International Journal of Architectural Heritage
Conservation, Analysis, and Restoration

ISSN: 1558-3058 (Print) 1558-3066 (Online) Journal homepage: https://www.tandfonline.com/loi/uarc20

HBIM (heritage Building Information Modell) of the Wang Stave Church in Karpacz – Case Study

Dominika Sztwiertnia, Agnieszak Ochałek, Alicja Tama & Paulina Lewińska

To cite this article: Dominika Sztwiertnia, Agnieszak Ochałek, Alicja Tama & Paulina Lewińska (2019): HBIM (heritage Building Information Modell) of the Wang Stave Church in Karpacz – Case Study, International Journal of Architectural Heritage, DOI: 10.1080/15583058.2019.1645238

To link to this article: https://doi.org/10.1080/15583058.2019.1645238

Published online: 30 Jul 2019.

INTERNATIONAL JOURNAL OF ARCHITECTURAL HERITAGE
https://doi.org/10.1080/15583058.2019.1645238

HBIM (heritage Building Information Modell) of the Wang Stave Church in Karpacz – Case Study

Dominika Sztwiertnia[a], Agnieszak Ochałek[b], Alicja Tama[b], and Paulina Lewińska [b]

[a]BIM Point, Kraków, Poland; [b]Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, Krakow, Poland

ABSTRACT
In recent years, Building Information Model (BIM) has become a leading topic for construction-related fields. This technology may be viewed as a process, a type of database, a software or even a 3D model, but in fact, it integrates all these roles and many more. Heritage (Historic) Building Information Model (HBIM) is a standard for heritage objects. It not only allows for the storing of spatial information and metadata but also provides the means of documenting changes that such structures undergo. The scope of application varies from simple documentation repository, through conservation planning tools, to construction and renovation simulation instruments. In this paper, we focus on the example of the so-called *Wang Temple* in Karpacz, Poland. This object was chosen due to its unique history. This project was done in cooperation with BIMPoint Company (Kraków). It was aimed at showing how effective HBIM can be in accurate spatial documentation of small-scale heritage sites.

ARTICLE HISTORY
Received 4 December 2018
Accepted 15 July 2019

KEYWORDS
3D model; BIM; HBIM; terrestrial laser scanning; vector model; Wang Temple

1. Introduction

Recent years have brought the fast development of IT technology that is utilized daily by a wide variety of users. Implementation of some of those techniques into architecture, archaeology, civil engineering, and other related industries was unavoidable. One of such applications, namely Building Information Modelling (BIM) systems has become a leading topic for construction-related fields (Baik et al. 2014; Kiviniemi 2012; Volk, Stengel, and Schultmann 2014). BIM technology may be viewed as a process, a type of database, a software or even just a 3D model, but in fact, it integrates all the previously mentioned roles and many more. It is a fast solution for selective problems that does not interfere with data gathering techniques that were already in use (Jensen and Jóhannesson 2013, Barazzetti 2015a, 2015b).

The BIM model is similar to the 3D vector model of a building's structure, but it also contains information on functionality, performance, and relationships between separate elements (Anil et al. 2013; Garagnani 2015; Jensen and Jóhannesson 2013). Every single element in the BIM model has its unique ID, which helps to store and manage a huge amount of data (Dore 2015). This leads to a large number of possible applications of gathered information (Volk, Stengel, and Schultmann 2014). It is possible to create sheets, cross-sections and data tables fitted to the needs of the receiver, whether it is for an architect, a constructor, an installer or an archaeologist trying to establish connections between various historical sites (Azhar 2011). The described methodology was shaped by building SMART association and as a result, Open BIM methodology was produced. To gain full cooperation and effectiveness, common standards, libraries, and formats were created. It was first of many such applications that introduced an IFC data format, which is currently used by designers, constructors, and managers all over the world.

BIM is ready for different methods of collecting data. Spatial information can be gathered via a total station survey, 2D documentation, photogrammetry, structure-from-motion and laser scanning (Garagnani 2015; Garagnani and Manferdini 2013). With new technologies now entering the market—augmented and virtual reality, advanced sensors, data exchange, this technology will constantly develop, becoming more and more complex and its solutions will start to be available to the wider public. (Azhar 2011; Kiviniemi 2012). Implementation of BIM methodology is not easy and requires more work at the early stage of planning and entering the data in comparison to the conventional approach to 3D documentation, but it rewards with greater efficiency in future maintenance.

CONTACT Paulina Lewińska lewinska.paulina@gmail.com Faculty of Mining Surveying and Environmental Engineering, AGH-UST University of Science and Technology, Al. Mickiewicza 30, Kraków 30-059, Poland
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uarc.

Currently, BIM technology is being implemented into different branches of the building maintenance industry (Hong et al. 2015). One of them is in the documentation of historical buildings or archaeological sites. Heritage (Historic) Building Information Modell (HBIM) can distinguish interdisciplinary features and allow us to organize and unify various types of data into one, organized data set (Pauwels et al. 2008; Dore 2012). Depending on the type of heritage site, the scope of application varies from simple documentation repository through conservation planning tools, to construction and renovation simulation instruments (Murphy, McGoverna, and Paviab 2013). There already are a few institutions which managed to create complex standards for HBIM (Logothetis, Delinasiou, and Stylianidis 2015). Historic England, which is a public body in English government, recently published a collection of *good practices*. It refers to HBIM as a solution for a wide term of historic information management.

Currently, many publications have emerged on the topic of HBIM. They are addressing a number of issues with the way HBIM technology is being done and some of the means of improving it. A lot of emphasis has been put on the input data quality and quantity (Oriel and Prizeman 2015). In the case of BIM, a lot of data can and is being taken from the initial projects, floor plans, etc. (Murphy, Mcgovern, and Pavía 2009). Assuming that current construction technology is present, the final result should be in accordance with the plan within the given tolerance. This cannot be done with the HBIM. However, for some of the structures, the original plans have been preserved, with wear and tear of the buildings structure and multiple rebuilds, this data can only be used as a suggestion and not as real geometrical information. Despite this, such documentation can be used if a part of the structure was demolished and needs to be rebuilt. Projects where HBIM has been used as an aid during restoration and as a concept of conservation's final effect have been emerging more and more. Currently, most of the data is obtained by the use of terrestrial laser scanners (Barber and Mills 2007; Logothetis, Delinasiou, and Stylianidis 2015; López et al. 2017) at times aided by airborne LIDAR, when the density of the point cloud is good enough. Publications have suggested various ways of scanning in order to achieve the point cloud detailed enough for LOD (level of detail) of the final model (Barazzetti et al. 2015b). The most prominent problems observed in those analyses are the target type and technology of the scanners construction (Fryskowska and Stachelek 2018). Another observed problem is access to the scanned structure. It is not always possible to place the device at the right level or height so the top of elements column alters, etc., is properly mirrored on the scan. This is where photogrammetry and in detail Structure-from-Motion software can be use (Bagnolo et al 2019b). The accuracy of so obtained point clouds and mesh models is still under evaluation but it is certain that this technology can provide a large number of data in a short time and with little effort (Continenza et al. 2016; Fadli and AlSaeed 2019). This data can be done with handheld cameras or with the use of unmanned aerial vehicle, UAV. Technology of merging point clouds from differed sources needs to be improved. In the case of heritage sites that have been rebuilt and modified many times, it is almost impossible to do a survey that would provide a right amount of detail on each step of construction after it was finished. This is when traditional documentation and current spatial data can be used within HBIM project. This provides a 3D representation of previous stages of buildings' lifecycle (De Luca 2012; Jung et al. 2014).

Another important issue being currently analyzed is the methodology of a 3D model creation (Themistocleous et al. 2018). Since BIM was born with Graphisoft ArchiCAD, it seemed natural that this software would transfer well into HBIM. However, many researches have stated that this is not the case (Nieto Julián et al. 2016) since ArchiCAD is somewhat based on the predefined elements that could be combined by the user into a proper shape of the building or its detailed elements (Murphy, Mcgovern, and Pavía 2009) this works well with new construction when all elements are not bend or tilted. In the case of heritage object, the task becomes more complicated with damage that each object undergoes over time. Bended beams, broken columns, damage to the façade must be modeled and this cannot be done usually with the use of predefined, mathematically ideal shapes. ArchiCAD offers the option for creation of the user's library of elements. However, this has been described as difficult, since the construction of the new, unique element takes time and effort. Besides, each building, usually, needs its own library of elements unique to its shape and also not all elements can be used more than once. This is mitigated, at least in part, by separating the object into smaller parts that can be connected and mixed in various ways. This approach has been used for various support beams and columns (Bagnolo, Argiolas, and Cuccu 2019a). At this point, it is worth mentioning that ArchiCAD is not the only BIM software. It has been observed, that in some cases, Bentley products present a more flexible approach to modeling and creation of unique elements.

Various publications have also mentioned an issue with the type of data stored within the HBIM (Quattrini, Pierdicca, and Morbidoni 2017). It is widely agreed that this is one of the strongest parts of BIM models; however, there seems to be a lot of debate on how each data type should be stored. Apart from the usual dimensions and sometimes coordinates, for heritage structures, type of texture, the covering material is important (Trizio et al. 2019). Texture can represent various data, age, material, wear and also phases of rebuilding. Texture also does not need to represent 'real', seen by the naked eye, colors, it might be created from other data, and, for example, infrared images (Stober et al. 2018). This all needs to be addressed either by the use of properly edited standard texture, provided by the software, or by the creation of a new customized texture based on the images of the object (Banfi et al. 2019). This leads to another problem of storing additional visual data, pictures, thermal pictures, scans of plans, etc. This can be addressed in various ways (Brumana et al. 2018a). One way is combining the HBIM model with GIS (Vacca et al. 2018). Other data, historical (age, maker, etc.) and practical (size, purpose, functionality) also need to be stored (Han et al. 2017, Brumana et al. 2018b). This task for the HBIM project has at times proven to be difficult since it needs to be useful not only for BIM or 3D modeling experts but also for tourists since those projects are often done to allow a large audience to experience historical sites without accessing them. (López et al. 2018).

In order to summarize the current stage of development of BIM for the historical community. HBIM is viewed as the long-awaited answer for the need for creation of a complete, accurate 3D model and combining it with available data (Brumana et al. 2018b). However, the experience of those few years has shown a number of problems that need to be addressed for the workflow to be flawless (Dore 2017). Still, the main issue remains the amount of time the project takes (Chiabrando, Sammartano, and Spano 2016). This can only be improved by the creation of more versatile libraries of new elements or by algorithms of proper conversion of mesh models and point clouds to 3D shapes (Díaz-Vilariño et al. 2015; Maalek, Lichti, and Ruwanpura 2019; Thomson and Boehm 2015).

In this paper, an example of such project has been given with a study area of so-called *Wang Temple* in Karpacz, Poland. This object was chosen due to its distinct, unique history and relatively easy access. A 3D terrestrial laser scanning survey was done in order to gain spatial information. Also, a series of detailed pictures was taken. Later, a 3D model was created within a BIM-related software that allowed for the implementation of all available information. The final effect was a full HBIM project.

This study had several aims:

(1) The creation of a detailed 3D model of the Wang Temple in order to preserve the current state of the temple.
(2) The creation of an HBIM model of the Wang temple that would be provided to the parish and also to tourists, historians, and the general public.
(3) To evaluate the Graphisoft ArchiCAD software in regard to the following 3D modeling issues: interaction with the point cloud, accuracy of the obtained model, modeling tools elevation, a level of detail that is possible to model in the case of old wooden structure, and the potential lack in functionality.
(4) To evaluate the Graphisoft ArchiCAD software in regard to the following HBIM: the type of data that can be stored, the visualization access technique, as well as metadata access and storage.

2. Study area—Wang Temple

The Wang Stave Church (Mountain Church of Our Savior), commonly known as the Wang Temple, is an Evangelical parish church located in the town of Karpacz at the foot of the Karkonosze Mountains in Poland (Lange 1992). Wang Temple, due to its unprecedented construction, stands out amongst wooden structures of sacred architecture. It owes its unusual name to the Norwegian town of Vang where it was first built between 12th and 13th century. It is a perfect example of Nordic pole churches (10th to the 13th century) erected in the period when Christian faith was mixed with pagan beliefs. This is mirrored within the characteristic features of these churches (Kurek 2017; Rösner 2006).

Wang Temple was made from pine wood beams saturated in resin, interestingly without the use of metal nails. All connections were made using wooden carpentry joints. The skeleton is a frame made of vertical corner posts joined by boards, which forms the church wall. The roofs of the temple are decorated with splines shaped like open dragon maws, which were a decorative characteristic of Viking boats. The interior of the church is decorated with many original elements such as wooden columns, richly carved portals, and Nordic lions. Each element in the temple has some religious premise. The external semi-columns at the church entree are decorated with floral and animal elements. On the capitals, there are statues of Nordic lions, which symbolically guard the entrance. In the upper corners of the portal, there are statues of dragons, symbolizing the eternal struggle between good and evil. The Viking faces were carved on the semi-columns forming the ornate frame of the entrance door. They refer to the Nordic traditions and the wisdom and knowledge imparted by generations. Other elements evidencing the rich architecture of the temple were the statues carved in the Byzantine style—the upper parts of the columns, decorated with figures of animals and plants. The engraved runic script located in the northern part of the portal is also an element that attracts attention. The runic script was one of the oldest used by pagans living in northern Europe (Lange 1992). This type of writing is uniquely associated with the Wang Temple since the famous rune-stone—Vang Stone was located next to the building.

In the 19th century, Wang church was dismantled in part due to the need for costly repair that was never finalized in Norway (Rösner 2006). In 1841, transported to Szczecin and then to the Royal Museum in Berlin, as a gift to Prussian king—Frederick William IV. After a long search of a convenient place for the temple where it could be used for devotion, it was moved to Karpacz (currently Poland, a part of Prussia and the time) in the spring of 1842. A large group of nobles, including the king of Prussia, attended the grand opening of the temples reconstruction (Lange 1992).

During the rebuilding process, it was noted that many original church elements were unusable. Therefore, it was decided, to reconstruct particular parts during construction. This included inter alia, cloisters, and windows. Also, a stone tower built of Silesian granite was constructed. Among the elements added during the reconstruction are the baptismal font characterizing the Lower Silesian baroque period made in 1740 and the pulpit made of wood brought from Norway. The columns in front of the altar, depicting the victory of good over evil, were reconstructed by a Polish sculptor. He is also an author of cross made of an oak trunk in 1844 and a figure of Christ carved from linden wood in 1846. In 1980, two monumental swan-shaped candlesticks, symbolizing faithfulness and love, were erected on both sides of the altar.

Wang temple can be called one of a kind with its interesting origins and complicated history. This is why it presents itself as a great object for performing an HBIM type model.

3. Data acquisition

The spatial data gathering process consisted of a terrestrial laser scanning survey performed during a period of 2 days in late October of 2016. Laser scanning process provided a 3D discrete model of the surface of the scanned object that is called a point cloud. The point cloud file consists of lines of the XYZ coordinates of points on the object's surface. It can also provide I—the intensity of the laser beam (camming back to the scanner) and RGB—data on the color of the object in the measured point. Spatial data can be later modeled into a vector shape of the building (Oreni et al. 2014; Yastikli 2007). The inventory was done with the use of Z + F IMAGER 5010c that provided scans within 320 vertical and 360 horizontal fields of view, with resolution up to 1 mm (Dawason et al. 2013). This particular version has a photo camera build within it and allows for generating point clouds in real colors. The nominal distance error of the measured point should not exceed more than 3 mm of the accuracy. During the survey, a scan that lasted about 6 min (including pictures) was chosen. It was decided that those settings allowed for the gathering of a sufficient amount of data in an optimal time (due to tourist visiting hours scanning time was limited). In order to connect the scans together (perform registration), a number of ideal spheres were placed on the object. During the registration process, they were used as predefined targets. The achieved point cloud density was about 2–3 mm inside and 3–5 mm outside the building.

During the survey, a few obstacles had to be taken into account. Since (in the case of historical buildings) the color and any fracture of elements is equally if not more important than their exact dimensions, the problem of providing proper, consistent light had to be taken into account. Due to these issues, the outside corridor of the structure ("Sobótka") that circles around all of the inner church were scanned during the night. This part of the temple is illuminated mostly by artificial light. The inner part of the church was surveyed in the early morning, when a smaller number of tourists were entering the building and the sun was low. This allowed for the keeping of similar colors on all of the interior scans. Unfortunately, due to a scanner accuracy malfunction that was noticed later, 3 of 36 performed scans could not be used for further modeling. In total, 12 scans of the outside and 24 scans of the inside were done.

Post-processing of scans included coloring and initial processing of the point cloud which was done in ZF-LaserControl software. In case of Z + F software, the initial processing requires removing all of the errors within the point cloud. Errors can be described as mismeasurements on a point cloud occurring when the laser beam bundle is sliding on the reflective surface. This creates extra points either in the front of a measured object or behind it, creating something that can be described as a scaled cross-section of the edge of the object. This usually occurs with reflective surfaces (body of water, metal) or when the object is covered with water. Also, in some cases, water vapor might cause false reflection. This is mirrored within the scan in the form of a snowstorm (since those points are often white—sky is mistaken for its RGB color). Not all scanners are susceptible to this problem since it depends on the construction technology used and very often the strength of the laser beam. However, if a scanner is susceptible, this issue can be mitigated in two ways. Either an internal software of the scanner cleans the point cloud or the external processing software will. In case of Z + F scanners, this is done externally. However, in case of this project previously mentioned scanners malfunction resulted in a point cloud with so much wrongly measured points that the Z + F could not correctly clean it. This is why some of the scans had to be cleaned manually. Initially, it was planned to first register all of the scans and then clean them. However, in a few cases, one-third of the point cloud was a product of lase measure and they needed to be cleaned, at least to some extend before or during the registration. Luckily, this was only visible on the outside scans and did not influence the inside.

Most of the registration process and manual cleaning was done in Leica Cyclone software. Registration was done in four steps in order to produce three clusters of data that were later merged to together. Within each cluster point, clouds were registered with the use of plastic spheres of defined dimensions (16 cm in diameter). The registration process looked different in each cluster. In the case of the outside corridor ("Sobótka"), the plan was to arrange the scanning procedure so that each pair of scans was registered by five spheres. The overlap between succeeding scans was at 40% to 60% but there was almost no overlap between every second scan since the corridor was so tight (no more than the 1.50 m with). The scanning procedure had to be done flawlessly. This part of the temple registered with an accuracy of 5 mm with the use of spheres only.

The interior of the church was also difficult to scan due to the almost constant tourist movement around the building. Initially, it was planned to register with spheres only but since there were some difficulties in scanning the staircase the led to the chancel, which overlapped a surprisingly large group of tourists, in touching the spheres at about 10 additional points on the walls of the church which were chosen to aid the registration process. There were two scans called base scans that covered a large part of the temple and there the overlap was at 60%. They were so devised that all other planned scans should have been at least 40% overlap with at least one of them and have at least five common sphere targets between them. This worked partially, the overlap was usually more than planned, but some of the spheres were moved during the acquisition, thus the need for extra targets on the walls. This part of the temple registered with an accuracy of 5 mm.

The outside part of the temple, scanned in a very straightforward way, was with pairs of scans having at least 60% of overlaps and every other at least 30%. Additionally, two scans were taken from the road that is at a higher elevation. Those two scans covered most of the roof of the temple. The only lack in the point cloud was the top of the roof of the tower and one side of the top of the roof of the temple. Both instances presented small issues in terms of the inventory since most of the decorative elements were scanned and only the metal and wooden roof shingle were not scanned to a detail. The registration was performed with the use of the spheres with the accuracy of 7 mm. This mostly resulted from the errors in the point cloud that lead to miss representation of the spheres and also miss calculation of the sphere center.

The three clusters were merged together with the use of natural GCP, edges of the door frame, snags of wood, pins, etc. In the case of two inside clusters, there was no other choice since the scans had to be done 1 day apart. In the case of inside to outside, this was done because one of the scans was unusable due to scanners malfunction and also some spheres were moved by tourists. The nominal average accuracy of the total registration did not exceed 7 mm. Maximum error of a single scan registration was at 16 mm and minimum at 2 mm.

4. General scheme of works on Wang Temple HBIM project

The laser scanning inventory of Wang Temple provided us with a large amount of spatial information. The HBIM project requires a proper kind of vector 3D model and textures, done within a 3D software that would work well with specialized BIM software. In order to facilitate this criteria, Graphisoft ArchiCAD was used. It allowed us not only to convert a discreet 3D model into a fully textured vector model but also allowed us to gain additional information, such as the number of components involved, etc., to be implemented within the project. It is a CAD-based software dedicated to architects and engineers who work with BIM technology and share data and resources on various building structures (Murphy, McGoverna, and Paviab 2013).

Designing a new building or performing a 3D digital model of existing structure includes a workflow that would allow for those complicated process to be effectively completed by many closely collaborating members of the survey, laser scanning, modeling, and managing teams. The cooperation is based on efficiently sharing project data between all cooperating teams. The basic concept of all BIM projects is for the 3D-detailed model to be a central database, which contains all available data—buildings various attributes' (including the point cloud). This 3D model becomes an access point for potential users of the final product.

Graphisoft ArchiCAD was designed in a way that would allow for the semi-automation of modeling procedures. ArchiCAD uses .xyz and .e57 standard file formats and converts them into object-type elements that can be placed in the project's 3D window. With the help of PointCab software, users can align the point cloud with a face plane and place it on an assumed floor plan so the prepared point cloud can be then displayed showing separate floors, cross-sections, facade views, etc. It is possible to automatically prepare clean and dimensionally accurate plans and view sections from point cloud (PointCab layers) which are then imported into ArchiCAD project. Prepared data become easier to manage and works better with users who are used to cross-section type of visualization and modeling. The modeling process in ArchiCAD is based on working with plans and view sections (cross-sections through the object—showing, for example, interior wall including the section of the floor, showing its width).

ArchiCAD contains packages, virtual libraries (GDL objects) of common construction objects—such as various kinds of doors, windows staircases, etc (Dore and Murphy 2014). Since there is no such thing as a 'standard door', all of those objects can be edited to some extent. This includes changing color, size and some parts of the detail design. Unfortunately, at the time of writing, options that would allow us to show how construction elements decay due to weather conditions, frequent usage, heavy loads, etc., are not fully developed. This prolongs the modeling of elements, such as bended support beams, twisted or cracked steps, crooked floor, etc., which need to be modeled from scratch.

Before starting to create BIM models, it is important to understand that most of BIM software such as ArchiCAD or REVIT were designed for planning new structures and not for visualizing existing ones. As such, they originally did not assume such detailed projects ate be done as they are done today. Therefore, before starting the modeling process, it is important to determine the level of development (LOD referred to also as Level Of Detail)—the level of complexity of three-dimensional model. This involves decreasing the number of details in the model (the reduced visual quality usually goes unnoticed and has no influence on the whole BIM model) and determination of maximal acceptable deviation between the creating model and the point cloud. Some elements, instead of being modeled, can be textured with 3D textures or 2D textures that would give the illusion of a model and would decrease the number of modeled parts of the object. Also, objects do not necessarily need to be present in a victories form, they can be left as polygon mesh textured models. The level of development in the case of BIM also describes other functions of the model such as stages of design, construction-caliber quantities, scheduling, estimations, on-site fabrication and so on.

LOD has been defined many times by many organizations and for various purposes. However, they do not vary to a large extent. In this paper, we are representing those classifications that currently seem to be the most significant for the BIM industry. The Level of Development Specification Guide (2017) defines LOD 100, to LOD 500. In case of the Wang temple, the model was planned to be within LOD 300—Detailed Design with some elements of LOD 350. In regards to other known classifications by Historic England (Brookes 2017), the temple should fall into L3 with elements of L4. Those types of LOD, however, do not entirely complement and facilitate this project most effectively. Since it was possible to model all structural and decorative elements of the structure, it is possible to measure them and the distance between them on the model and in many cases additional metadata is attached. Each element is produced with '*the quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modelled information such as notes or dimension call-outs*' (Level of Development Specification Guide 2017). Also, some facilities were inventoried during the scanning in detail, such as the dragon-shaped gutters, chandeliers and other light fixtures. There are no other facilities within the Wang temple. For the Wang Temple, the detailed architectural model was created. It contains not only all structural and architectural elements but also furniture and utilities (including such components as the altar, roof decoration, benches, and fences).

LOD 300 was chosen due to the fact that it seemed to be the best possible compromise between time management and final quality effect. Due to its history, the Wang temple, is far less complicated, detail wise, than other temples. This is an Evangelical Church of the Augsburg Confession in Poland and, in accordance with religious beliefs, it is limited in the number of statues and other decorative elements. This is why it was possible to do a detailed scan of the object in between tourist visits. In contrast, wooden temples of the Eastern Orthodox Church in Poland would take at least twice as much effort to scan and model, and still the results might not facilitate LOD 300. It was important during this project to preserve as many geometrical and structural elements of the building as possible, since there have been many fires destroying or partly destroying various old temples in those few years. Many of them have never been inventoried and there was a limited number of data during restoration.

5. Modeling methods

The point cloud, taken as result of laser scanner survey, provides information on complex shapes that represent the inventoried objects. The dataset, with millions of points containing discreet information on complex geometries of various objects, can be imported into BIM software for documenting, visualizing, and modeling aims. Graphisoft ArchiCAD offers BIM tools that can be used to model many regular objects with simple geometries (Dore and Murphy 2014). However, those simple object libraries are mainly designed for new construction assemblies, so they often cannot be easily used to visualize complex shapes, or elements in the different states of wear and tear, e.g. antique windows or doors. This is where different, more unique architectural shapes are needed. The process of creating 3D models of the Wang Church elements consisted of using both simple software tools for simpler forms and some complex processes to visualize irregular or sophisticated objects. The scan was divided into several parts that included: structural components such as walls, vaults, arches, floor, stairs, windows, doors and other utilitarian and inside elements: balustrades, benches, altar, etc. This section described details of modeling some of the elements. Other custom objects were done similarly.

5.1. Methodology of custom windows

Custom windows are a good example of the 3D modeling process based on a point cloud and PointCAB's layers. In ArchiCAD, windows are always placed into walls by making see-through openings, so they are objects that simulate the look and behavior of real windows (such as transparency of glass). Creating structural elements can be very useful for long-term projects because saving complex elements as objects can decrease the polygon count in the project (less complicated file). In ArchiCAD, objects are created on the Floor Plan as GDL files.

The process of window modeling consisted of a few stages. The first stage involved locating the window of interest in the point cloud and at the sections in order to recognize all of the object's components and get their proper size and dimensions. Secondly, using simple drawing tools (such as Polyline) to make a general profile of the window and differing all of its components: frames, glass borders and advanced decorative elements (the precision of differing the details depends on the accuracy that is needed to achieve in the final models designed accuracy—LOD). In this particular example, an important issue was modeling the window lamps—a round glass details occurring in some of the windows types. Morph tool in ArchiCAD gives the opportunity to create a 2D polygon or a line that is displayed in the 3D view but has no geometric parameters which are not needed for the lumps detail. As a result, it can be used to visualize such a detail on the glass (Figure1).

The actual modeling is done primarily in 2D at a defined plane and 3D features are added either by a predefined depth or by changing the plane. Because the profile window has been drawn on the Elevation Plan, the next step was to rotate it to the Floor Plan in order to transform it into a spatial object. This can be done by using the Slab tool and giving the right thickness of all determined components. As previously mentioned, the window object required the making of a hole in the wall and there was a need of creating another shape that would serve as the opening in which the custom window would be placed. The shape of the hole was defined as a slab which had the same size as a window frame. Afterward, an ID of "Wall-hole" was assigned to it.

In ArchiCAD, custom objects can be positioned by points (hotspots) defined in the Library Part as the 2D symbols. One of these points is initially defined as the primary positioning point—'Placement Anchor'. For easier window placement in the Wang Temple model, the 'Placement Anchor' point has been set in the lower-left corner of each custom window. The final step was saving the created window as part of the Library. The custom windows can be easily loaded into the model and edited. There were 10 types of windows with different components and different sizes created for the Wang Temple project. Figure 1 shows one of the modeled custom objects in ArchiCAD.

5.2. Methodology of wooden pulpit

Another unique object that was modeled in the Graphisoft ArchiCAD exclusively for the Wang Temple was the wooden pulpit. It is worth mentioning that while modeling this object both point cloud, cross-sections as well as non-metric photographs were used as the basis. Due to the complex geometry, the modeling process required dividing the object into several separate parts. It began with modeling the main, structural parts including the pulpit body and the base of the pulpit (with its lateral elements) using the functions: *Shapes generated from polylines* and *Extrude*. Afterward, smaller and more complicated

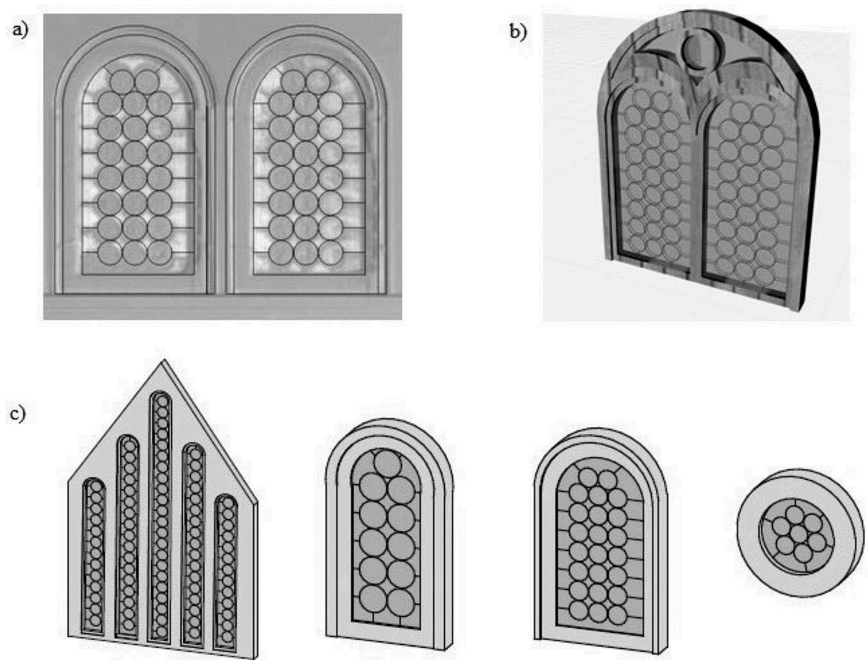

Figure 1. (a) The example of the window's profile at Elevation Plan (PointCAB drawing in the background). (b) The example of modeled church's custom window in 3D view. (c) Examples of modeled custom windows in Wang Temple. LOD of the windows was at LOD300.

elements were carved from basic shapes like a rectangle, circle, etc.

Another unique element was the staircase. Because of its complicated shape and lack of data in a point cloud, photos taken during the survey with the laser scanner and with the handheld camera became useful in distinguishing between the point cloud of steps and other elements. Work began with the creation of the exact 2D contour of the element with regard to the curvature, and then it was transferred to 3D elements (taking into account the height increments for each step of the stairs). Then, after the entire process, the modeled pulpit was transformed into a GDL type object.

In general, many structural elements could be done out of preexisting elements stored in Archicad Libraries. Objects like floors, walls, columns, support beams, some of the staircases and parts of the roof columns could be taken strictly from Libraries or mildly edited and trimmed to facilitate the real geometric conditions of the Wang Temple. Decorative elements, uniquely designed windows and doors, sculptured objects needed to be done by the modeling team and were the most time consuming. The result of this combined approach can be seen in Figures 2 and 3.

6. Textures

Texturing of heritage and historical objects' 3D models is an extremely important task. It not only provides a sort of 2D to 3D documentation of decorative elements—that on its own holds a historical value—but also gives better, more real experience for potential viewers. In the instance of the Wang Temple, two approaches were used. As was mentioned before, scanning sessions were planned in the way that would allow for at least the partial usage of pictures from Z + F laser scanner as textures. This was possible due to the fact that this instrument takes pictures of relatively good quality and covering large parts of the object (in comparison to other laser scanners). Also, exporting pictures was done automatically. In the areas where those images could not have been used, photographs of the different parts of the building taken with handheld camera were utilized. Some of them were slightly corrected to fit their shading balance to others, as light conditions were changing while taking pictures. Some minor elements ware also textured with textures provided by the software (Boeykens and Bogani 2008; Boeykens, Himpe, and Martens 2012; Zalama et al. 2011).

7. Complete model—advantages

Heritage Building Information Model (HBIM) allows for a better representation and management of spatial data stored within. Certain 3D views can be opened through a quick access mode, which helps to point out important or of greater historical value elements (Stefano 2015). There is a possibility to smoothly switch between 3D and 2D documentation and layouts, and

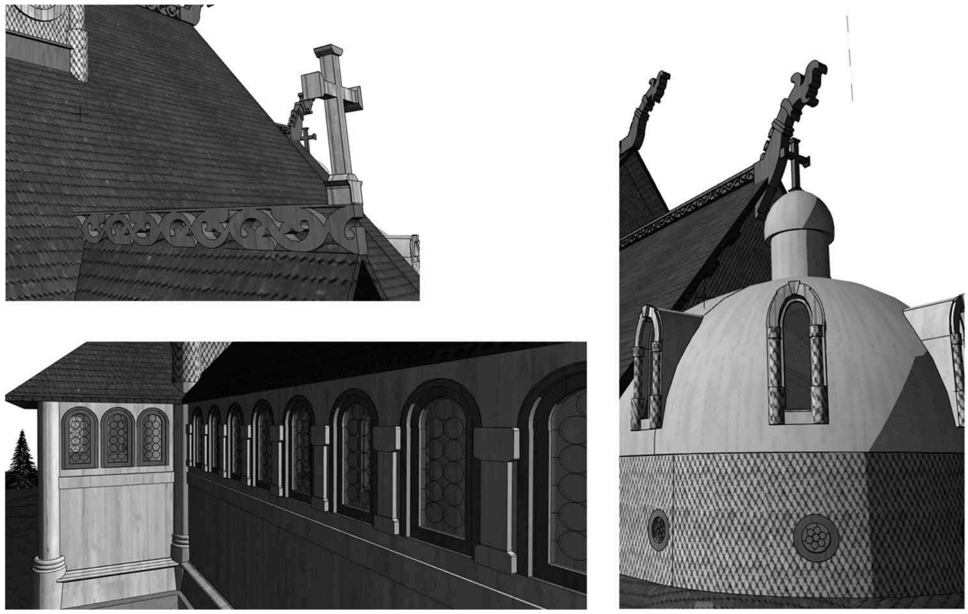

Figure 2. Top left—roof decorations, bottom left—part of outside façade with placed see-through windows, right—part of the roof with the decorative Viking dragon.

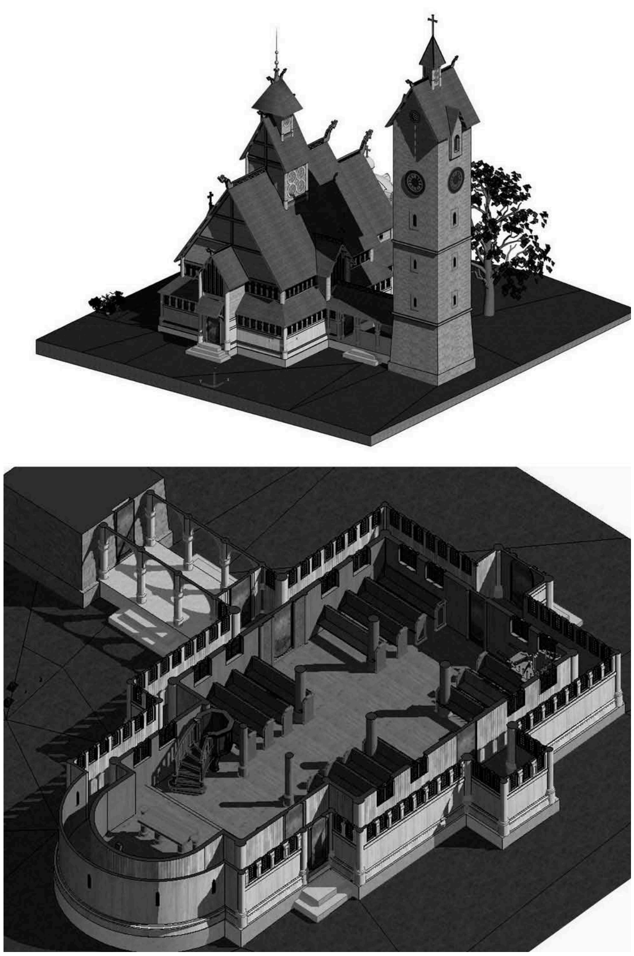

Figure 3. Top: complete exterior model of Wang Temple, bottom: cross-section of one of the levels.

section placements are also available. This is useful so that when viewing a 3D model that could be difficult to comprehend by an architect or a constructor, one can move to a predefined 2D models or define new cross-sections. It allows the user to better experience the model. This cannot be viewed as a small improvement since classical digital 3D models usually do not allow to do this semi-automatically. Also, during the creation of a cross-section, only a few tools available allow for fast dimension measurements. Whereas in BIM, this becomes a natural part of the process.

The availability of storing various sets of data is a leap toward a new standard of documentation. Every single BIM model element can be highlighted and its properties can be shown within the 3D model space. Properties are defined by the author of the model and may consist of all the information that users might find useful. Material or dimensions are a standard feature, but in HBIM there is an infinite amount of possibilities to include other not geometry-related information. This might be the date of construction and every past renovation, authors, value, type of used paint and so on. What is more, connections and relations between certain elements can be highlighted. This includes not only similar features (author, material) but the way how one element corresponds with another. This can be exemplified by the way chimneys on different levels of the building are connected or how sewerage ductwork is situated between buildings. Also, ArchiCAD lets users rebuild and visualize the model from different stages of the construction process, so in one model there might be a virtual representation of the current state, as well as the designed or renovated, rebuilt version. Additionally, chosen layers might be displayed independently, which can enable the potential user to see elements of special interest.

The creation of a proper HBIM documentation was the last step of the Wang Temple project. In order to present modeling results in a clear and user-friendly way, a graphic override was used. This minimized the number of colors by introducing a grey-scale representation (a black and white one with slight shading, bringing out the details in the facade finishing). This representation gives a better insight into the geometric, architectural details not fully represented when covered with colorful and eye-catching textures. Those two representations combined (full color and greyscale) give a better understanding to the structural and decorative variety of the Wang Temple and amount of skill that the various construction workers and artists needed to put into the creation of this object. The documentation was published as a set of sheets, with a scale bar (linear scale) and proper description, but also as a BIMx Hyper-model. A method of sharing 3D models, but without the need of having Archicad license. This allows the user to have easy access to the model in all its variances as well as providing stored meta-data on a mobile device without having to use specialized software. The model can be viewed in a perspective or axonometric view, with a VR stroll for navigating through the model. Creating such documentation included editing and transforming the 3D model of the Wang Temple into sections and layouts that contained the most information. They were created and saved as views and then published as sheets.

There were 3 floor plans and 4 elevation views and 13 section views through Wang Temple 's creation. In the case of the Wang temple project, it was decided very early on how many floor plans should be and what they should be representing. Since the object has no ventilation systems or other utilities that go through the walls, there was no need to create such plans. However, the outside corridor ("Sobótka") has proven to be an interesting example of futuristic vision at the time, since it introduced the concept of building within a building. Windows have been placed on all sides of the corridor so the outside light penetrated into the building and through the "Sobótka" and then passed another set of windows inside the building. A floor plane representing how the floor of the corridor and the inner church and how the two sets of windows correspond is another interesting feature (the windows were similar in design but not the same). Also, an elevated view through the middle of the church has proven to be interesting since it shows how much the attic was cut out of the design or made obsolete. Elevated views gave a good overview of the architectural details and some decorative elements.

All modeled elements had geometrical, and material type attributes attached to them and also some, more interesting elements of known history. All of those attributes can be easily accessed and the elements to which they retain to visualize. The results show Figure 4 BIM model allows for different types of shading, sun position, and light color settings in order to get the most realistic visualization. This model can be used as a precise and reliable background for renovating works. The Wang Temple model includes standard and customized meta-data. This includes standard information on dimensions, location, and the purposes of all elements. Also, more distinct parts of the temple have customized data stored, which includes texture (origin), age, author, usage, state, origin, functionality, etc. Those attributes vary since there is no detailed data on all parts of the Temple. Data can be accessed by clicking on the chosen element. This opens the meta-data menu visible in Figure 4.

In case of Wang temple there is a lot of data available from the time when the church was rebuilt. It is possible to discern original elements and a few new construction elements. This was all put within the HBIM model. The temple was in surprisingly good shape when it was rebuilt so those elements can be easily distinguished. The most prominent of these is, of course, the belfry tower which is a completely new addition. This element was included within the HBIM model with additional information of the funding body, date, and material used. Other such elements include the altar and the cross. Since we know the material and the funding body, they were all properly described. Also, the artists' name and the rough dates are available. A similar case exists in regards to the wooden pulpit. Since some of the windows needed to be redone and replaced this data was also put into the model. Other elements were also described.

Original elements of the building can be separated into two groups. The first group consists of structural elements and other of decorative elements. The structural elements were described by their detailed dimensions and the relationships between them. Also, if there was a need to, there was descriptive information that however similar some elements may look, they might be different at closer inspection, e.g., bended beams. All other decorative elements were also described by what they represent and what their symbolical function was. If they had also practical function, e.g., dragon-shaped gutters this was also added to the meta-data.

The final product consisted of an HBIM model that included a LOD300 3D model of the temple 3 floor plans and 4 elevation views and 13 section views, standard

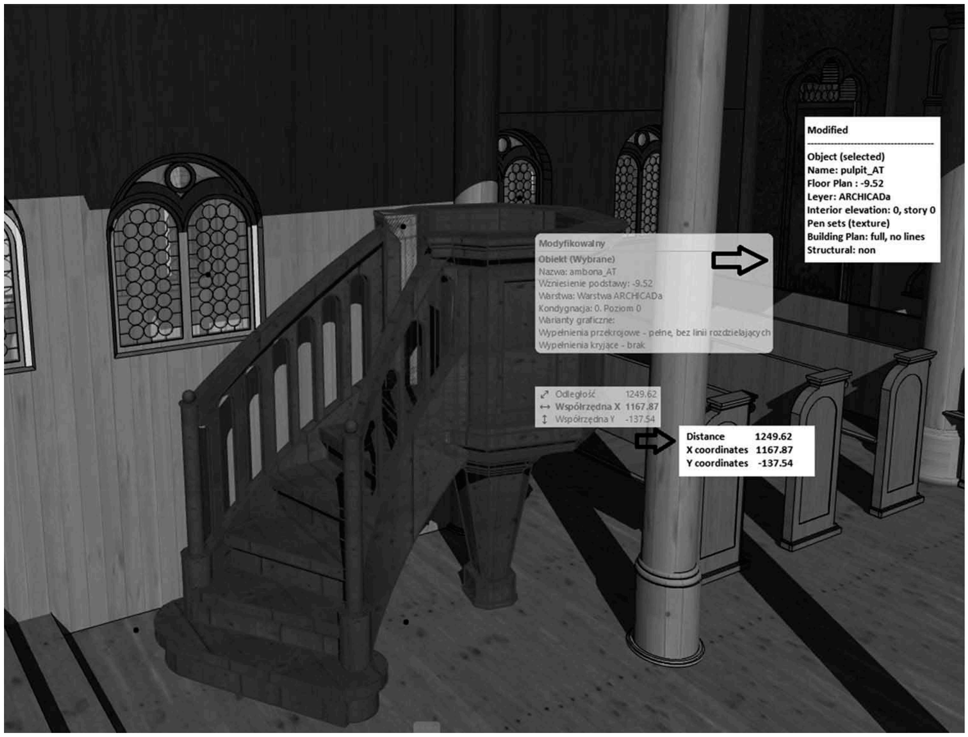

Figure 4. The Wang Temple pulpit included meta-data stored within the BIM model.

information on the dimensions, location, relations and functionality and also historical, functional, religious meta-data.

8. Discussion

The final effect of the pretested work was welcomed and appreciated by the public. Some findings of the study have proven to be important from a construction point of view. For the first ever, these features had been documented with such accuracy. This included the significant difference in the floor height between the internal corridor and the number of types and the actual difference in the shape of the windows.

However, during the creation of the HBIM model, several issues emerged. ArchiCad philosophy of using prefabricated libraries of elements had little use in terms of HBIM models. Elements such a floor and mast-shaped support could be done to a certain degree using this method but almost every other element had to be done manually. The most troublesome element, surprisingly, turned out to be bended support beams. In this case, they had to be chosen, if a certain amount of bend deserves the time and effort needed to do a proper model. Similarly, four types of windows, as described previously, needed to be modeled separately, even though in some cases the difference was minimal. However, overlooking them was outdone the question, since they would not fit the size of the window frame, and when more of them would be added together, they would not fit the building. Also, some of the modelers noted that however natural working on 2D cross-sections may be for some, for others accustomed to plans for people used to working with other software may find it problematic to navigate. In summary, the usage of ArchiCad strictly for modeling did not provide any simplification of the procedure in the case of a wooden temple consisting of many bent elements.

At this point, it is worth mentioning, that in case of ArchiCAD there are methods of creating various textures from various images. The quality of the texture can be described as good but in comparison with, for example, MicroStation, it is still quite limited. The visual effect is realistic but is not photorealistic. The color, type of bump, ray trace, shading, all of those elements that construct a real texture, seem to be still in the making or not fully developed. Giving an image that does not fool the potential viewer, making it obvious that it is a model and not the real object. This is of no issue with BIM since the main target is the management of new building or existing structure, thus visual effects are of a less importance. But in instances dealing with architectural heritage, this starts to be an issue since it would be done in the public's interest.

ArchiCad is a perfect software for creating an easy to use the representation of an HBIM model. It is extremely flexible in terms of data storage, type of data and a means of accessing them. This stage can be done fast and to a very detailed level. Also, the publication stage done with the use of the viewer's software that can be transmitted almost too every mobile device, seems to be a perfect way to show a heritage object to the public. With cross-sections, elevation views and historical and dimensional data attached to each element it is an excellent tool for conserving and preserving heritage buildings, while opening them to the wider public.

9. Conclusion

The Wang Temple project was done in cooperation with BIMPoint Company that provided software and training. It was aimed at showing how effective BIM (Building Information Model) can be in accurate spatial documentation of small-scale heritage sites (Bryan et al. 2009; Chevrier et al. 2010). With the use of Archicad software and all connected packages, a point cloud-based model was created. Upon its release it possessed not only great spatial and visual qualities but, more importantly, all of its components had spatial and other attributes attached to it. They provide curators, engineers, architects even tourists and history buffs with more knowledge than any type of 3D documentation ever provided before. What is more, it can be accessed without almost any previous knowledge of 3D graphics and with open-source software.

Differences between BIM models and other spatial data can be seen clearly with this model. The BIM model is in almost all its parts vector-based. However, this is just a base for all other descriptive and spatial information on the object structure, history, current and past state that are ingrained into the model. Vector models that hold true, automatically checked during production, topological rules are realistic in terms of accuracy of spatial information and placement of elements. Also, all vector models can be relatively and easily edited and modified if such a need occurs (new data, reconstruction of building elements, etc.). Vector based shapes can be textured with 2D and 3D textures that can be done manually (from pictures) or chosen from pre-existing texture libraries. This feature, however mild it might seem, when combined with appropriate, virtual weather, sun and light conditions, adds to the models' value. This is the case not only by showing and documenting 2D (fresco, tapestry, etc.) and 3D decorative elements (sculptures, balustrades, etc.) but also by showing how artists and architects worked with the existing light conditions to emphasize those features. This is the limit of what 3D virtual models can store. The most prominent advantage of BIM is the availability to store various, descriptive data within BIM model elements, not unlike a GIS database stores attributes of a differed type or origin. BIM and HBIM models offer point clouds and automatically finished 2D sheets and plans as an integral part. Information on dimensions, age origin, and creator is stored. Also, if available data on how each element works with another can be placed into a model. And this all can be access via a model by clicking on various elements. Easy to create and navigate a 3D database that includes all no-spatial attributes is a revolutionary and advantageous attribute of this approach that cannot be found to that extent in any other data management system. This provided aid to the construction planning and the historical-architectural documentation.

The Heritage BIM project of the Wang Temple allowed us to create a vast, complicated and extremely detailed documentation of a unique building. It provides virtual tourists and more importantly, people responsible for maintenance of this object, with a state of the art and up to date 3D database. This short survey provided us with enough data to create a detailed database of the object that did not exist before. The model itself shows a bow of wooded beams supporting the matroneum, and unevenness of the floor. Also, with the differences between the shapes of seemingly identical windows, it is possible to see the level of craft needed during the reconstruction when new frames were placed. Attributes showed how after the reconstruction of the Temple elements were added to its structure, this includes the bell tower, pulpit, cross, etc. Also, the time span between each iteration of adding elements, material that was used can be monitored. This could not be done with a standard 3D digital model. All of the data would have to be stored separately and accessed via a different application. The Wang Temple HBIM model can, and most likely will be, further developed by adding more data on the object history and also as a base for all mild and larger-scale repairs and renovation projects. It is our belief that all historical sides should have such documentation. This is important with fragile and flammable wooden constructions that can be demolished and lost forever within hours, as it so often happened before. HBIM documentation would provide a great memorial for those lost historical objects (Fai et al. 2011; Fai and Rafeiro 2014).

This study had several aims. The first two were presented in detail above. In regards, to the third aim, it was proven that it is possible to create a 3D model of a wooden structure. However, it was also noticed that the process appeared to be more tedious and time consuming than originally intended. Also, the vast library of shapes was of little help during initial modeling. In the authors' opinion, this issue could be mitigated in two ways. Firstly, allowing for more ways of modifying the elements, e.g. adding a bend option to a straight element, or adding vertexes in a more effective way. Another way could be an online library consisting of not so many elements (like a staircase, for example) but elements that create a larger element (steps, handles, etc.), or a better link up to the other online libraries. The interaction with the point cloud was adequate but some users had problems with navigation within the data of the 3D to 2D views.

In regards to point four, Graphisoft ArchiCAD fulfilled all the criteria of data storage that occurred during this project. Metadata and 3D data access were done in a way that was easy for the provider and to the data receiver.

This manuscript has a supplementary material attached. It shows details of the final product in the layout proposed by the BIM Point company.

Acknowledgments

This work was supported by the AGH 16.16. 150.545 and AGH Rectors' Fund for KNGK Geoinformatyka (students association).

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the The article was prepared under the research subvention of AGH University of Science and Technology (Faculty of Mining Surveying and Environmental Engineering) No. 16.16.150.545 in 2019. [16.16.150.545].

ORCID

Paulina Lewińska http://orcid.org/0000-0002-8141-754X

References

Anil, E. B., P. Tang, B. Akinci, and D. Huber. 2013. Deviation analysis method for the assessment of the quality of the as-is Building Information Models generated from point cloud data. *Automation in Construction* 35:507–16. doi:10.1016/j.autcon.2013.06.003.

Azhar, S. 2011. Building Information Modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering* 11 (3):241–52. doi:10.1061/(ASCE)LM.1943-5630.0000127.

Bagnolo, V., R. Argiolas, and A. Cuccu, 2019a. Digital survey and algorithmic modeling in HBIM. Towards a library of complex construction elements, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-4/W12, 2019 5th International Conference on Geoinformation Science – GeoAdvances 2018, Casablanca, Morocco, October 10–11, 2018.

Bagnolo, V., R. Argiolas, and A. Cuccu, 2019b. HBIM for archaeological sites: From SfM based survey to algorithmic modeling. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W9, 2019 8th Intl. Workshop 3D-ARCH "3D Virtual Reconstruction and Visualization of Complex Architectures", Bergamo, Italy, February 6–8, 2019.

Baik, A., A. Alitany, J. Boehm, and S. Robson. 2014. Jeddah Historical Building Information Modelling 'JHBIM' – Object library. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* II-5:41–47. doi:10.5194/isprsannals-II-5-41-2014.

Banfi, F., M. Previtali, C. Stanga, and R. Brumana. 2019. A layered-web interface based on HBIM and 360° panoramas for historical, material and geometric analysis The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W9. 2019 8th Intl. Workshop 3D-ARCH "3D Virtual Reconstruction and Visualization of Complex Architectures", Bergamo, Italy, February 6–8, 2019.

Barazzetti, L., F. Banfi, R. Brumana, D. Oreni, M. Previtali, and F. Roncoroni. 2015b. HBIM and augmented information: Towards a wider user community of image and range-based reconstructions. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-5/W7, 2015 25th International CIPA Symposium 2015, Taipei, Taiwan, 31 August–04 September 2015.

Barazzetti, L., F. Banfi, R. Brumana, G. Gusmeroli, D. Oreni, M. Previtali, F. Roncoroni, and G. Schiantarelli. 2015a. BIM from laser clouds and finite element analysis: Combining structural analysis and geometric complexity. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information* XL-5/W4:345–50. doi:10.5194/isprsarchives-XL-5-W4-345-2015.

Barber, D., and J. Mills. 2007. *3D laser scanning for heritage: Advice and guidance to users on laser scanning in archaeology and architecture: English Heritage*. Historic England, January 2018. https://historicengland.org.uk/images-books/publications/3d-laser-scanning-heritage/heag155-3d-laser-scanning/

Boeykens, S., C. Himpe, and B. Martens. 2012. A case study of using BIM in historical reconstruction - The Vinohrady synagogue in Prague. The 30th International Conference on Education and research in Computing Aided Architectural Design in Europe, Prague, Czech Republic, September 12–14, 2012.

Boeykens, S., and E. Bogani. 2008. Metadata for 3D models. How to search in 3D Model repositories? Conference: ICERI 2008 Proceedings, vol. 1, Madrid, Spain.

Brookes, C. 2017. The application of Building Information Modelling (BIM) within a heritage science context. Accessed June 5, 2019. Reserch Department Reports, Report number: 29/2017.

Brumana, R., P. Condoleo, A. Grimoldi, A. Giuseppe Landi, D. Attico, A. Turrina, F. Banfi, and M. Previtali. 2018a. HBIM feeding open access vault inventory through GeoDB

HUB. In *Digital heritage. Progress in cultural heritage: Documentation, preservation, and protection. EuroMed 2018. Lecture notes in computer science*, vol. 11196, 27–38. Springer. doi:10.1007/978-3-030-01762-0_3.

Brumana, R., T. Stefano Della, L. Daniela Oreni, M. Cantini, M. Previtali, L. Barazzetti, and F. Banfi. 2018b. SCAN to HBIM-Post earthquake preservation: informative model as sentinel at the crossroads of present, past, and future digital heritage. In *Progress in cultural heritage: Documentation, preservation, and protection. EuroMed 2018. Lecture notes in computer science*, vol. 11196, 39–51. Springer Nature Switzerland AG 2018. doi:10.1007/978-3-030-01762-0_4.

Brusaporci, S., ed. (2015). *Handbook of research on emerging digital tools for architectural surveying, Modeling, and representation* vol. 2, 1-794). Hershey, PA: IGI Global. doi: 10.4018/978-1-4666-8379-2

Bryan, P., B. Blake, J. Bedford, D. Barber, J. Mills, and A. David. 2009. *Metric survey specifications for cultural heritage*. English Heritage, The Engine House, Fire Fly Avenue, Swindon SN2 2EH

Chevrier, C., N. Charbonneau, P. Grussenmeyer, and J. P. Perrin. 2010. Parametric documenting of built heritage: 3D virtual reconstruction of architectural details. *International Journal of Architectural Computing* 8 (2):131–45. doi:10.1260/1478-0771.8.2.135.

Chiabrando, F., G. Sammartano, and A. Spano. 2016. Historical buildings models and their handling via 3D survey: From points clouds to user-oriented HBIM. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. doi:10.5194/isprsarchives-XLI-B5-633-2016.

Continenza, R., I. Trizio, A. Giannangeli, and A. Tata. 2016. HBIM for restoration projects: Case-study on san cipriano church in castelvecchio calvisio, province of l'aquila, Italy. *DISEGNARECON* 9:15.1–15.9.

Dawason, P. C., M. Bertulli, R. Levy, C. Tucker, L. Dick., and P. Cousins. 2013. Application of 3D laser scanning to the preservation of fort conger, a historic polar research base on Northern Ellesmere Island. *Arctic Canada, Arctic Institute of North America* 66 (2):147–58.

De Luca, L. 2012. Methods, formalisms and tools for the semantic-based surveying and representation of architectural heritage. *Applied Geomatics* 6:115–139.

Díaz-Vilariño, L., B. Conde, S. Lagüela, and H. Lorenzo. 2015. Automatic detection and segmentation of columns in as-built buildings from point clouds. *Remote Sensing* 7. doi:10.3390/rs71115651.

Dore, C. 2017. Procedural Historic Building Information Modelling (HBIM) for recording and documenting European classical architecture. Doctoral Thesis, Dublin Institute of Technology.

Dore, C., and M. Murphy. 2014. Semi-automatic generation of as-built BIM facade geometry from laser and image data. *Journal of Information Technology in Construction*. 19:20–46. ISSN:1874-4753.

Dore, C., and M. Murphy. 2015. *Historic Building Information Modelling (HBIM)*. doi:10.4018/978-1-4666-8379-2.ch007.

Fadli, F., and M. AlSaeed. 2019. Digitizing vanishing architectural heritage; The Design and development of Qatar Historic Buildings Information Modeling [Q-HBIM] platform. *Sustainability* 11 (9):2501. doi:10.3390/su11092501.

Fai, S., and J. Rafeiro. 2014. *Establishing an appropriate Level of Detail (LoD) for a Building Information Model (BIM)*, vol. II-5, 123–30. West Block, Parliament Hill, Ottawa, Canada: ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.

Fai, S., K. Graham, T. Duckworth, N. Wood, and R. Attar. 2011. Building information modelling and heritage documentation. XXIII CIPA International Symposium, Prague, Czech Republic, 12–16 September.

Fryskowska, A., and J. Stachelek. 2018. A no-reference method of geometric content quality analysis of 3D models generated from laser scanning point clouds for hBIM. *Journal of Cultural Heritage* 34:95–108. doi:10.1016/j.culher.2018.04.003.

Garagnani, S. 2015. Semantic representation of accurate surveys for the cultural heritage: BIM applied to the existing domain. *Handbook of Research on Emerging Digital Tools*. doi:10.4018/978-1-4666-9619-8.ch040.

Garagnani, S., and A. M. Manferdini. 2013. Parametric accuracy: Building information modeling process applied to the cultural heritage preservation. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information* XL-5/W1:87–92. doi:10.5194/isprsarchives-XL-5-W1-87-2013.

Han, S., C. Wu, D. Li, Y. Li, K. Liu, and Y. D. I. Feng. 2017. Workflows for condition inspection documentation of architectural heritage based on HBIM: Taking three duty rooms in forbidden city of Beijing as an example. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume IV-2/W2, 2017 26th International CIPA Symposium 2017, Ottawa, Canada, 28 August–01 September 2017. doi:10.5194/isprs-annals-IV-2-W2-123-2017.

Hong, S., J. Jung, S. Kim, H. Cho, J. Lee, and J. Heo. 2015. Semi-automated approach to indoor mapping for 3D as-built building information modeling. *Computers, Environment and Urban Systems* 51:34–46. doi:10.1016/j.compenvurbsys.2015.01.005.

Jensen, P., and E. Jóhannesson. 2013. Building information modelling in Denmark and Iceland. Engineering. *Construction and Architectural Management* 20 (1):99–110. doi:10.1108/09699981311288709.

Jung, J., S. Hong, S. Jeong, S. Kim, H. Cho, S. Hong, and J. Heo. 2014. Productive modeling for development of as-built BIM of existing indoor structures. *Automation in Construction* 42:68–77. doi:10.1016/j.autcon.2014.02.021.

Kiviniemi, A. 2012. *Open BIM Learning Xchange*. Salford, Manchester: SOBE, University of Salford.

Kurek, J. 2017. Norwegian stave churches– in dietrichson And Håkon Christie research. *Przestrzeń i Forma*. doi:10.21005/pif.2017.32.B-02.

Lange, T. 1992. *The position of Vang church, alias Wang Temple (Karpacz, Poland), in Norwegian stave church literature, Wydawnictwo Naukowe UAM, Folia Scandinavica*

Posnaniensia, vol. 1, 51–57. Poznan, Poland: Wydawnictwo Naukowe UAM. ISBN 978-83-232-2098-5.

Level of Development Specification Guide. November 2017. Accessed June 5, 2019. https://bimforum.org/wp-content/uploads/2017/11/LOD-Spec-2017-Guide_2017-11-06-1.pdf.

Logothetis, S., A. Delinasiou, and E. Stylianidis. 2015. Building information modelling for cultural heritage: A review. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 177–83. doi:10.5194/isprsannals-II-5-W3-177-2015.

López, F. J., P. M. Lerones, J. Liamas, J. Gómez-García-Bermejo, and E. Zalama. 2017. A Framework for Using Point Cloud Data of Heritage Buildings Toward Geometry Modeling in A BIM Context: A Case Study on Santa Maria La Real De Mave Church. *International Journal of Architectural Heritage Conservation, Analysis, and Restoration* 11/7. doi:10.1080/15583058.2017.1325541.

López, F. J., P. M. Lerones, J. Llamas, J. Gómez-García-Bermejo, and E. Zalama. 2018. Linking HBIM graphical and semantic information through the Getty AAT: Practical application to the Castle of Torrelobatón. *IOP Conference Series: Materials Science and Engineering* 364:012100. doi:10.1088/1757-899X/364/1/012100.

Maalek, R., D. D. Lichti, and J. Ruwanpura. 2019. Automatic recognition of common structural elements from point clouds for automated progress monitoring and dimensional quality control in reinforced concrete construction. *Remote Sensing* 11. doi:10.3390/rs11091102.

Murphy, M., E. Mcgovern, and S. Pavía. 2009. Historic building information modelling (HBIM). *Structural Survey* 27:311–27. doi:10.1108/02630800910985108.

Murphy, M., E. McGoverna, and S. Paviab. 2013. Historic building information modelling – adding intelligence to laser and image based surveys of European classical architecture. *ISPRS Journal of Photogrammetry and Remote Sensing* 89–102. doi:10.1016/j.isprsjprs.2012.11.006.

Nieto Julián, J. E., J. Moyano, F. Rico Delgado, and D. Y Antón. 2016. Management of built heritage via the HBIM project: A case study of flooring and wall tiling. *Virtual Archaeology Review* 7 (14):1–12. doi:10.4995/var.2016.4349.

Oreni, D., R. Brumana, S. Della Torre, F. Banfi, L. Barazzetti, and M. Previtali. 2014. Survey turned into HBIM: The restoration and the work involved concerning the Basilica di Collemaggio after the earthquake (L'Aquila). *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* II-5:267–73. doi:10.5194/isprsannals-II-5-267-2014.

Oriel, E., and C. Prizeman. 2015. HBIM and matching techniques: Considerations for late nineteenth- and early twentieth-century buildings. *Journal of Architectural Conservation* 21/3. doi:10.1080/13556207.2016.1139852.

Pauwels, P., R. Verstraeten, R. De Meyer, and J. Van Campenhout. 2008. Architectural information modelling for virtual heritage application, Digital Heritage – Proceedings of the 14th International Conference on Virtual Systems and Multimedia, 18–23, Limassol, Cyprus, 20–25 October.

Quattrini, R., R. Pierdicca, and C. Morbidoni. 2017. Knowledge-based data enrichment for HBIM: Exploring high-quality models using the semantic-web. *Journal of Cultural Heritage* 28:129–39. doi:10.1016/j.culher.2017.05.004.

Rösner, A. 2006. Kirche Wang. Reise ener Stabkirche von Norwegens Fjorden ins Riesengebirge. In *Heiner Labone Verlag*.

Stober, D., R. Žarnić, D. Penava, M. Turkalj Podmanicki, and R. Virgej-Đurašević. 2018. Application of HBIM as a research tool for historical building assessment. *Civil Engineering Journal* 4. doi:10.28991/cej-0309195.

Themistocleous, K., M. Ioannides, S. Georgiou, and V. Athanasiou. 2018. The first attend for a holistic HBIM documentation of UNESCO WHL monument: The case study of asinou church in cyprus. In *7th International Conference on Digital Heritage, EuroMed*, 408–414, Nicosia, Cyprus, 29 October–3 November.

Thomson, C., and J. Boehm. 2015. Automatic geometry generation from point clouds for BIM. *Remote Sens* 2015 (7):11753–75. doi:10.3390/rs70911753.

Trizio, I., F. Savini, A. Giannangeli, R. Boccabella, and G. Petrucci. 2019. The archaeological analysis of masonry for the restoration project in HBIM. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W9, 2019 8th Intl. Workshop 3D-ARCH "3D Virtual Reconstruction and Visualization of Complex Architectures", Bergamo, Italy, February 6–8, 2019.

Vacca, G., E. Quaquero, D. Pili, and B. Mauro, 2018. GIS-HBIM integration for the management of historical buildings. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2, 2018 ISPRS TC II Mid-term Symposium "Towards Photogrammetry 2020", Riva del Garda, Italy, June 4–7, 2018.

Volk, R., J. Stengel, and F. Schultmann. 2014. Building Information Modeling (BIM) for existing buildings — Literature review and future needs. *Automation in Construction* 38:109–27. doi:10.1016/j.autcon.2013.10.023.

Wu, T. C., Y. C. Lin, M. F. Hsu, N. W. Zheng, and W. L. Chen. 2013. Improving traditional building repair construction quality using historic building information modeling concept. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information* XL-5/W2:691–94. doi:10.5194/isprsarchives-XL-5-W2-691-2013.

Yastikli, N. 2007. Documentation of cultural heritage using digital photogrammetry and laser scanning. *Journal of Cultural Heritage* 8 (4):423–27. doi:10.1016/j.culher.2007.06.003.

Zalama, E., J. Gómez-García-Bermejo, J. Llamas, and R. Medina. 2011. An effective texture mapping approach for 3D models obtained from laser scanner data to building documentation. *Computer-Aided Civil and Infrastructure Engineering* 26 (5):381–92. doi:10.1111/mice.2011.26.issue-5.