Article

Analysis of the Possibilities of Using HBIM Technology in the Protection of Cultural Heritage, Based on a Review of the Latest Research Carried Out in Poland

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Abstract: The implementation of HBIM technology in the research carried out with historical objects remains at a very early stage and constitutes only a fracture of current studies, including in Poland. This process becomes indispensable for the analysis of the existing condition, management and protection of cultural heritage. Therefore, it proves necessary to elaborate directions and guidelines for the implementation of HBIM technology. The present article deals with research and analysis of Polish conservation studies. We discuss the methods for recording information, the scope and detail of the elaborated 3D model, including library objects. The possibility of further editing of objects, the digital tools applied and the data recording formats were all analyzed. The tables present the discrepancies in the creation of 3D objects. We described and compared the studied objects. The collected analyzes were used to summarize important parameters and collected data. This in turn allowed us to elaborate universal guidelines that could be used in the implementation of HBIM technology in other countries as well. Digital tools and data recording formats used to develop the discussed models of objects pave the way to the possibility of further editing and implementation of HBIM technology.

Keywords: cultural heritage; scanner; photogrammetry; BIM; HBIM; 3D modeling; virtual reconstruction

1. Introduction

BIM in Cultural Heritage Protection

The development of technology, measuring systems and tools supporting CAD design now enables multidirectional use and combination of new digital tools. In the mid-nineties of the twentieth century, analogue methods were replaced by digital photogrammetry technology, and digital stations equipped with appropriate software largely improved data processing. Scanning technologies were developed, triggering the increase in data acquisition rates, while photogrammetry received additional support from scanning. Currently, this reduces the time required to collect 3D data, simplifying the measurements of existing objects [1]. The use of data acquired by means of both photogrammetry and laser scanning supports the construction of realistic three-dimensional models of buildings. Depending on the level of accuracy of the measurements taken, it is also possible to include even the very minute details.

The cultural heritage that surrounds us is subject to various damages, through human interference, unexpected catastrophes or destruction resulting from the passage of time. Modern technologies allow us to preserve whole objects or even areas, in the exact condition they currently are in. Modern technologies provide us with the ability to depict numerous past and future scenarios for the already created virtual object. The value of these activities rests in striving to save the heritage, which includes the inventory of immovable and movable items and the related spiritual, historical and moral values, from oblivion. These values are considered the basis for legal protection for the good of a specific society and its development, required for their transmission to the subsequent generations, proving the

truths and commemorating historical events, cultivating a sense of beauty and civilization community [2].

Cultural heritage buildings are structurally complex architectural objects, complex structures and their history-rich movable interior furnishings. Frequently basing upon incomplete documentation, mutually exclusive data, the researchers attempt to inventory objects using multiple methods and collaboration of interdisciplinary teams. Currently, advanced digital technologies and measurement methods allow the acquisition and processing of growingly complete data, as well as the combination of acquired models and their application in various processes and analyzes [3–5].

The majority of new buildings are constructed with computer assisted methods. Use of digital tools and new technologies has completely changed the way we design. Currently, the models contain huge amount of descriptive and analytical information that is readily available. Such a model is a complex architectural design where one can filter geometric, spatial and technical information, perform simulations and assess energy consumption. As Silva [6] writes, the logic of digital production in architecture initiate to shape the way the architects design, and the builders build, and how the industry reorganizes. For a growing number of technologically advanced practices designing with use of Building Information Modeling technology-BIM no longer proves a challenge. The process of automating many activities and using the resources of predefined groups of material elements or object libraries is self-explanatory, as a new object is created based on the indicated groups of elements. The adoption of BIM technology as the standard of work is observed all over the world, both as a process facilitating and improving the course of construction as well as due to the normative requirements imposed in the design process [7–9].

What remains of extreme importance in the process of creating building information is the data storage format, as it shapes information exchange and cooperation. The IFC format is essential within the BIM methodology to share the information of the model with different software specific to each engineering and BIM architecture platform. Currently, there are numerous CAD tools available that support design towards BIM design. This conception of the project gathers all the information necessary for its development: geometry, structures, construction systems, building services, measurements and quantities, as well as sustainability and management [10].

The process of virtual construction of the designed building allows us to trace any information assigned to the element used in the project and read the detailed geometric, material, and construction information related to it. Unlike the BIM (Building Information Modeling), the HBIM Heritage (Historic) Building Information Modeling is a new technology based on working with an already existing object that often constitutes our cultural heritage, which results in a wider and more detailed and accurate scope of work with the created 3D model. A 3D model is created based on the pre-existing physical object, based on historical materials and an analysis of the current, physical object [3,4]. In cultural heritage, the application of BIM technology, namely the HBIM, is a relatively new activity [10] involving combining numerous fields in order to process and connect information. The purpose of researching historic objects is to understand the concept of their design, creation and construction techniques used in their structure [10]. Data scanning and processing technologies that apply modern digital tools enable the execution of detailed 3D models of the surveyed buildings [4,11].

The growing interest in BIM and HBIM technology encourages growing amounts of interdisciplinary teamwork, bringing together many participants in the construction process-architects, constructors, installers, future managers of the facility, and as a result of the history of building's operation, also archaeologists, conservators and art historians.

We observe the main difference between BIM and HBIM at the beginning of our work. In both cases, at the starting point, data is collected for the work process, and in order to save it, in principle and in both of the cases, we use computer support and available software as the tools for saving the output data. These data becomes part of the model, but in the case of BIM we rely on creating a new, virtual condition, we predict the entire process

of construction and operation of the design assumptions. In case of HBIM, we work by scanning and photogrammetry of the existing condition, and we reconstruct data from flat documentation. The existing object is built in an application supporting the design; its architectural and structural elements are reconstructed. These elements constitute unique data strings, and we detail the information level thereof, depending on the required level of detail.

Designing in BIM technology requires standardization solutions that will be understandable to all participants of the investment process. One of the elements of standardization is to define the level of detail and classification of objects, it is important for various stages of the investment, and in the case of HBIM it is important due to the level of precision of the mapping of the existing elements.

It is common practice to use the common term of LOD-i.e., Level of Detail to refer to the levels of detail, and credibility of geometric and non-geometric information for the image of object. Several international specifications are well known and commonly applied.

In 2008 the American Institute of Architects [12,13] defined the notion of levels of detail of the LOD—Levels of Development model, with six distinctive six levels. Subsequent years saw the introduction of the British PAS 1192-2: 2013 [14] standard, distinguishing two concepts: the level of graphic detail that is the LOD—Level of Detail—and the level of non-graphic information that is the LOI—Level of Information.

In the following years, the United Kingdom became the leading country in the development of documents and standards concerning the approach to BIM implementation. These documents formed the basis of the currently issued international ISO 19,650 standards, which are constantly being expanded. The currently applicable version is the ISO 19650-5:2020, organization and digitization of information about buildings and civil engineering works, including building information modeling (BIM). Information management using building information modeling was published July 2020 [15].

BIMForum Level of Development Specification published the most comprehensive and specification describing LOD, which is updated annually, with the last revision published in December 2020 [16].

On the other hand, Uniformat and Omniclass, which are commonly used in the BIM process as quantitative measurements, 3D coordination and planning, do not apply to HBIM [17].

The English guidelines developed by Historic England and COTAS try to adapt the BIM methodology to cultural heritage objects, however they also emphasize the difficulties in defining standards on numerous levels. These difficulties arise in particular due to the differences in monuments, materials, the level of destruction and the required further conservation activities [17].

CIDOC-CRM (International Council of Documentation Conceptual Reference Model) became an ISO standard in 2006, and it is an international standard of controlled information exchange in cultural heritage documentation; in recent years it has also found its application in the BIM environment.

Bruno et al. [17] believe that the classification is still an open field of research and that rigid classification interferes with many of the methods and analyses of work on monumental and historical objects, therefore there is still no single correct way of working and recording.

Many researchers propose interesting approaches to the issue of preserving cultural heritage and carry out analyses with the use of computer aided processes, including Rechini [18], who emphasizes the integration of BIM and GIS systems in research and studies. Chimera is the result of research, and it was created with cultural heritage in mind; this IT system allows the use of integrated data, e.g., 3D model, 2D maps, images, allows for further work in a large-scale approach.

Pocobelli et al. [19] provide an overview of the last ten years of work by various researchers in the field of BIM technology development and the application of BIM to protect cultural heritage. The authors analyze the activities undertaken by other researchers

in the field of BIM/HBIM. They analyze the recording and methods of data recording and processing of information about objects, and investigate the way the libraries of cultural heritage objects are processed. For example, they analyzed the study of JHBIM, an HBIM extension designed for Old Jeddah built heritage, aimed at creating a parametric library of smart objects that could be used in buildings in Jeddah and other monuments. This activity provided a comprehensive smart library graphically linked with metadata, which enables modifying and matching elements to any BIM models [19].

This review is particularly important for researchers from countries with less advanced legal procedures regarding activities and applicable legal norms in the application of BIM technology. This renders it possible to trace metadata specific to heritage objects in relation to specific cases, organizing the direction of typical activities required from future researchers in retracing their efforts [19].

Among the studies analyzed by Pocobelli et al. [19] there were these by Project of Batawa Fai et al. [20], studies by Oreni et al. [21] studies by Chenaux et al. [22] and also by Murphy et al. [23]. Pocobelli et al. [19] contained the most important information in one of the tables called BIM maturity levels, supporting the heritage-specific metadata group and the knowledge about the conducted research, presenting the activities carried out on many levels of BIM. In most cases, BIM technology was applied and metadata successfully integrated with the BIM model, making it also possible to refer to these data. The review of the available research demonstrates that it is still a process that requires further joint action that will provide a direction that is understandable and uniform for similar activities.

The article presents Polish pioneering activities in the area of HBIM creation. We discuss the process for elaboration of documentation of cultural heritage objects in various scales and various purposes, present the methods for acquisition, linking and processing of data, and discuss the activities and difficulties in creating 3D HBIM models.

The entire study had the objectives of:

- Analysis of activities carried out in Poland towards the preservation of cultural heritage using the BIM and HBIM technologies.
- Analysis of the procedure for creating a 3D object with the use of available digital tools and the possibility of preparing HBIM with the use of laser scanning and photogrammetry.
- Analysis of discrepancies in implementing BIM technology and creating 3D models for cultural heritage objects.

2. Materials and Methods

In order to achieve the assumed research objectives, and in order to assess the directions of development and the level of application of BIM and HBIM technologies in Poland, the materials available in the subject literature concerning research conducted both in the European Union and in Poland were analyzed. In order to formulate guidelines for the implementation and organization of the BIM and HBIM process for cultural heritage objects, a review study of the available studies was undertaken. This study rendered it possible to review the technologies and approaches used in the development of documentation of historic objects. This article analyzes the applied methods of 3D modeling and acquiring object metadata as well as the method of processing it and the directions of using BIM technology. The work is based on the analysis of case studies of research carried out in Poland. The analyses were limited to selected examples of elaborated documentation of the 3D objects, implemented in recent years. Such a limitation made it possible to accurately trace the methods applied for data acquisition and elaboration of 3D model documentation. This activity allowed us to analyze the software used, and applications supporting the process of recording and processing of metadata. We analyzed the data exchange and presentation methods. The actions taken in the studies are listed for selected objects. In terms of the use of BIM technology, the methods for creating 3D models, object libraries and the methods of disseminating knowledge and sharing information about cultural heritage were all listed and ordered. The research used reports, scientific articles, materials

popularizing the possible HBIM applications and materials obtained directly from their creators. We compared the results of the analysis of the methods used in order to determine the advancement of HBIM applications. This compilation allowed us to formulate general guidelines that are universal in their nature. These guidelines can be applied in Poland and other countries in order to better synchronize processes involved in the implementation of HBIM technology to protect cultural heritage sites.

3. BIM/HBIM against the Background of Europe and Poland

The current state of research in the European Union on the possibilities of using and applying BIM/HBIM technology to improve knowledge and protect architectural heritage is at a much higher level than in Poland. Examples include the extensive activities carried out as part of many research projects in European academic centers associated within the ISPC-Istituto di Scenze del Patrimono Culture. The BHiLab-Built Heritage innovation Lab operates within ISPC. This lab focuses on activities, analyses and work for the benefit of cultural heritage.

The cooperation of many European universities and research institutions is visible in jointly implemented projects. For example, the BEEP-BIM for Energy Efficiency in the public sector project, bringing together seven countries in the Mediterranean area, aims to strengthen the application of BIM technology in the development of digital models of cultural heritage objects to further manage the energy efficiency of buildings.

In the result of the pilot research of facilities and case studies, a document was developed for future HBIM studies, Guidelines For EE-HBIM Development Of Existing Buildings [24]. Another project is the ongoing IDEHA—Innovation for Data Elaboration in Heritage Areas [25].

The University of Łódź was one of the research centers involved in implementation of the European project entitled INNOVA CONCRETE [26]. In this project, the Centennial Hall was selected as one of the 100 most significant cultural heritage sites made of concrete in Europe. As part of the previous Keeping it Modern project of 2014, this facility became one of the first ones to have a BIM model elaborated with the possibility of its future supplementation with further information. As part of the project, the study entitled "Hala stulecia we Wrocławiu, konserwatorski plan zarządzania" was elaborated. Earlier activities at this facility demonstrated the importance of the elaborated BIM model for the further effectiveness of object management, and it can also be used by other researchers for further studies and analyses.

The current state of BIM knowledge in Poland is scarce, and according to the prevailing understanding of BIM the scope of BIM focuses in the area of architectural modeling. This awareness is changing year by year; in 2012, the BIM Klaster Association was established, in 2014 the Stowarzyszenie BIM dla Polskiego Budownictwa, in 2016 the Centrum Certyfikacji BIM was established, and in 2019 was the establishment of the building SMART Polska association [27].

All these activities were aimed at broadening the scope of knowledge and possibilities of work and implementation of BIM technologies in design studies. In 2018, the BIM Standard PL project was initiated in cooperation with, among others, PZITB-Polish Association of Civil Engineers and Technicians and SARP—Association of Polish Architects and numerous leading construction companies. In 2019, the first stage of work on the project was completed and it was subjected to public consultation. However, these activities did not terminate with the enactment of a law that would apply to norms, specifications or Polish BIM standards [27].

Cases where projects applying BIM technology were implemented relate to a limited number of public investments and road infrastructure projects, but they are not publicly available for analysis. On the other hand, the implemented projects or studies for the protection of cultural heritage relate to individual objects. The results of these studies are not available in the form of digital elaborations, as they were not commissioned by public institutions. Laser scanning companies offer model development at a simplified geometric

level and visualizations. The modeled geometric data is often inconsistent and does not connect the metadata with the model, this is created in isolation from historic data. This reflects the failure to reach even the basic level of BIM design. The process of implementing BIM/HBIM technology in Poland requires continuous improvement, observation and learning from activities carried out by European and global researchers.

3.1. Examples of Different Levels of Detail in the Elaboration of 3D Models of Cultural Heritage Objects in Poland

3.1.1. Centennial Hall in Wrocław

In 2014, the Museum of Architecture in Wrocław was awarded a grant from the "The Getty Foundation" foundation as part of the Keeping it Modern program, which resulted in the elaboration of "Hala stulecia we Wrocławiu, konserwatorski plan zarządzania" (The Centennial Hall in Wrocław conservation management plan). The hall was constructed in Wroclaw between 1911–1913, according to the design by Max Berg, a German architect, to commemorate the 1813 battle of nations near Leipzig. A landmark building for its time, it is an example of contemporary modernism with an innovative approach to large scale application of reinforced concrete. In the years of its construction it was the largest reinforced concrete dome in the world. The Centennial Hall is located in south-western Poland, and in 2006 it was listed on the UNESCO World Heritage List [28]; Figure 1a,b presents the view of the interior of the hall, the stand, the dome with spans, and the entrance facade.
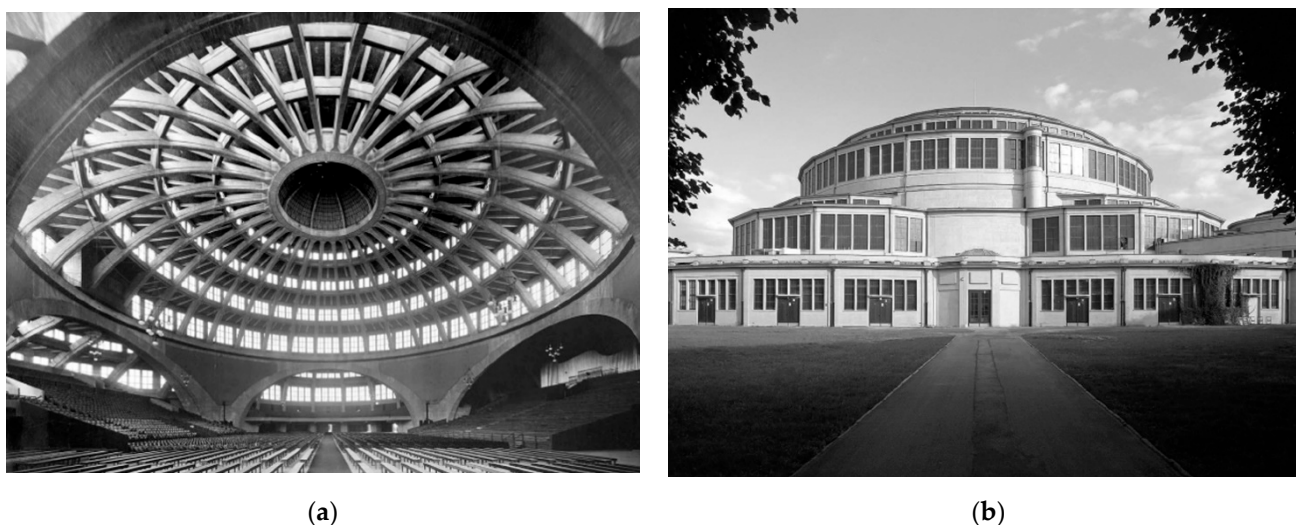

(**a**)   (**b**)

Figure 1. Centennial Hall in Wrocław, present condition (**a**) view of the interior of the hall, (**b**) view of the entrance facade from the north-west, photo taken in 2014. Source: Mirosław Łanowiecki, Museum of Architecture [28].

As part of the grant, conservation research was carried out and a conservation plan for the facility management elaborated. One of the activities was to prepare full documentation of the Centennial Hall in 2D and 3D, and for this purpose in 2015 3D laser scans were performed, using among others the Faro X330 scanner, which enabled the preparation of material for 3D documentation of the object. A total of over 50 scans and numerous spherical photographs were taken both inside and outside the object. This allowed us to obtain detailed material in the form of a cloud of points from individual scanning stations, which was saved in separate files, and then the clouds were connected using an external program. The cloud density was also reduced in order to be able to further process the material; as a result of the combination of point clouds, a three-dimensional image of the object was developed. Based on the data acquired, the geometry of the object was recreated and the data was exported to the CAD environment, where the high LOD BIM model was constructed. This object has all possible parameters of the real object with particular regard to the structure. Two BIM models were executed for further research. These activities were

aimed at demonstrating the possibility of using various software to prepare the BIM model from acquired scans. The BIM model one was executed using groups of compatible digital tools used with the following software: Autodesk ReCap, AutoCAD, Revit, Meshlab. The BIM model two using the following software: FARO SCANE, Geomagic Design X, Rhino Ceros [28].

The study included the architectonic analyses of the building, its structural analysis, study of colors, the reconstructions and repairs of the building. Structural tests were carried out by modeling the respective structural elements. Material tests of physical and mechanical properties of materials used for construction were also carried out. Plans of the respective floors and sections of the building were obtained from the developed model. The presented (Figure 2a) roof story was created from the BIM modeled hall object, taking into account structural elements with precisely marked structural axes. The developed BIM model enabled us to generate precise 2D documentation, projections and any section of the hall, (Figure 2b) presents the cross-section based on construction axes. The digital object model created in BIM technology was used to describe the preserved condition of the Centennial Hall structure.
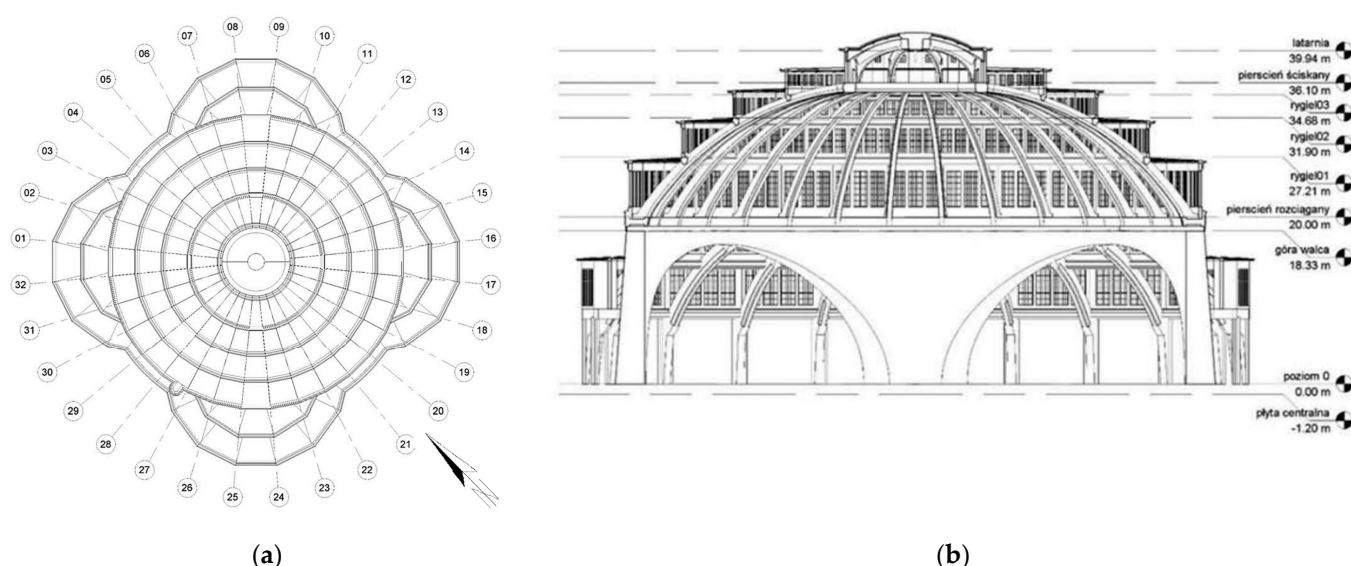

(a)

(b)

Figure 2. 2D drawings of the Centennial Hall, (**a**) view of the Centennial Hall roof generated from the BIM model, (**b**) cross-section generated from the BIM model. Source: [28].

The entire development of such precise documentation of the object model in BIM technology assumes the possibility of constant monitoring of the building's security, which will help to quickly predict which operational and construction elements, and where, should be subjected to maintenance or strengthening. When creating a 3D model of structural elements in the Revit software suite, the following structural templates were used (Figure 3), [28] "Metric Structural Framing- Beams and Braces", "Metric Structural-Column" and "Metric Window" [28]. Research carried out in the Centennial Hall during works using the created BIM model focused on structural aspects, with separate and modeled individual structural elements developed. The BIM model was executed taking into account the analytical properties of the components for static and strength calculations, then the model was exported to calculation programs, which enabled the assessment of the stress conditions of the structure, taking into account its current geometry. The analytical model is presented in Figure 3a–c, and the first figure presents the structure based on the BIM model; the subsequent ones detailed sets of information from the modeled components to the analytical model.
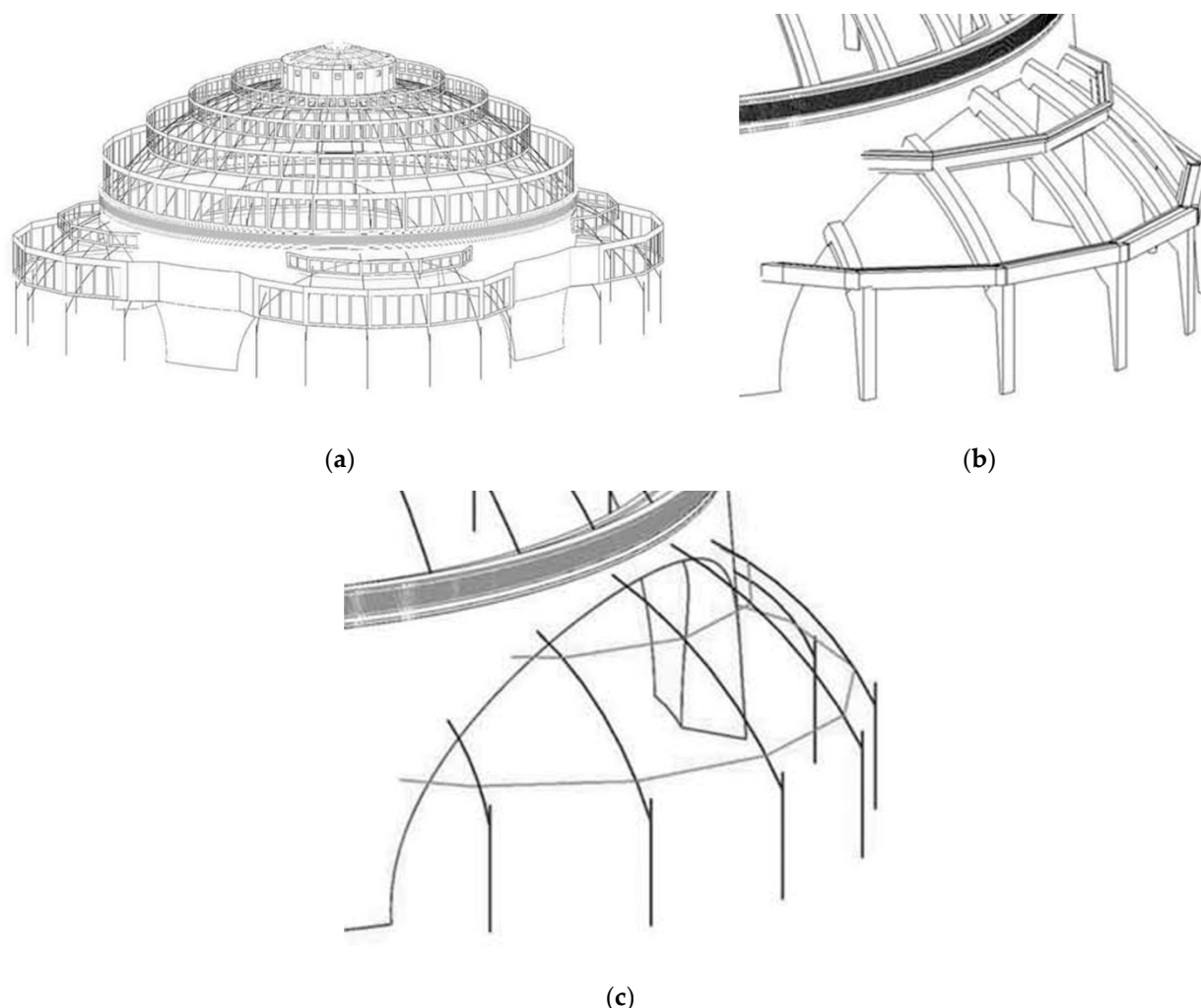
(a)

(b)

(c)

Figure 3. (**a**) Analytical model generated from the BIM model, (**b**) BIM model and comparative, (**c**) purely analytical model used for calculations. Source: [28].

The Centennial Hall object generated with the use of BIM technology contains all possible actual material and construction parameters. This allows us to analyze most of the object information, much more than analysis of 2D documentation would offer. The BIM model can be analyzed with the use of many computational programs and viewed in dedicated browsers [28].

The option of superimposing future scans on the BIM model will help us to present changes in the geometry of the building [28]. Based on the detailed analyses of the BIM model for the object in question, the Centennial Hall Conservation Management Plan was elaborated. This pioneering study demonstrates how many activities should be implemented in the protection and plans for the effective conservation of other monuments in Poland, in which the development of a 3D model in BIM technology for HBIM historical buildings should form the starting point for analyses and elaboration of conservation management plans.

3.1.2. The Wang Temple in Karpacz

The Protestant church called the Wang Temple, located in the town of Karpacz in Poland, forms another example of an architecture object with documentation prepared in HBIM technology (Figure 4). The unusual history of the church dates back to the 12th and 13th centuries. The temple was originally built in Norway, when the Christian religion prevailed there. The early years of Christianity were intertwined with pagan beliefs that

held ground in this area, which was reflected in many parts of the interior. The church was built entirely of wood, without the use of metal nails; the church's structural skeleton is a frame made of vertical corner posts fastened with boards, and the boards form the inner walls of the church. An external structural corridor surrounds the entire building, and there are windows that illuminate the corridor [28]. The interior of the church is decorated with columns and richly decorated portals, with many elements referring to Scandinavian traditions. In the nineteenth century, the church was dismantled due to its poor condition, and it was not repaired, but transported to Szczecin and then to a museum in Berlin. In 1842, the church was taken to Karpacz, where it was rebuilt, reconstructing the damaged elements of the cloisters and windows. The interesting history of the church and its unique design prompted architecture researchers [29] to develop documentation and elaborate its HBIM model.

Figure 4. Wang Temple in Karpacz, present condition. Source: (Public domain) Wikimedia Commons, the free media repository.

The research started in 2016. The object was scanned with use of the Z + F IMAGER 5010c scanner, with 12 scans taken outside and 24 inside. The final processing of the scans consisted of staining and processing the point cloud in the ZF-LaserControl software suite. In the case of this software, it consisted in removing errors in the point cloud [29]. In the initial stage of our work, point clouds were processed and cleaned, then after conversion to ArchiCAD the 3D model was converted to a fully textured vector model [29], and the development of the HBIM model initiated. For this purpose, additional PointCab software, coupled with ArchiCAD, was used, which made it possible to prepare accurate plans of point cloud images. Creating a HBIM model for existing objects that have been deformed for years, due to external factors and their use, is associated with numerous issues faced by researchers, with the main problem posed by the components used to build the model. The obvious desire to reproduce the inventoried object most faithfully when developing the model is fraught with difficulties resulting from the lack of the right amount of components, which puts many obstacles in achieving high LOD of the object. In developing the 3D documentation of the church, a detailed architectural model was elaborated that also included structural elements. New window library parts and window details were also developed. Interior fittings such as furniture, altar parts, and stairs were also modeled [29]. In Figure 5a, an object modeled in HBIM technology is presented, where one can see every detail of the model, finishing of the wall corners, detail of the ridge end,

vertical arrangement of boards on the facade, wooden cladding of the roof and the stone tower. These elements correspond to the actual object, and they can be compared with actual images (Figure 4). Thanks to the developed HBIM technology documentation of the object, executing a cross-section from the documentation in various places does not require additional studies and information details. Each resulting cross-section contains comprehensive information about each part of the temple viewed. In this documentation, the properties are defined by the author of the model, and the elements are assigned all definable information, e.g., material, dimensions, function, color, construction information about past overhauls and repairs. The cross-section (Figure 5b) presents the structural elements of the object and the full equipment of the temple. The digital documentation enables us to obtain information about each indicated object, in accordance with the properties defined for it.
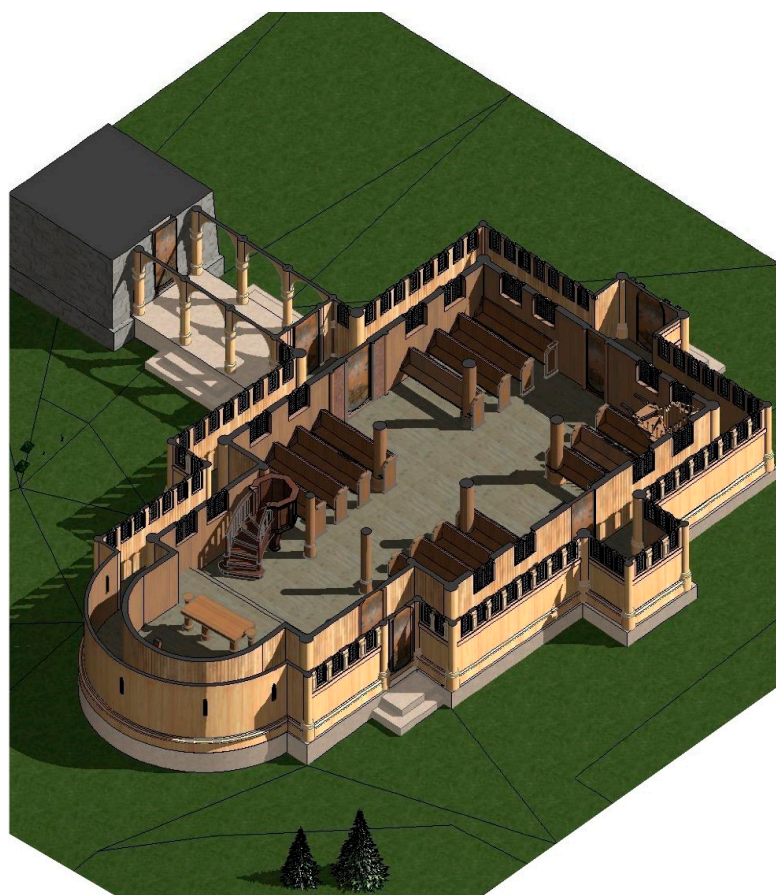

(**a**)

(**b**)

Figure 5. *Cont.*

(**c**)

Figure 5. (**a**) Ground floor of Wang Temple in Karpacz (**b**) 3D model of Wang Temple in Karpacz. (**c**) 3D model of Wang Temple in Karpacz, cross-section. The image presents a cross-section at arbitrarily selected location of the model, thanks to the documentation developed in HBIM technology, and fully modeled elements, e.g., beams, columns, stairs, windows, are visible at each cross-section level, furthermore it is also possible to filter the information assigned to them. Source: [29].

Detailed models of non-standard windows found in the facility were developed as part of the digital documentation, and these were saved as separate elements, creating library objects from them. The windows are shown in (Figure 6), and they contain a number of details such as frames, sashes and division of the filling and glazing, elaborated according to the description forming part of the LOD300 level. Thanks to the detailed development of the object model, including structural elements, and assigning them details at the LOD 300 level [29], this object forms an excellent example of elaboration in HBIM technology. This allows us to analyze the object in a transparent manner, filter and display independent elements of the object, and the full geometric, construction, historical, and functional material information allows us to understand the variety of elements that make up the church architecture.
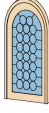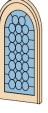
List of windows						
Sill height	110	306	314	419	422	513
Nominal size W x H x T	28× 3×17	48×114×17	48×114×17	22×64×17	22×64×17	80×80×17
3D Axonometry						
Quantity	5	1	1	1	4	2

Figure 6. Example of windows modeled for the documentation of the object. The windows have been saved as library objects with the possibility of editing their parameters. Source: [29].

The authors, who developed the 3D model of the presented historical object in HBIM technology, additionally took care of the possibility of further editing the object data and supplementing information about its renovations and repairs. The additional value of this study is the dissemination of knowledge about the historic building by making this church available as a 3D model in the free BIMx application that allows the user to use a phone or tablet to view the complete HBIM model. The documentation created digitally for the Wang Temple may be subject to further refinement, monitoring of the building condition and further analytical work; this is an example of a detailed historical object development, where the included object data and properties are required for forecasting conservation works.

3.1.3. St. Gertrude Chapel in Koszalin

The St. Gertrude Chapel in Koszalin is an example of an object where photogrammetry was applied as a standalone measure for developing the 3D documentation of the historic monument. The chapel was constructed in 1389 outside the city walls, and initially served as a hospital chapel. Over the years the function of the building changed repeatedly; it housed an ammunition store, a warehouse, and after the Second World War it also operated the Baltic Dramatic Theater and a bookstore. In 1956, the chapel was entered in the register of monuments [30]. In order to develop the model, due to its small dimensions, it was only possible to use a single camera, the data of which could be used in full without losing information, e.g., about the height of the object and texture. The photographic documentation was made by one person [31]. Photogrammetry and the selected Photomodeler Scanner software were used in this case both to develop 2D and 3D documentation, as well as to generate files for further modeling and visualization of a historic sacred object in software compatible with the Photomodeler Scanner file format. The documentation was prepared based on the initial data, in combination with the available tools supporting design. Exporting the files for further editing of the resulting model allowed us to use the study as both a conservation documentation of the cultural heritage and a 3D model. The 3D model executed for the sacred building of St. Gertrude Chapel in Koszalin in Poland is presented in Figure 7a,b; it is a surface model with a texture applied.

(**a**)   (**b**)

Figure 7. St. Gertrude Chapel in Koszalin, (**a**) 3D object generated in the Photomodeler Scanner suite, the coordinates of the three-dimensional object were textured using the texture mapping method. (**b**) Model imported from the Photomodeler Scanner, presented as a white mockup in Rhino suite, prepared for further editing and texture application. Source: [31].

Work on the documentation was divided into two phases, each of which was based on separate tasks. The first phase consisted of field work, taking a series of photograms and additional photos of details of the object. The images were taken with use of a NIKON D200 digital camera and a 18 mm AF S NIKKOR lens, after calibrating it in a suitable module of the Photomodeler Scanner program and additional calibration in the field with the help of test images. The amount of time spent on collecting photographic documentation always depends on the detail of the study and the size of the object; in this case it took just one hour to complete. Sixteen terrestrial photograms shot from a tripod in similar lighting conditions and with a maximum resolution of 12 Mpx, as well as appropriately set camera parameters, were used for the project. The photos were taken in a plane parallel to the facade of the chapel—i.e., perpendicular to the object, with the cross-coverage of the paintings at the level of 70% from a distance of about 6 m [31]. The object and the locations from which the photograms were taken are shown (Figure 8), and the number of photos taken also allowed us to acquire data for texture mapping.
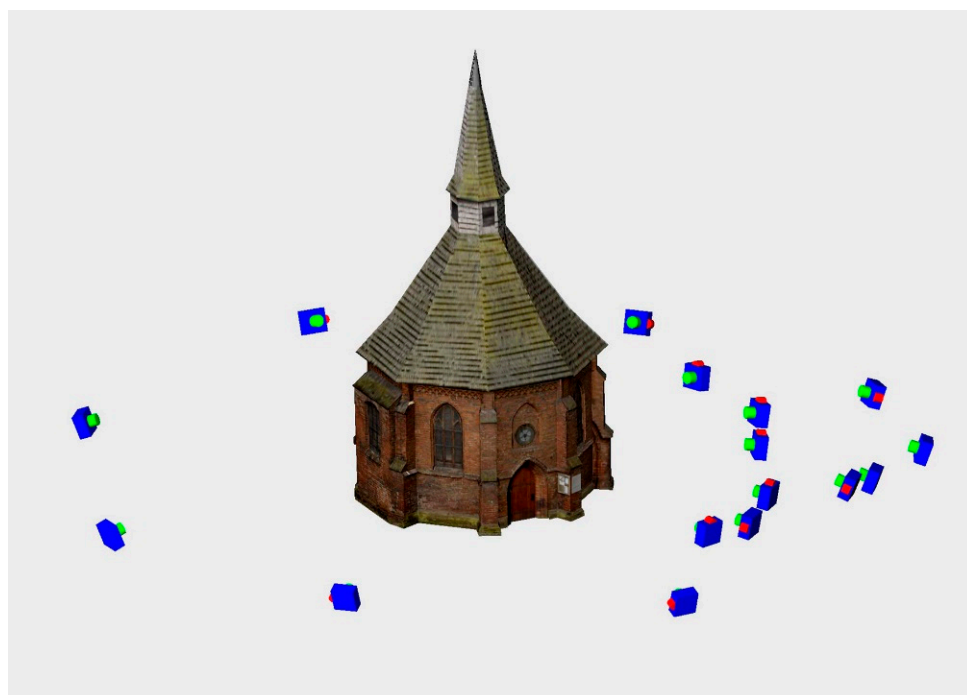
Figure 8. St. Gertrude Chapel in Koszalin, a 3D object generated in the Photomodeler Scanner software with graphic information presenting the locations from which the photos that were later used to construct the model were taken. Source: [31].

The photograms were processed by software automatically, in several stages. The first stage was the internal and mutual orientation of images, using the SmartPoints function. The second stage was the generation of a dense point cloud with use of the DSM—Dense Surface Modeling—tool. The third stage consisted of triangulation of a point cloud to a triangle mesh mapping the surface of the object. The second phase of work after linking the object as a whole consisted of direct development of the acquired data with use of applications that the Photomodeler Scanner suite can exchange (import and export) the data with [31].

After generating the object in Photomodeler Scanner, the file was then exported for further model processing. In the case of the discussed object, further development of the model and application of textures was carried out using the Rhino program, in which various visual effects of the object were developed, from the mock-up to the presentation of the chapel with the texture applied to the model. The phases of work on the development of documentation are presented in Figure 9a–d. This summary presents the respective stages of preparation of the chapel's 3D model. In the upper right corner we can trace the beginning of the activities from uploading the point cloud, to the left corner, where we see the condition of model following the generation of the triangle mesh. The lower right corner presented the Rhino-generated mock-up surface model. The left corner presents the full 3D object model with applied texture.
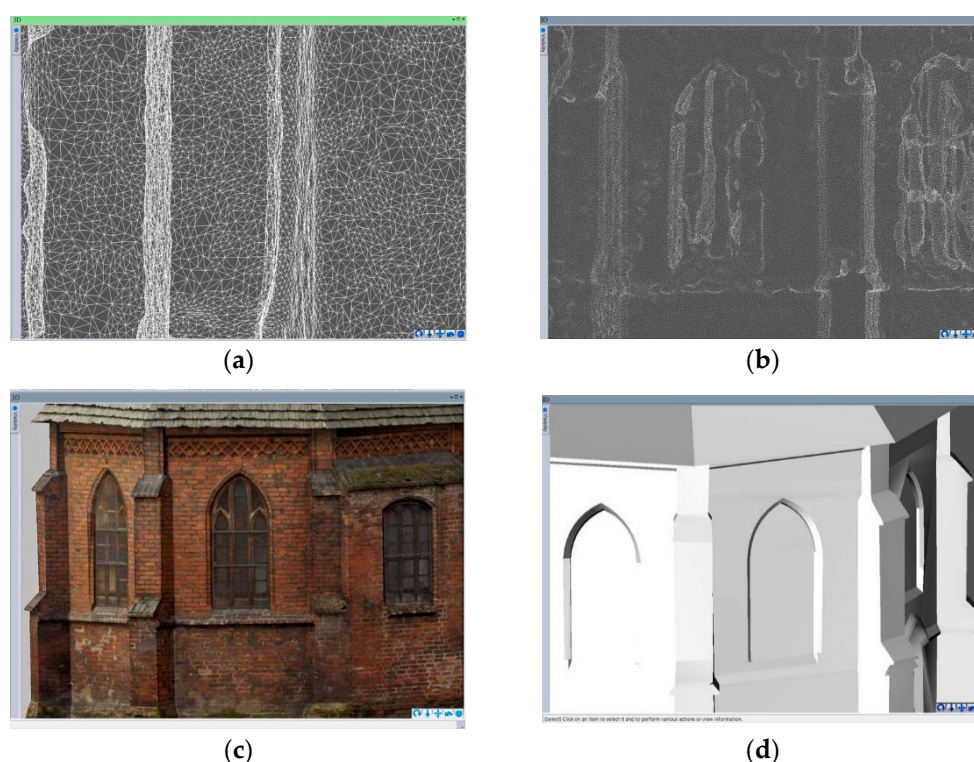
Figure 9. Summary of development stages of the model of the St. Gertrude Chapel in Koszalin, (**a**) upper right corner presents the generated point cloud in the Photomodeler Scanner program, i.e., a high-density cloud presenting only the outline of the object. (**b**) The upper left corner presents the triangle mesh obtained after the triangulation of the point cloud to the triangle mesh in the Photomodeler Scanner program, here, again, the image of the object is not complete yet, and thus difficult to read. (**c**) Left bottom corner presents the white mockup 3D model generated in Rhino, the model was based on the file imported from Photomodeler Scanner, here the image is already clearly visible, and the geometric shapes of the object are clearly visible. (**d**) 3D model of the chapel in the Rhino program, the most understandable and legible study, this shot is the final geometric model that contains full information about the texture of the object. This model is an accurate form of conservation inventory showing geometry, detail, material, defects, and information required for further studies and conservation works. Source: [31].

The full 3D model of the chapel prepared in Rhino can be exported to further programs supporting design using Open NURBS formats, e.g., to Revit, or ArchiCAD. While working on this object, the most commonly used data exchange formats were DXF (2D and 3D), 3D Studio, OBJ, Open NURBS/Rhino, STL.

The documentation does not include the developed HBIM model. In the discussed case, a solid model was created with only geometrical information, lacking construction and material information, details and library objects as well as historical information. The scope of the study consists of 2D and 3D images, which are the basis for further editing, which shows that the research and digital documentation performed may still constitute the basis for supplementing information and creating comparative analyzes, while also leaving the possibility of working on the subsequent stages aimed at developing HBIM documentation.

3.1.4. Church in Iwięcino

Another example that presents the activities carried out to preserve the cultural heritage with aid of modern digital tools is the church in Iwięcino, where in 2019 an inventory of the entire resource was carried out. The object is a 14th century church located in the middle of a village in Western Pomerania in Poland. The oldest equipment inside the temple proves the presence of Cistercians in Pomerania. The church in Iwięcino belongs to a unique group of 75 gothic buildings in the coastal belt of Western Pomerania

(See http://encyklopedia.szczecin.pl/wiki/Kośció\T1\l_Matki_Boskiej_Królowej_Polski_ (Iwięcino) (accessed on 5 October 2019)). The facility and its surroundings were listed in 1960 (Figure 10). Work on the digitization of the resources of the presented church was undertaken to increase accessibility of cultural heritage. Inside, the church has a very rich collection of liturgical furnishings and movable monuments; our attention is drawn to the beam ceiling covered with polychrome, depicting the Judgment Day dating back to 1697 [32].
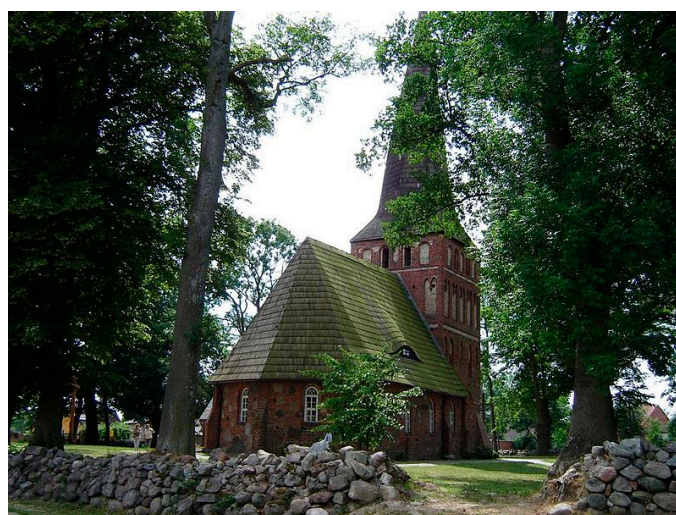

Figure 10. The church in Iwięcino—present condition. Source: (Public domain) Wikimedia Commons, the free media repository.

All property resources, together with the church facility, were digitized and developed in the form of both 3D objects of movable property with descriptions of monuments and a 3D temple model (Figure 11a,b) available in VR technology. A publicly available website dedicated to this project is an activity promoting the discussed facility and access to cultural heritage.

When constructing the 2D and 3D documentation, the emphasis was on displaying all the elements constituting the cultural heritage resource. In this case, due to the scale and number of modeled 3D elements, various tools were used to acquire data, including a scanner, handheld scanner, camera and drones. The initial stage of the work was based on the analysis of source materials and the analysis of the possibility of using and selection of tools, the interior of the object was scanned using various scanners (both ground-mounted and handheld). This action was aimed both at selecting the appropriate tools and their settings in order to maintain the largest number of precise parameters of the scanned object, and at elimination of measurement errors. During the preparation of the documentation, physical digitization from the ground and air was performed, and for this purpose a FARO FocuS 150 terrestrial scanner was used, supplemented with drones with 6K Cinema DNGRAW digital cameras. In order to accurately capture the complex structure of movable monuments, optical scanners of white and blue structural light with resolutions of 0.1 mm/0.05 mm/0.01 mm were applied. The acquired output data in the form of point clouds from laser scanning at over 100 measuring and photogrammetry stations (Fundacja Wirtualizacji Narodowego Dziedzictwa Kulturowego, (Szczecin, Polska); Personal communication, 2019) was then processed in a dedicated RealityCapture program. This program enabled the work and processing of point clouds, acquired both from scanning and photogrammetry. Based on the combined scans, a three-dimensional model of the object with a superimposed texture was developed (Figure 12a), the projection of the object and its cross-sections were also generated (Figure 12b,c). The projection obtained from the scan shows the actual condition of the object and all distortions.

(**a**)   (**b**)
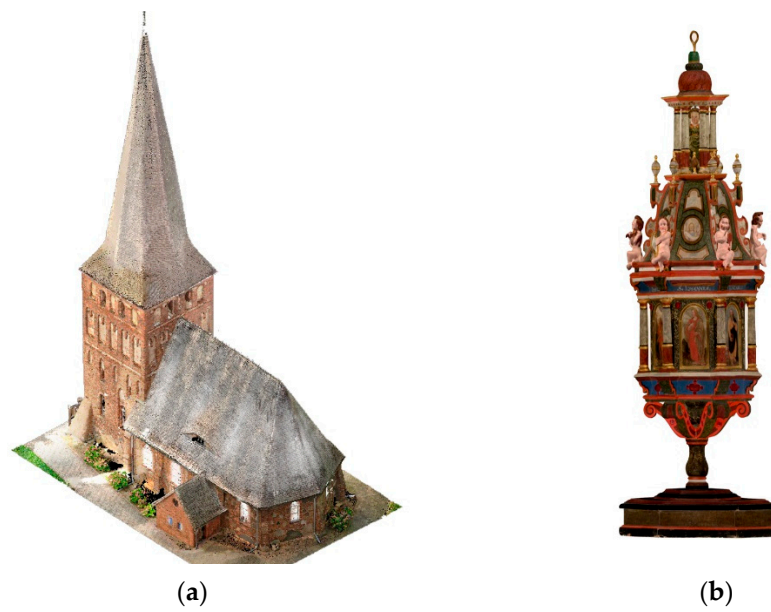
Figure 11. (**a**) The church in Iwięcino, the scanned object presented in 3D form. (**b**) 3D model of a movable object, a six-sided baptismal font from the 17th century, located in the presbytery, designed as a separate element. Using the interactive website, users can view all digital models of the entire study with a breakdown into objects, sculptures, arts and crafts, painting, blacksmithing. Source: Fundacja Wirtualizacji.

(**a**)

(**b**)

Figure 12. *Cont.*

(c)
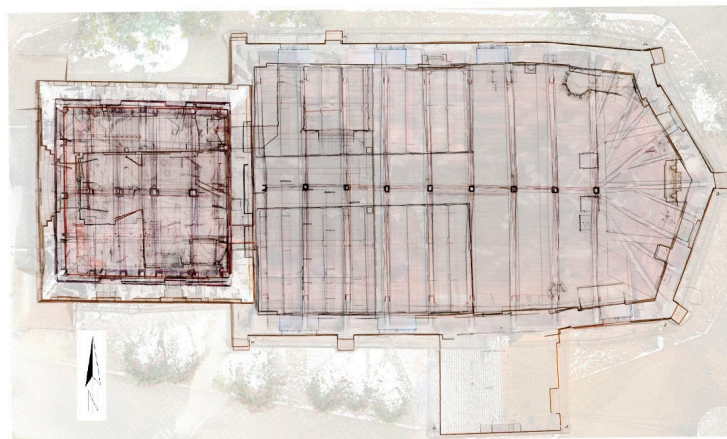
Figure 12. (**a**) Church in Iwięcino, 3D model based on combined scans with superimposed texture. (**b**) Object projection, horizontal section, based on the model obtained from complex scans. (**c**) Vertical section based on the model obtained from complex scans. Source: Fundacja Wirtualizacji.

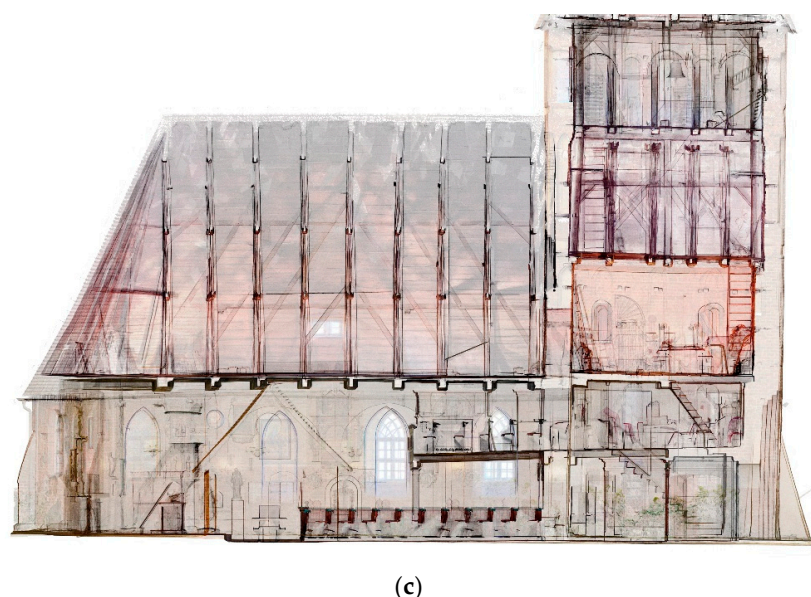After processing the scans, the 3D model was elaborated and then a mesh model containing a set of vertices, edges and points, then the object was exported to a CAD program, which allowed for the elaboration of technical 2D projections. The digital visualization of the object was developed using the Unity engine. The model and visualization prepared in this way served as an interactive source of data allowing us to view information about the digitized object of cultural heritage. The entire study was divided into permanent elements such as the church itself (Figure 11a) and movable items such as Figure 11b. Models of moving objects were elaborated in detail, creating 3D objects with full texturing. In addition, detailed information was assigned to the objects, constituting the monument file (Figure 13). Fixed elements, i.e., the church and the permanent interior equipment, altar, pulpits, and benches are also 3D models with the possibility of reading their measurements and relative distances inside (Figure 14). For this purpose, software was used to enable the conservators of monuments quick access to the entire information resource concerning the object. 2D and 3D documentation, projections, cross-sections, facades and a model have all been developed.

In order to disseminate knowledge about the monument, a website was developed, devoted to the church in Iwięcino. This provided the possibility of a virtual walk around the object, recreating the model and individual moving monuments with a 3D preview (Figure 15) or in virtual reality (Fundacja Wirtualizacji Narodowego Dziedzictwa Kulturowego, (Szczecin, Polska); Personal communication, 2019). Playback is possible directly from the link provided at the indicated object on the Sketchfab (See https://sketchfab.com/3d-models/koscio-pw-matki-bozej-krolowej-polski-6530aaf0115c43c09739c7b352594707 (accessed on 29 October 2019)) platform, which the users are redirected to from the website dedicated to the object. Apart from the model, the application contains basic information about the object: its material, style, location, and object description.
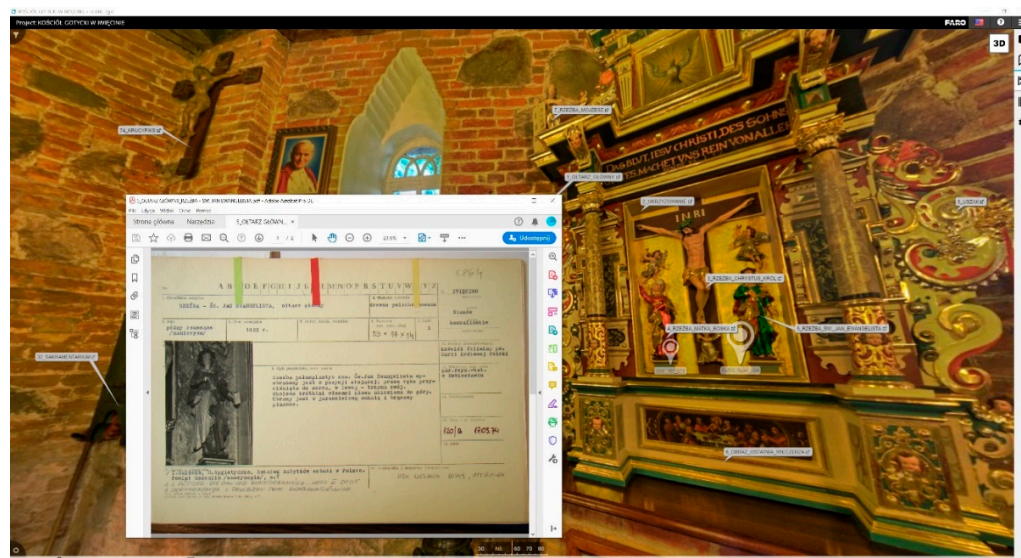
Figure 13. The church in Iwięcino, an example of an interactive combination of a scanned movable monuments developed as a 3D model with added information, a conservation file of the monument. It depicts a statue on the main altar. Source: Fundacja Wirtualizacji.
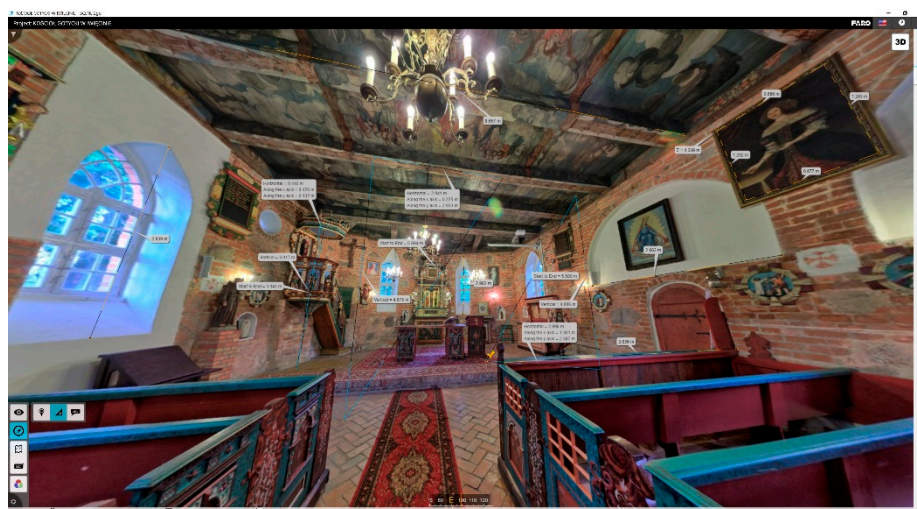
Figure 14. The church in Iwięcino, an example of an interactive combination of a scanned object and permanent interior furnishings with conservation information. Source: Fundacja Wirtualizacji.

The development of digital documentation for the object in question was executed in a very detailed manner with important conservation information already added to the historic buildings. In this case, no documentation was developed in BIM technology, but the resource of collected data and basic technical studies, based on the constructed information base, enable the transition to the next stage of HBIM technology implementation. On this basis, it would be possible to prepare a conservation management plan for the monument, which will enable constant monitoring of the changes taking place in it and supplementing information about the building itself.

Figure 15. The church in Iwięcino, a 3D model of the church and moving objects, as made available on the Sketchfab platform. By providing a model of the church and individual elements of the altar interior, sculptures, paintings as 3D objects, it is possible to analyze them, it is a form of popularizing a historical object, giving the possibility of a virtual tour. Source: Sketchfab [33].

4. Results

4.1. Comparative Assessment

The discussed examples and processes of creating 3D documentation for the implementation of HBIM technology for cultural heritage objects in Poland present the diversified uses and applications of CAD software as well as laser scanning and photogrammetry. The analysis of the examples included in Table 1 presents the procedures for creating documentation of cultural heritage objects and the degree of use of BIM and HBIM technologies. The examples discuss how the documentation of a historic object was created as a 3D model and to what level of accuracy and detail the object was actually developed. The summary also presents the directions of further actions to fully implement HBIM technology in these buildings, which is an option as the files can be further edited.

The analysis of the implementation of HBIM/BIM technology for cultural heritage objects proved that in all cases a 3D model was elaborated, which was editable in CAD software. In three cases, the object was saved in a format supported in CAD programs; however, only in two cases, that of the Centennial Hall and the Wang Temple, were the models detailed with information on the level of geometry, structure, and materials, while in the remaining two the models were left as solid.

Table 1. Procedure for creating digital models of individual objects, including the possibility of their further editing. Source: authors' work.

Facility Name	Data Acquisition Technology	Data Processing Technology, Software Used	Type of Model Developed, Information Included	The Direction of Further Editing and Development of Information about the Object
Centennial Hall in Wroclaw	Faro X330 scanner, spherical photography More than 50 scans inside and out	Two BIM operating methods I Autodesk ReCap, AutoCAD, Revit, Meshlab, BIM software II: FARO SCANE, Geomagic Design X, Rhino Ceros	Digital model of the object in BIM technology, which was used to describe the condition of preservation of the Hall structure, The model contains construction and material information, unique library elements created for the needs of the construction study	The possibility of further editing the data about the object and overlaying the BIM model with subsequent scans revealing changes in the geometry of the building
Wang Temple in Karpacz	Z + F IMAGER 5010c scanner, 12 external scans, 24 internal scans	Software: ZF-LaserControl, ArchiCAD, PointCab	Digital model of an object in BIM/HBIM technology containing construction and material information, new library elements that have all definable information assigned, e.g., material, dimensions, functions, color, construction information, e.g., about past overhauls and repairs	The possibility of further editing object data about and supplementing information about its renovation, repairs, the model can be further detailed, thus making it possible to monitor the condition of the building
St. Gertrude Chapel in Koszalin	Digital photography NIKON D200 and the AF S, NIKKOR 18mm lens, 16 photograms taken	Photomodeler Scanner, Rhino	No HBIM model, a solid 3D model of the object developed, with a texture applied using the mapping method, 2D and 3D drawings,	The file format enables exporting it to a CAD program and construction of a model in HBIM technology
Church in Iwięcino	FARO scen 150, drones with 6K Cinema DNGRAW digital cameras, Optical scanners for moving objects, digital photos, over 100 measuring stations indoors and outdoors	Software: FARO SCANE scans and photograms, RealityCapture, 2D in Auto CAD, visualization in Unity engine	No HBIM model, a 3D surface model with an applied texture was developed, 2D and 3D drawings elaborated, visualization and 3D models of historic buildings were made, conservation files were attached to the models	The file format enables the construction of the model in HBIM technology, Moving 3D objects with monument conservation files can be constantly updated with new information

We also present the summary of differences in development of the digital models of the respective objects (Table 2). In the case of the Centennial Hall, great emphasis was put on detailing the construction elements and strength simulations were carried out. In the Wang Temple, more attention was paid to the modeling of windows and elements in the interior, whose significant deformation prevented the use of library elements available for modification, but here the strength aspects of the structure were not analyzed. In the church in Iwięcino, it is possible to further detail information in HBIM technology

at the model level. The value, which undoubtedly distinguishes the latter study, is the attribution of detailed conservation information to interior furnishings and movable objects, which is missing in the case of first two HBIM-developed objects and the solid model of St. Gertrude Chapel.

Table 2. List of differences in the elaboration of digital models of the respective objects. Source: authors' own elaboration.

Basic Model Parameters	Centennial Hall in Wroclaw	Wang Temple in Karpacz	St. Gertrude Chapel in Koszalin	Church in Iwięcino
Features of the object documentation model	BIM Model Structure/Architecture	BIM Model Structure/Architecture	3D solid model	3D surface model/3D models of movable items of church equipment
Object libraries created for object development	yes	yes	no	no
Option of editing and exchanging files in CAD software	yes	yes	yes	yes
Material information included in the model	yes	yes	no/only the texture mapped	no/only the texture mapped
Conservation study, including a description of the object	yes/publication available on the facility's website	no	no	yes/descriptions available on the facility's website
Conservation information assigned to items of equipment	no	no	no	yes/available via the website of the facility
Open access to information on the website	yes	no/only the subject publication available	no/only on the author's website	yes
Conservation management plan for the facility	yes	no	no	no

4.2. Guidelines for HBIM

The analysis of the discussed examples of HBIM implementation in Poland demonstrated that the resulting discrepancies in the implementation of technology and the development of documentation of the monument are the result of the lack of top-down standards. There are no mandatory levels of detail for the elaborated digital documentation and the method of its digital recording. This causes a number of discrepancies in the grouping of information about material, construction, historical and architectural data in the created library models and objects.

Further work on the HBIM application in the protection of cultural heritage sites should be based on the following four basic principles:

1. unification of the saving file format in form of the open IFC format,
2. development of an object and library objects with a minimum level of detail of LOD 300,
3. assigning conservation data in the form of interactive conservation files to movable objects, 3D models, which constitute interior furnishings or an architectural detail of an object,
4. open access to object data for the purpose of analysis and protection of the object through the possibility of creating a maintenance plan for object management.

These general guidelines are universal and their fulfillment forms the basis for further evolution in the activities aimed at implementing and applying HBIM. These guidelines can also be taken into account in other countries, allowing researchers to easily analyze signifi-

cant new developments in HBIM technology. Observation of the direction of development and implementation of HBIM in the world and the first efforts in Poland demonstrates that the object conservation management plan should become part of the facility documentation in HBIM technology. This will enable constant insight into the functioning of the object and its protection, as well as the analysis of planned conservation works, but it will only be possible after the first three principles are met.

5. Discussion

Laser scanning and photogrammetry quickly became methods used to illustrate the preservation of cultural heritage objects [4,34,35]. 3D models created from flat 2D images are not only virtual models, as they are used for further analysis and cognitive research. The standardized use of the open IFC file-saving format could pave the way to further applications of BIM models. These activities will help us to better understand the complexity of the object, and its historical transformation and historical construction phases [4]. The accuracy of the developed HBIM models opens numerous possibilities for interdisciplinary research. Based on the generated models, its fragments can be recreated or scaled-down into copies created using 3D printers [36], and reverse engineering renders it possible to reconstruct damaged elements. Promoting the implementation of new technologies in the development of conservation documentation is becoming an indispensable process in the pursuit of creating plans for the conservation of monuments. This is confirmed by many authors in their research on historical objects [34–38], where they discuss the application of various methods for combining digital tools, CAD programs and the possibility of using laser scanning and photogrammetry also in future planning of activities in the researched objects.

In Poland, designing with the use of CAD tools and creating designs using BIM technology were subject to analysis conducted by Kepczyńska-Walczak [39]. What followed from that research is that most design offices still develop 2D vector documentation, and even if 3D models are created, they constitute a separate development in surface modeling programs, or are separated from the 2D projection. Lack of conviction, knowledge and skills at work slows down the process of implementing new solutions. This condition of commonly practiced design activities proves that the awareness of correct uses of BIM is a prerequisite to implementation of HBIM and its application to heritage preservation.

HBIM technology, both in Poland and in other countries, still requires the development and preparation of uniform guidelines [4,37,38]. One of the limitations of HBIM technology research is the lack of parametric library objects; in principle it proves difficult to reflect the less than perfect condition, deviations and deformations in CAD programs [20], and the solution close to correctness is the creation of objects with a high level of detail.

Numerous authors [4,37,40] argue that the application of BIM for historical objects is still problematic, although many architects and engineers consider BIM to be a groundbreaking means of documenting that will also assist in preserving cultural heritage. Diara and Rinaudo [37] believe that the creation of a database and library resources is the pivotal point in HBIM, that will render it possible to use the recorded information (condition, structure, geometry, materials, historical phases) to document the current and future conditions

The research presented in the article for four objects in Poland confirms these views and, moreover, indicates the crucial issue of defining uniform rules of conduct in order to standardize the information recorded when applying BIM/HBIM technology. An example confirming this is the object of the Centennial Hall, for which most of the proposed rules were satisfied, and hence it gives the opportunity for subsequent researchers to view the open file, evaluate library elements, analyze the conservation plan and further supplement it with additional information.

In many countries, authors in their research projects [4,38,41–44] conducted analyses with the use of photogrammetry techniques and a laser scanner for modeling objects from point clouds. They used available CAD suites [38,42,44], examining the possibilities of applying BIM HBIM in the creation of cultural heritage objects. This confirms that the use of

BIM technology as a new method in preserving cultural heritage has become an increasingly frequent activity in recent years, recognizing HBIM as the primary direction of workflow in the modernization or reconstruction of historic monuments. These projects mainly analyzed the possibilities of data entry, the creation of custom databases of historical elements' libraries, the possibility of creating digital 3D models, and conservation documentation and object management.

Similar activities were also initiated in Poland, albeit on a smaller scale, however they still constitute a good direction for the implementation of BIM/HBIM technology in future conservation works. The Polish examples, developed in HBIM, include the Centennial Hall and the Wang Church. These objects were supplemented with intelligent material and geometrical construction data, with new library elements modeled in these objects, and the focus was on the feasibility of building a digital 3D model, based on data most often sourced from ground-based laser scanners and photogrammetry techniques. The authors of the HBIM documentation of the Wang Church [29] hope that the documentation will be further supplemented with further historical data and will form the basis for further remedial actions and conservation activities. At the same time, they confirm, similarly to other researchers [37,42–44], that all historical objects should have such documentation. It is particularly important in the planning of further activities and monitoring of the monument's condition.

Limitations of Research

The limitations that appeared in the study of the analyzed cases are the result of the lack of information systems and platforms gathering research results or data on cultural heritage objects that could be applied for further analysis. Defined information, or the results of analyses, is still source-documented in paper form; the digitization of existing research processes often does not combine them with 3D models, and even if there are 3D models available, they are stored in the archives of the research authors. Qualitative analyses of the developed models could be helpful in monitoring the condition of these objects and further stages of comparative research, e.g., with subsequent studies of other objects. We based our interpretation of the results on access to source materials for two objects; these materials did not constitute deposited information, which is generally available for analysis, but they were archival material that was made available for our research. In the case of the Church in Iwięcino, analyses were possible on raw materials created during scanning, and on a ready model made available in VR. The materials for the Gertrude Chapel could be analyzed in the form of initial photograms, elaborated for the development of the model, and on the finished model. The remaining facilities were analyzed on the basis of publicly available final data.

Even with the numerous difficulties in implementing BIM technology in cultural heritage (HBIM) in Poland, this technology opens an opportunity to obtain complete documentation enabling management and planning conservation protection [20,38]. This is further confirmed by the analyzed Polish objects, where the scale of progress in the implementation of HBIM technology is ordered (Table 3) from the least advanced to those meeting the postulated four principles of HBIM implementation as follows: St. Gertrude Chapel, the church in Iwięcino, the Wang church, to the most advanced object of the Centennial Hall.

Table 3. Progress in the implementation of HBIM technology on the example of the application of the four proposed principles, in the order from the least advanced to the closest to the adopted principles. Source: authors' own elaboration.

Name of the Object in the Order of Advancement of the Implementation of HBIM Technology, According to the Proposed Four Principles	Advantages of the Study	Disadvantages of the Study
St. Gertrude Chapel in Koszalin	The easiest way to develop a model that can be exported to CAD software	No BIM model, no access to a 3D model saved in an open format and no interactive data, lack of conservation data
Church in Iwięcino	Advanced 3D model with moving models and conservation data, the ability to export the published resource to CAD software, access to an interactive model database, models available in VR	No BIM model, no access to a 3D model saved in an open format
Wang Temple in Karpacz	BIM model, data available solely in the application, own library database	Lack of access to the 3D model and interactive conservation data about the object, no access to the 3D model saved in an open format
Centennial Hall in Wroclaw	BIM model, own library database, Object conservation management plan,	Lack of access to the 3D model and interactive conservation data about the object, no access to the 3D model saved in an open format

6. Conclusions

In summary, the use of photogrammetry and laser scanning significantly increased the quality and accuracy of conservation studies, also affecting the development of architectural research on cultural heritage. Precise measurements, more precise analyses and access to 3D documentation enable the supplementation of data and the monitoring of object conditions. Although the use of HBIM technology in the protection of cultural heritage in Poland is still at the initial stage, as further confirmed by the analyzed studies, it remains a necessary course of action to fully preserve and supplement data about the monuments.

The implementation of BIM/HBIM technology forms a great interdisciplinary challenge for the numerous design and research teams dealing with both architecture and historical construction. The activities of researchers aiming at collection and processing of data as well as generating complex 3D models are inconsistent, resulting in the lack of homogeneous studies. In general, the application of HBIM technology to conservation protection should become the basis for the renovation of historic buildings, object management and giving independent researchers the opportunity to analyze the object. The right direction for the correct implementation of HBIM should be to use and organize the source materials acquired during the measurements and analysis. The amount of collected and digitally processed information, as in the case of the discussed objects of the church in Iwięcino and the St. Gertrude Chapel, cannot remain only at the stage of good visualizations and 3D models generated for the purpose of their viewing in virtual reality. In further stages of the work on the protection of monuments, the possibilities of effective development of HBIM documentation should be analyzed. Adoption of the proposed guidelines can facilitate and improve the communication process between research teams.

The guidelines may also be adopted in other countries. The universality of the guidelines consists not of indicating digital tools and CAD software and the method of data acquisition, but in standardized recording and accessibility. These four principles will facilitate the process of implementing and completing the output data, thus enabling in the future the further process of implementing further data and analyses, and the development of new management and protection strategies. The lack of unified guidelines for the elaboration of documentation demonstrates difficulties in the uniform structural assessment of objects in the Polish examples discussed. Incomplete HBIM studies inhibit the possibility of further analysis of the object and effective management and planning of conservation activities.

The use of design assisting tools, the creation of 3D models and the resulting modeling possibilities of complex geometries created in open formats are the directions that introduce us to the implementation of BIM/HBIM technology in historic buildings. This will enable the generation of open-ended documentation studies, which, even if incomplete, can be further supplemented with historical data, and will also form the basis for further conservation works. Greater effort with interdisciplinary cooperation and awareness of values of HBIM documentation is an important direction that supports the preservation of cultural heritage.

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