in question more appealing and making cultural heritage accessible to a wide audience, including online. Some concern in this context is the possibility of excessive laicization of knowledge and flattening the historical perspective by reducing it to irrelevant but attractive curiosities or peculiarities. Broad access to data may also raise concerns about potential threats and cybercrime. There is a risk that shared information, used inappropriately or modified, will be lost which may lead to data falsification. Potential damage to servers or problems with the power supply may temporarily prevent or hinder visiting. Therefore, it is essential to properly secure digital collections and constantly improve the systems responsible for security.

The virtual museum allows for a completely new experience of the exhibition space. The demands of modern times regarding the role that museums should play in society are very broad. In addition to the educational function, increasing emphasis is being placed on the individual experience of the recipient and on the culture-forming and social role of such facilities. Ongoing research indicates that the digitization of collections not only does not reduce the interest of potential recipients, but often provides them with an additional incentive to visit the museum. The opportunity to get acquainted with collections (e.g., to see the paintings in macro photographs) allows for a more personal attitude to the exhibition. Digital twin technology extends this experience to the building in which the collections are displayed which allows for supplementing knowledge about it and showing the broader context of a given place. The beginning of the 21st century requires a redefinition of the museum space. Therefore, it is necessary to continue research, especially due to the dynamic development of new technologies and taking on new challenges posed to historic buildings that serve as museums, such as ensuring accessibility for people with disabilities or energy efficiency and climate protection. Appropriately planned and optimised activities are necessary so that, returning to the tandem analogy, each party can benefit from this cooperation and work together towards one goal – better protection of historic buildings and collections, increasing the attractiveness of exhibitions and social acceptance as well as understanding of issues related to heritage protection.

Translated by
Paulina Kowalczyk

Acknowledgements
Thanks to the director of the Adam Mickiewicz Museum, Dr. Emilian Prałat, for making the museum building available and enabling the necessary measurement and research work to be carried out, as well as to the supervisor of BIMba Scientific Club, dr inż. arch. Borys Siewczyński for technical and substantive support.

References

Boje, Calin, Annie Guerriero, Sylvain Kubicki, Yacine Rezgui. "Towards a semantic construction digital twin: Directions for future research." *Automation in Construction* 114, (2020): 103179. https://doi.org/10.1016/j.autcon.2020.103179.

Campanaro, Danilo M., and Giacomo Landeschi. "Re-viewing Pompeian domestic space through combined virtual reality-based eye tracking and 3D GIS." *Antiquity* 386, no. 96 (2022): 479–486. https://doi.org/10.15184/aqy.2022.12.

Czajkowski, Karol. *Nowoczesne technologie w dokumentacji zabytków. Spójny system zbierania, opracowania i prezentacji danych jako podstawa działań konserwatorskich*. Warszawa: Narodowy Instytut Dziedzictwa, 2023.

Folga-Januszewska, Dorota. *Muzeum: fenomeny i problemy*. Kraków: Universitas, 2015.

Folga-Januszewska, Dorota. *EMOCJONEUM. Muzeum jako instytucja emocji*. Warszawa: Muzeum Pałacu Króla Jana III w Wilanowie, 2022.

Funari, Marco F., Ameer E. Hajjat, Maria G. Masciotta, Daniel V. Oliveira, Paulo B. Lourenço. "A Parametric Scan-to-FEM Framework for the Digital Twin Generation of Historic Masonry Structures." *Sustainability* 19, no. 13 (2021): 11088. https://doi.org/10.3390/su131911088.

Götz, Steven, Bernhard Fritsch, Wolfgang Filser, Michaela Reinfeld, Christoph Klose, and Paolo Vitti. "Mixing methods: The use of 3D techniques at the ancient villa of Capo di Sorrento." *Studies in Digital Heritage* 6, no. 2 (2023): 25–50. https://doi.org/10.14434/sdh.v6i2.34835.

Grieves, Michael, and John Vickers. "Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems." In *Transdisciplinary perspectives on complex systems*, edited by Franz-Josef Kahlen, Shannon Flumerfelt, and Anabela Alves. Springer International Publishing, 2017.

Jouan, Pierre, and Pierre Hallot. "Digital twin: A HBIM-based methodology to support preventive conservation of historic assets through heritage significance awareness." *ISPRS Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* XLII-2/W15, (2019): 609–615. https://doi.org/10.5194/isprs-archives-XLII-2-W15-609-2019.

Kritzinger, Werner, Matthias Karner, Georg Traar, Jan Henjes, and Wilfried Sihn. "Digital Twin in manufacturing: A categorical literature review and classification." *IFAC-PapersOnLine* 51, no. 11 (2018): 1016–1022. https://doi.org/10.1016/j.ifacol.2018.08.474.

Kukushkin, Kuzma, Yury Ryabov, and Alexey Borovkov. "Digital twins: A systematic literature review based on data analysis and topic modeling." *Data* 12, no. 7 (2022): 173. https://doi.org/10.3390/data7120173.

Leshchenko, Anna. "Cyfrowe wymiary muzeum: definicja przedmiotu badań cybermuseologii." In *Muzeologia cyfrowa. Muzeum i narzędzia cyfrowe humanistyki*, edited by Małgorzata Baka. Toruń: Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, 2020.

Li, Yuan, Yanan Du, Mengsheng Yang, Jiaqi Liang, Huanxia Bai, Rui Li, and Andrew Law. "A review of the tools and techniques used in the digital preservation of architectural heritage within disaster cycles." *Heritage Science* 11, (2023): 199. https://doi.org/10.1186/s40494-023-01035-x.

López, Facundo J., Pedro M. Lerones, Jose Llamas, Jaime Gómez-García-Bermejo, and Eduardo Zalama. "A Review of Heritage Building Information Modeling (H-BIM)." *Multimodal Technologies and Interaction* 2, no. 2 (2018): 21. https://doi.org/10.3390/mti2020021.

Luther, Wolfram, Nelson Baloian, Daniel Biella, and Daniel Sacher. "Digital twins and enabling technologies in museums and cultural heritage: An overview." *Sensors* 23, no. 3 (2023): 1583. https://doi.org/10.3390/s23031583.

Murphy, Maurice, Eugene McGovern, and Sara Pavia. "Historic building information modelling-adding intelligence to laser and image based surveys." *ISPRS Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* XXXVIII-5/W16, (2011): 89–102. https://doi.org/10.5194/isprsarchives-XXXVIII-5-W16-1-2011.

Musée du Louvre. "Virtual tours". Accessed April 15, 2024. www.louvre.fr/visites-en-ligne/petitegalerie/saison6/.

Musei Vaticani. "Virtual tour". Accessed April 15, 2024. www.museivaticani.va/content/museivaticani/en/collezioni/musei/tour-virtuali-elenco.html.

Muzeum Zamoyskich. "A series of short films that was created to bring the realities of servant life in the 19th and 20th centuries". Instagram, June 22, 2024. https://www.instagram.com/muzeumzamoyskich/.

National Museum in Poznań, Śmiełów. "Virtual tour". Accessed April 15, 2024. https://modulor-vr.com/smielow/.

Negri, Elisa, Luca Fumagalli, and Marco Macchi. "A review of the roles of digital twin in CPS-Based Production Systems." *Procedia Manufacturing* 11, (2017): 939–948. https://doi.org/10.1016/j.promfg.2017.07.198.

Niccolucci, Franco, Beatrice Markhoff, Maria Theodoridou, Achille Felicetti, and Sorin Hermon. "The Heritage Digital Twin: a bicycle made for two. The integration of digital methodologies into cultural heritage research." [version 1; peer review: 2 approved with reservations]. *Open Research Europe* 64, no. 3 (2023): 15496.1, https://doi.org/10.12688/openreseurope.15496.1.

UNESCO. "Chapter on the Preservation of the Digital Heritage." (2003). Accessed March 15, 2024. https://unesdoc.unesco.org/ark:/48223/pf0000179529.page=2.

Zabytek.pl. "Zespół pałacowo-parkowy w Śmiełowie." Accessed March 15, 2024. https://zabytek.pl/pl/obiekty/smielow-palac/dokumenty/PL.1.9.ZIPOZ.NID_N_30_EN.157094/7.

Streszczenie

Muzeum im. Adama Mickiewicza w Śmiełowie
– w stronę współczesnej koncepcji muzeum z wykorzystaniem technologii digital twin

Współczesne wymagania i dynamiczny rozwój technologiczny, szczególnie w obszarze sztucznej inteligencji i metod maszynowego uczenia, stawiają przed nauką konieczność adaptacji i weryfikacji dotychczasowych metod. Obejmuje to również dziedziny związane z historią architektury oraz ochroną dziedzictwa kulturowego. Coraz większą popularność zdobywa koncepcja digital twin – wirtualnej kopii obiektu zabytkowego, która umożliwia głębsze zrozumienie jego struktury i optymalizację procesu ochrony oraz eksploatacji.

Celem autorki artykułu była analiza potencjału digital twin w kontekście zabytkowych obiektów muzealnych, gdzie zbiorom muzealnym często przysługują odrębne zasady ochrony. W pracy omówiła ona aktualny stan badań nad cyfrowymi bliźniakami, w tym wyzwania związane z tworzeniem dokumentacji HBIM oraz problemy, z jakimi mierzą się współczesne muzea. Przedstawiła także wyniki przeprowadzonych w latach 2022–2024 badań nad pałacem w Śmiełowie, będącym siedzibą Muzeum im. Adama Mickiewicza. Tradycyjna dokumentacja techniczna posłużyła jako podstawa do prac badawczych, konserwatorskich oraz planowania dalszej rozbudowy muzeum, a także stworzenia nowej cyfrowej ścieżki wystawienniczej.

W konkluzji podkreśliła perspektywy rozwoju w kontekście koncepcji „muzeum w zabytku" jako innowacyjnej formy prezentacji dziedzictwa kulturowego. Współczesne muzeum w zabytku powinno łączyć tradycję z nowoczesnością, a „cyfrowy bliźniak" może stanowić pomost pomiędzy przeszłością i teraźniejszością, dostarczając zwiedzającym niepowtarzalnych wrażeń.

Słowa kluczowe: cyfrowy bliźniak, HBIM, ochrona dziedzictwa, muzeum w zabytku