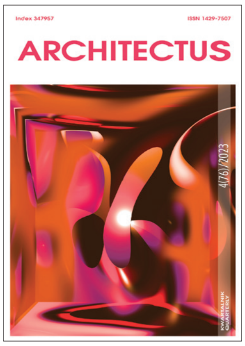

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Usage of digital surveying techniques in monuments of wooden architecture. Example of documentation of churches on Silesia and Lesser Poland border

Introduction

Digital methods of architectural surveying – laser scanning and close-range digital photogrammetry are becoming more popular and accessible amongst architectural researchers. This article is aimed at historians and historical monuments researchers, and it is intended to show the potential of applying digital measurements methods while also underlying the possible inaccuracies of using a given technology.

This article compares architectural surveys of wooden churches on Silesia and Lesser Poland border based on data from laser scanning and photogrammetric imaging (conducted by the National Institute of Cultural Heritage – NID) with measurement drawings conducted in the 1930s and 1940s, amongst the others for a study entitled *Katalog zabytków sztuki w Polsce* [The catalogue of the monuments of art in Poland] [1]. The comparison results in listing both the advantages (including the accuracy of data, allowing the diagnostics of deformations and damages to wooden architecture) and the challenges (mostly concerning the correct interpretation of the data) of using the digital measurement technologies of architectural structures.

The ease, speed and accuracy of obtaining spatial data in the process of terrestrial scanning and digital photogrammetry (producing point clouds, orthorectified imagery and 3D models) significantly sped up the process of compiling survey documentation. Due to the automatisation of the measurement data collection process, with certain technological restrictions, as well as transitioning most of the work from the location itself to the offices, being adequately prepared to conduct the field work became essential. The author of the article does not focus on the technological aspects of laser scanning and digital photogrammetry, but mostly tries to define what is the extent of the use of digital technologies for the needs of architectural, historical and conservation research – whether the use of such technologies is necessary, advisable, or insufficient for the correct surveying of wooden churches and other wooden structures of a similar level of complexity. Any architectural facilities that are wooden constructions require particular accuracy of the measurements and the mapping of the individual elements of their complex architectural structure. The indispensability of analytical presentation of the elements whilst marking the joinery or visible damages, despite the technological progress, still poses a challenge. The goal of this text is to diagnose problems that can occur whilst conducting a survey of wooden structures using these digital methods. Comparative analysis of the historical survey drawings versus the imaging acquired via scanning and photogrammetry allowed us to point at positives and possible errors stemming from applying digital techniques. Comparing the data collected with scanners with the product of photogrammetry shows in which aspects these methods can be used interchangeably (or in a complementary way) to the wooden structures surveys.

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A group of wooden churches on the Silesia and Lesser Poland border – the subject of the research

The relevant group of the wooden churches[1], located in the former Duchy of Oświęcim (Księstwo Oświęcimskie), in its original form dates back to the 1st half of the 16th century [2], [3]. These churches are not one-phase buildings, but were re-designed and expanded many times. This is visible in their structure and it is also confirmed by dendrochronological research conducted in Cięcina, Gilowice and Stara Wieś [4].

The "blockbau"-built churches, built upon their stone foundations, represent different types of modelling of the architectural shape. The church in Gilowice and the original form of the church in Cięcina represent the so-called Lesser Poland model, where the construction of the roof maintains the shared ridge for the entire church with the unique system known as "zaskrzynienie" (extended beams of the upper part of the chancel's side walls which support the truss upon the nave). The churches in Poręba Wielka and Stara Wieś belong to the group of Silesian churches and are covered with separate trusses – a narrower one over the presbytery and a wider and higher one over the church's nave. An intermediate type is represented by a church in Graboszyce, where the nave construction was realised with "zaskrzynienie" system, yet the presbytery has a separate truss construction with the ridge located underneath the nave roof ridge [5]. The churches have post-and-beam construction towers, dating back to different periods. The facilities in Gilowice, Poręba Wielka and Stara Wieś are circumscribed by a porch known as "soboty". The roofs are covered with shingle while the outside walls are covered with the vertical wooden cladding, covered with shingle, or partially the "blockbau" construction is visible. The interiors of churches in Cięcina, Gilowice, Stara Wieś and Poręba Wielka are entirely covered in polychromy, while the interior walls of the Graboszyce church are finished with raw wooden cladding.

The church group in discussion is diverse in terms of structure, constructional history, the way of shaping the architectural model and its particular elements, as well as the design of the façade and the interior. Therefore the group displays a full spectrum of challenges and can be assumed representative for a discussion of the issues of surveying wooden churches.

[1] Parish church of St. Catherine of Alexandria in Cięcina (municipality Węgierska Górka, Register of monuments no. A-597/89/90), Parish church of St. Andrew the Apostle in Gilowice (municipality Gilowice, Reg. no. A/1091/22), Parish church of St. Andrew the Apostle in Graboszyce (municipality Zator – rural area, Reg. no. A-79/M), Parish church of St. Bartholomew in Poręba Wielka (municipality Oświęcim, Reg. no. A-364/78) and Parish Church of the Exaltation of the Holy Cross in Stara Wieś (municipality Wilamowice – rural area, Reg. no. A/475/2016).

Surveying the wooden sacral buildings using traditional and digital methods – the state of research

The history of surveying wooden religious buildings

The interest of the monument experts in wooden architecture (initially mostly the religious kind), and thus the start of the surveying thereof, can be dated back to the 1st half of the 19th century [6] when a problem was noted, i.e. in the process of replacing the wooden churches with new, brick facilities, the valuable historical structures were getting destroyed [7]. Hence at the start of the 20th century, the wooden architecture, and specifically the part encompassing the religious facilities, became a part of a photographic and measurement survey, and also an element of the cataloguing effort of these heritage buildings[2] [8]–[13].

The damage to the heritage substance – in particular of the wooden constructions – during World War I [14] resulted in an in-depth study of wooden architecture. Apart from photographic documentation, it became a wide practice to carry out measurement sketches of wooden churches (catholic and orthodox), but also residential buildings and farm plots. Better researched – thanks to organised survey actions[3] [15] – wooden architecture resource became a subject of numerous catalogue and problem studies. These studies, apart from the photographs of the described monuments, also contained the plans of the churches, and at times even architectural sections. The subject of this article, churches in Cięcina and Gilowice, together with their architectural layouts, became a part of *Katolog zabytków sztuki w Polsce* for Żywiec County [1] – developed in the 1930s, but published only in 1951. In 1962, the Institute of Art of Polish Academy of Sciences (at the instigation of Michał Walicki), began a systematic documentation effort for the wooden religious architecture. That effort included the structures from the border of Silesia and Lesser Poland [17], and the fruit of that effort are consecutive editions of *Inwentarz drewnianej architektury sakralnej w Polsce* [Inventory of wooden sacral architecture in Poland] – which to this day are compiled and published.

[2] Wooden churches in Lesser Poland became subject of conservators' interest (among others conservators belonging to Grono Konserwatorów Galicji Zachodniej in Kraków). Wooden architecture was included in *Teki Grona Konserwatorów Galicji Zachodniej* [Files of Western Galician Conservators' Circles]. Authors included not only the descriptions or views of wooden churches, but at times also detailed architectural drawings. Moreover, religious wooden architecture became also a topic of monument catalogues including descriptions, photographs and architectural drawings.

[3] Different academic institutions carried out surveys of wooden architecture. Folk Architecture Section in Zakład Architektury Polskiej of Faculty of Architecture Warsaw University of Technology (ZAP WA PW) from 1922 carried out surveys of wooden constructions and architecture (including churches and tserkvas). That work continued after World War II. The research carried out by Centralne Biuro Inwentaryzacji (CBI) established in 1929 by Departament Sztuki Ministerstwa Wyznań Religijnych i Oświecenia Publicznego was of particular importance. Working for CBI Jerzy Szablowski developed the concept of *Katalog zabytków sztuki w Polsce* and started working on first volumes of the catalogue [16].

3D Scanning and digital photogrammetry in surveying heritage wooden architecture

In the last 20 years, digital surveying technologies have become a more and more popular method used for documenting heritage architecture. They became widespread not only as a method to undertake meticulous surveys (documentation required for the research and conservationist work), but they are also considered as a method of protection of the valuable structures of architectural heritage [18]. Furthermore, the process of digitizing architectural heritage monuments also follows recommendations of The European Commission, which advocates that by 2030 at least half of the most visited monuments and endangered sites should be digitised [19]. Wooden facilities that are in particular danger of destruction can be classified as endangered sites.

Digital surveying methods, from the start of their use in Poland[4] were used to digitise wooden architectural monuments. One of the first facilities in Poland, surveyed with laser scanners, was the wooden Saint Michael the Archangel church in Michalice [20]. The development of technology, the simplification of the user interface for the hardware and software, and also miniaturisation and automatisation of the measurement tools resulted in more widespread methods of digital surveying. Geometrically complex structures of the wooden monuments are now increasingly surveyed with the use of scanning lasers [21], even though due to the high cost of the necessary measurement instruments, this method is less accessible. Despite the high accuracy of the measurements carried out with the laser scanners, the data collected for the architectural survey – due to its non-continuous character – requires interpretation: defining the surface and edges of multiple elements of the building construction, which due to edge noise effect are registered ambiguously. Another limitation in the use of this scanning technology is the atmospheric phenomena. Rain drops, fog, or pollen in the air, generate additional reflections of the laser beam, thus generating erroneous data [22]. The quality of the obtained data is affected by the resolution of the measurement (impacting both the density of the final point cloud and the accuracy in binding the consecutive scans), placement of the measuring positions (which decides the angle of the projection of the laser beam onto the surface and the completeness of the measurement data) and the shape of the facility and its surroundings (which can result in generating blind spots – locations inaccessible to the laser beam) [23].

Digital photogrammetry, due to the development of computer technology, became an unusually popular method, thanks to both simplification of the process of acquiring data (photos), as well as the later post-production. The cost of digital photogrammetry is also much lower in comparison to laser scanning measurements. The mapping of an architectural structure in a 3D model currently relies on the photographs made by non-metric cameras[5], whilst the process of spatial orientation of the collected photos and generating a point cloud and models based on 3D triangle meshes is carried out mostly automatically. This means it does not require specialist knowledge and skills from the person carrying out the survey, as it was the case with the traditional stereophotogrammetry. The accuracy of measurements depends on a multitude of factors such as the conditions in which photos were taken, placement of the control points, equipment used, the way of carrying out the imaging, and lastly, software used for analysing the data [24], [25]. Source material that was appropriately obtained allows for a relatively detailed reconstruction of the geometry of the architectural shape and the detail. It brings added value by acquiring a photo realistic texture of the model, thus enriching the information obtained from the surveyed facility [26]. In the process of measuring uncomplicated construction structures, both flat and three-dimensional (stone walls, sculptures), the accuracy of spatial data obtained with photogrammetry is adequate for the architectural research description[6] [27] and can complement the data obtained from laser scanning [28]. However, with more complicated forms, especially the construction structure of wooden monuments, specifically tower construction and roof trusses (locations that are usually difficult to reach and often poorly lit), it is necessary to use laser scanning for obtaining accurate measurements [29], [30]. Laser scanning technology allows for reliable registration of the structures' geometry, even with poor light conditions. The conditions of taking the photos[7] are an extremely important factor defining the geometrical accuracy of photogrammetric reconstruction [31]. Additionally, an even more important issue for whoever is ordering a digital survey (potentially not thoroughly informed on the used technologies) is a lack of set standards or minimum requirements for carrying out a survey of particularly precious historical buildings[8] [32], [33].

Surveying of wooden churches on Silesian and Lesser Poland border – the research method

The churches that are the subject of this article had existing architectural documentation, carried out in various scopes and different scales, before and shortly after the Second World War[9]. As a part of a consecutive volume

[4] In Poland new techniques of surveying architecture: laser scanning and close-range digital photogrammetry have been used since the 1st decade of the 21st century.

[5] For users it means they do not have to use professional specialist cameras.

[6] Digital photogrammetry allows accuracy of ±2 cm in buildings of 20–30 m tall and wide.

[7] When preparing photos for digital photogrammetry it is important to provide appropriate lighting of surveyed structures and also to take adequate amount of photos (with at least 60% of photographs overlap), which in narrow and dark spaces between construction elements (e.g. between the roof truss elements) is sometimes impossible – even using wide-angle lenses.

[8] The minimum standard of preparing architectural surveys of monuments using digital methods was prepared by NID being the Centre of Competence in Monument Digitisation. That document is not legally binding but it can be treated as the guidelines for customers contracting digital surveys of monuments of architecture.

[9] Church of St. Catherine of Alexandria in Cięcina – drawing of reconstructed plan and situation plan before last changes (extension of the nave and relocation of the tower) made in 1936 in Oddział Sztuki Urzędu

Fig. 1. Orthophotography of south elevation of church in Cięcina, 2022 (elaborated by K. Czajkowski, R. Trochimiak, K. Kantorowicz, NID)

Il. 1. Ortofotograficzne zobrazowanie elewacji południowej kościoła w Cięcinie, 2022 (oprac. K. Czajkowski, R. Trochimiak, K. Kantorowicz, NID)

Inwentarz drewnianej architektury sakralnej w Polsce[10], released by the Institute of Art of Polish Academy of Sciences (PAS), the team from National Institute of Cultural Heritage (NID) carried out measuring surveys for the aforementioned group of churches[11] in 2022. The spatial data was collected in a process of terrestrial laser scanning using an impulse scanner[12] which resulted in virtual mapping of the structure as a point cloud. Simultaneously, using an Unmanned Aerial Vehicle[13] and a photo camera[14], photos were taken, constituting starting material for the photogrammetric description of the outside of the facility. The photos were taken around the facility from each camera position: perpendicular to the façade surface and angular in two directions (to the left and to the right) in 20 MPx resolution. The overlap, horizontal and vertical, between the consecutive photos perpendicular to the façade was no less than 60%. Based on these photos, MESH models were produced[15]. They are shared on the NID website [34]–[38] for the reason of popularisation, and also were used to create metric orthographic photo plans of the façades (Fig. 1). Based on the data collected

Wojewódzkiego Krakowskiego on a scale 1:100 (inventory no. 921); plan published [1]; Church of St. Andrew the Apostole in Gilowice – plan with scheme sections of roof truss and scheme plan with extensions drawn in 1933 for Oddział Sztuki Urzędu Wojewódzkiego Krakowskiego by arch. Bogdan Treter on a scale 1:100 (inventory no. 825 and 826); plan published [1]; Church of St. Andrew the Apostole in Graboszyce – survey prepared in 1946 by Wiesława Dzięciołowska, Zbigniew Mikołajewski and Jerzy Dajewski (students from Faculty of Architecture, AGH University of Science and Technology in Krakow): 2 plans, 2 sections and 3 façades on a scale 1:50 [WA PW Collection]; Church of St. Bartholomew in Poręba Wielka – plan on a scale 1:100 made in July 1939 by Stefan Świszczewski for CBI (inventory no. 3339a) [WA PW Collection]; Church of the Exaltation of the Holy Cross in Stara Wieś – architectural survey made before 1930 for CBI by arch. Zygmunt Gawlik: plan, 2 sections and 2 façades on a scale 1:100 [WA PW Collection].

[10] *Inwentarz drewnianej architektury sakralnej w Polsce* collection which presented the oldest wooden religious buildings in Poland with full architectural surveys, have been published since 1983 in Institute of Art PAS.

[11] The digitalisation of churches developed within "Digitalizacja i udostępnianie cyfrowych dóbr kultury – zabytków oraz grobów i cmentarzy wojennych" (no. POPC.02.03.02-00-0017/18) project co-financed by Program Operacyjny Polska Cyfrowa supported by the European Regional Development Fund and Ministry of Culture, National Heritage and Sport of the Republic of Poland.

[12] Churches were scanned with Faro Focus 3D and Faro Focus S350 scanners with resolution allowing to register 9 points per square centimetre on the structure, placed 10 m from scanner head. Registration of raw data and building point cloud of the building was conducted in FaroScene using the "cloud to cloud" method. The geodetic control points were used to locate the point cloud in the geodetic coordinates system.

[13] Photogrammetric flight was conducted by Unmanned Aerial Vehicle DJI Phantom 4 Pro equipped with a camera with built-in lens of 24 mm. Photos were made with 60% horizontal and vertical overlap, with a maximum 2 mm ground sampling distance.

[14] Photos made with Canon EOS R6 camera with 24 mm and 35 mm lens were used as supplementary material illustrating bottom of cornices and eaves or space under the "soboty" porches, which is only partially visible for UAV camera. The photos taken from maximum 5 m distance resulted in obtaining a ground sampling distance of maximum 2 mm.

[15] Photogrammetric models were created by joining the photos made from UAV and camera. Calibration conducted in ContextCaptre program for each photographic instruments (DJI Phantom, Canon with 24 mm lens and Canon with 35 mm lens) preceded joint aerotriangulation of the photo groups. The geodetic control points also have been used for better mutual orientation of photo groups. Depending on the complexity of the church form, the number of control points differed from a dozen to more than thirty (in churches surrounded by "soboty"). The control points were distributed on church facades, on different heights (reachable by the surveyors) in feature points of the church plan. Three-dimensional geodetic coordinates were surveyed with Leica Flexline ts07 Manual Total Station in Kronsztad geodetic reference system.

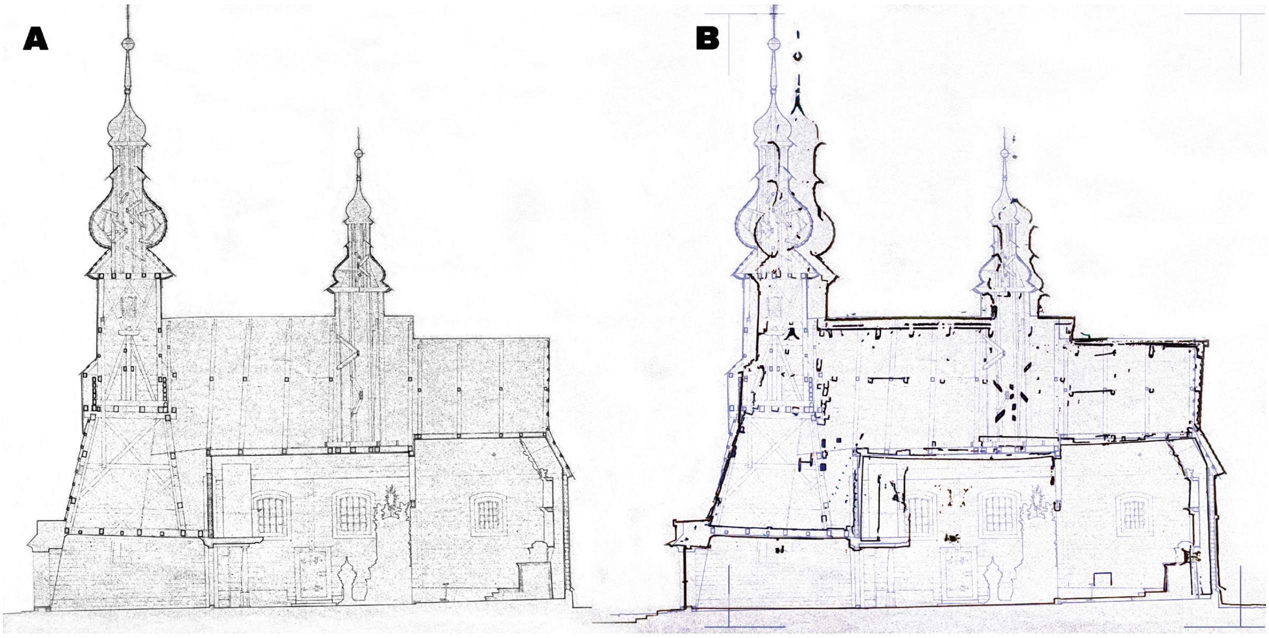

Fig. 2. Church in Graboszyce:
A – longitudinal section, 1946 (elaborated by W. Dzięciołowska, Z. Mikołajewski, J. Dajewski, students of WA AGH in Cracow, WA PW Collection),
B – comparison of traditional measurements with point cloud (elaborated by K. Kantorowicz on the basis of survey form 2022: K. Czajkowski, K. Kantorowicz, M. Rustecka, R. Trochimiak, measurement by NID)

Il. 2. Kościół w Graboszycach:
A – przekrój podłużny, 1946 (oprac. W. Dzięciołowska, Z. Mikołajewski, J. Dajewski, WA AGH w Krakowie, archiwum WA PW),
B – porównanie opracowania tradycyjnego z chmurą punktów (oprac. K. Kantorowicz na podstawie pomiaru z 2022 r.: K. Czajkowski, K. Kantorowicz, M. Rustecka, R. Trochimiak, NID)

from the scanning and photogrammetry, detailed vector survey drawings were created. They show plans, sections and façades of the described facilities.

Specificity of surveying wooden monuments – documentation carried out using traditional and digital methods

Specific construction of wooden facilities that consist of separate, autonomic elements requires the architectural documentation to be carried out with great attention to detail and an analytical way of drawing the building structures[16]. Wood, as it is susceptible to a changing environment, "warps", which results in changes to the original geometry of the building and introduces irregularities in the construction. Documenting all the geometry changes and deformations is crucial, both for the research-conservationist standpoint, as well as monitoring the state of the construction.

The traditional methods of surveying rely on measuring and drawing sections, and projections of the building on 2D drawings in assumed scales (thus accuracy) fitting the intended purpose of the documentation. Reliable measurement should be carried out from points independent from the building: geodesic matrix or levelling. It allows the elimination of stacking errors stemming from measuring a structure from itself. The measurement starts from scrupulous familiarisation with the structure, and taking measuring notes that denote all of the visible elements that are being measured. Measurement of the angles, and the space relation of the points, is traditionally carried out by a triangulation method that is binding the dimensions into a mesh of triangles as shapes that are geometrically unchangeable. The problem lies in accurate sketching of the measured geometry in the intended scale of the documentation, where even small errors can result in the wrong interpretation of the angles and mutual location of each element. Currently used laser rangefinders (as opposed to a measuring tape) led to simplifying of the measuring process, enabling more accurate and faster measuring of the distances (even at significant heights), and sketching the measurement in CAD software substantially lowered the errors stemming from drafting in an intended scale. However, as a rule, the process of surveying remained the same.

Conversely, documenting facilities with digital methods is, characteristically, a completely different process, that is increasingly more common in the architectural survey process, including heritage wooden monuments. Undoubtedly, an advantage here is the velocity of collecting the spatial information and geometrical accuracy of the collected data. Using the laser scanner in the measurement process allows for acquiring accuracy otherwise unattainable in traditional measuring methods. This accuracy is vital in documenting the irregular shapes of wooden churches. Correct documentation of geometric disfigurements and their elements (bending, buckling or torsion of the beams)

[16] In the survey drawings each element of the building construction should be drawn separately showing carpentry joints and supplementary elements such as window and door carpentry or roof sheathing.

Fig. 3. Church in Stara Wieś, longitudinal section – comparison of traditional measurements with point cloud (elaborated by K. Kantorowicz on the basis of survey form 2022: K. Czajkowski, R. Trochimiak, T. Żebrowski, NID and measurements by Z. Gawlik, 1930, WA PW Collection)

Il. 3. Kościół w Starej Wsi, przekrój podłużny – porównanie opracowania tradycyjnego z chmurą punktów (oprac. K. Kantorowicz na podstawie pomiaru z 2022 r.: K. Czajkowski, R. Trochimiak, T. Żebrowski, NID oraz oprac. Z. Gawlika z 1930 r. z archiwum WA PW)

is particularly crucial if the carried out survey is supposed to be used for the evaluation of the state of the construction, or further research and conservation process [39]. The laser scanning method, allowing for accurate geometrical representation of each element is extremely helpful in the diagnosis of disfigurement and defects in the structure of the building (Fig. 2B) [40].

In the documentation obtained with traditional methods (compared to geometry registered with laser scanners), a substantial simplification of all of the irregularities can be noted – vertical deviation and inaccuracies in the level differences. In the case of churches, where windows are usually placed at a considerable height, it is problematic within the use of traditional measurements to qualify the thickness of the walls that were estimated based on the differences in external and internal measurements. In traditionally carried out surveys, the relative location in the section of the interiors placed on different levels is often very simplified. For instance, the positions of roof trusses relative to the nave interior (Figs. 2, 3).

It is worth remembering that before the beginning of any measurement (also when digital methods are used) it is paramount to get familiar with the structure of the facility. Initial discernment of the geometry and the construction of the building traditionally resulted in measurement notes (Fig. 4). In the case where digital technologies are used, getting familiar with the geometry of the facility is necessary in correctly designing the scanning process so that fully automated scans can be joined together in a cloud that fully represents all of the building elements. It is also important for defining any information that will not be recorded by the scanning process, and that should be registered using other methods. The biggest challenge of measuring wooden buildings is complex construction

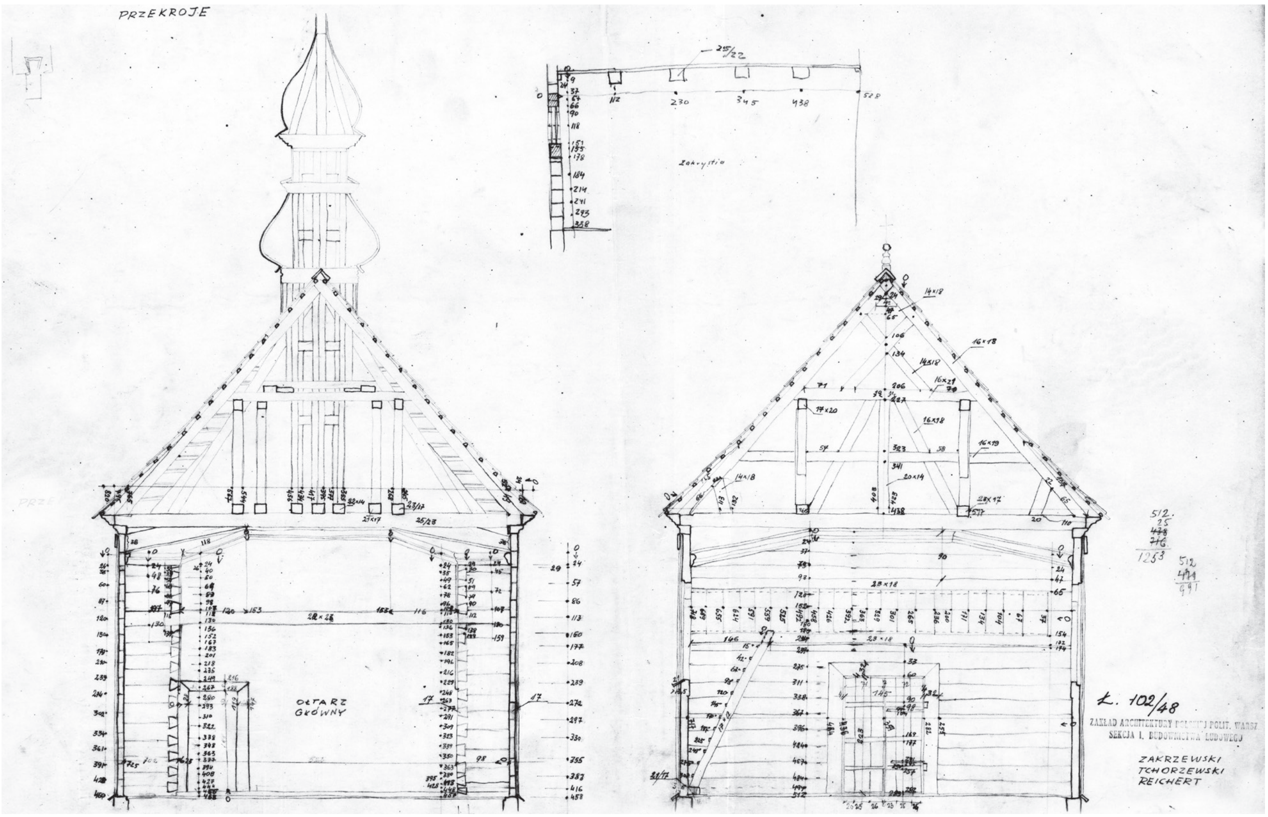

Fig. 4. Church of St. Nikolaus in Tum near Łęczyca – survey notes, 1933 (elaborated by Z. Zakrzewski, H. Tchorzewski, Reichert, WA PW Collection)

Il. 4 Kościół filialny pw. Św. Mikołaja w Tumie pod Łęczycą – notatka pomiarowa, 1933
(oprac. Z. Zakrzewski, H. Tchorzewski, Reichert, archiwum WA PW)

structure, resulting in a phenomenon of mutual obscuring of the elements. For this reason, during a scanning process the information about the building's geometry may remain incomplete in various places. In a similar situation in the process of generating a digital model of interiors and construction based on photos, artefacts can be generated, thus giving the wrong information about the shape of a building. At the current level of technology, carrying out an accurate and complete measurement of complicated, multi-element structures of towers or roof trusses with the photogrammetry method is very difficult, and can lead to an incorrect interpretation of the structural layout.

Photogrammetry however yields great results in documenting paintings (Fig. 5C) or the façade (exterior shape) of the structure (Fig. 1). A comparison[17] (Fig. 6) was made of a point cloud representing the exterior of Cięcina church – generated in a photogrammetric process[18] and geo-referenced based on the geodetic control points[19] with a point cloud registered with laser scanners in 21 positions. This comparison shows that in the case of well-lit wooden surfaces[20], the measurement error of the photogrammetric survey is within 1 cm range (Figs. 6C, 6D). Bigger discrepancies (up to 8 cm in a few particular spots) were noted in exceptionally shaded locations, mostly under the eave or by the sculpted elements (Figs. 6E, 6F). The most significant discrepancies between the cloud generated from scanning versus the photogrammetric one (even up to 20 cm) are localised in the glass pane parts or similar reflective materials, where the reflections of the environment prevent the photogrammetric software from making an appropriate interpretation of reflective surface geometry. Additionally, these kind of discrepancies occur in locations where the shaping of the structure itself and its environment are not attainable for the laser beam[21] (Fig. 6B). One could state that for an appropriately detailed imaging, in favourable lightning conditions, photogrammetric measurement of an external architectural shape of a wooden structure is suffi-

[17] Comparison of surveys was conducted in the CloudCompare program. A point-cloud from laser scanning was used as the reference data. A point-cloud generated from the photographs was compared (with the "cloud to mesh" method) with a MESH made from a scanned point cloud. This method showed minimal distance of points from the MESH surface.

[18] The photogrammetric model was reconstructed with the Bentley ContextCapture program on the basis of more than 4500 photos taken by UAV camera and digital camera in bright sunlight conditions (photo parameters described earlier).

[19] Assigning the 3D coordinates of tie points was conducted on the basis of six (out of seventeen) control points. The geo-referencing average deviation was ±3.1 mm: on the x-axis from –5.9 to 3.8 mm, on y-axis from –3.5 to 6.7 mm and on the z-axis from –3.1 to 8.4 mm.

[20] Wooden surfaces – cladding, shingle and "blockbau" walls – being non-homogeneous and having unique structure and pattern are well recognised by photogrammetric programmes. Automatic recognition of tie points is better, contrary to uniform surfaces like plaster walls or metal roofing which generate more spatial errors because of difficulties of data interpretation.

[21] It is mostly seen on surfaces of low slope roofing, which were also shaded by surrounding trees.

Fig. 5. Colourful views:
A – Church in Poręba Wielka, point cloud view of the chancel wall, 2022 (measurements by K. Czajkowski, K. Kantorowicz, R. Trochimiak, T. Żebrowski, NID),
B – Church in Gilowice, polychrome visible prom the roof truss, 2022 (photo by K. Kantorowicz),
C – Church in Gilowice, polychrome visible prom the roof truss: orthophotography, 2022 (elaborated by K. Czajkowski, K. Kantorowicz, R. Trochimiak, T. Żebrowski, NID)

Il. 5. Barwne zobrazowania:
A – kościół w Porębie Wielkiej, zobrazowanie chmury punktów północnej ściany prezbiterium, 2022 (oprac. K. Czajkowski, K. Kantorowicz, R. Trochimiak, T. Żebrowski, NID),
B – kościół w Gilowicach, polichromie na zaskrzynieniu widoczne na więźbie dachowej, 2022 (fot. K. Kantorowicz),
C – kościół w Gilowicach, polichromie na zaskrzynieniu widoczne na więźbie dachowej, ortofotoplan, 2022 (oprac. K. Czajkowski, K. Kantorowicz, R. Trochimiak, T. Żebrowski, NID)

ciently accurate for the needs of architectural research or conducting construction and maintenance design[22].

An undeniable asset of the digital methods of spatial registration is the aforementioned colour information that is collected. In the cloud points, each point has an RGB value assigned (Fig. 5A), whilst for photogrammetric models a colour texture is assigned to the surface geometry. It is of the utmost importance if the documentation is intended for diagnosing damages, or the material processing method, as well as damages due to biological factors[23]. Thanks to that feature, photogrammetry is an excellent way of imaging polychromes. Not only does it allow for precise registration of the form of the painting, but also constitutes a record of the state of preservation of the paintings and possible damages to the structure of the wall (beams) that they cover (Fig. 5C).

In conducting an architectural survey using digital methods, it is essential not to put one's unlimited trust in automated technology. As mentioned, in the scanning process only the surfaces visible for the instrument placed in concrete spots are recorded. Due to that, any occluded or internal structure of the multilayered structures (e.g. covered with wooden cladding) is not in any way documented. Also, the wall surfaces that are obscured by liturgical furnishing – altars, wardrobes in the sacristy or confessionals (Fig. 7) – remain invisible for the scanner. The way of binding a particular construction element also remains unrecorded, leading to missing important information on the facility's structure. In a complicated construction of roof trusses or tented roofs on tower tops, the elements that mutually obscure each other often prevent the scanner laser

[22] The specificity of architectural facilities requires (to make a complete survey) collecting special data from different heights (not only from human or terrestrial scanner point of view). Some parts of the wall or roof surfaces are not visible from a human point of view, especially when the building is surrounded by high trees or other buildings, thus not allowing the scanner to register these parts from a distance. That is why the photos made by UAV cameras are often the only data which allows a complete survey of all surfaces of the external shape of the building.

[23] Photogrammetry documentation made for the restoration documentation of polychromes or analyses of structure of carpentry types of cutting wooden material have to be prepared with significantly higher accuracy and resolution than surveys made for architectural and construction purposes. The polychromes were photographed using artificial light (LED lamps) with Canon EOS R6 camera with 35 mm lens. Photos were made with minimum 70% horizontal and vertical overlap from approximately 1 m distance, which resulted in maximum 0.5 mm ground sampling distance. The polychromes placed 2 m above the ground or higher were photographed using a telescopic mast (6 m high).

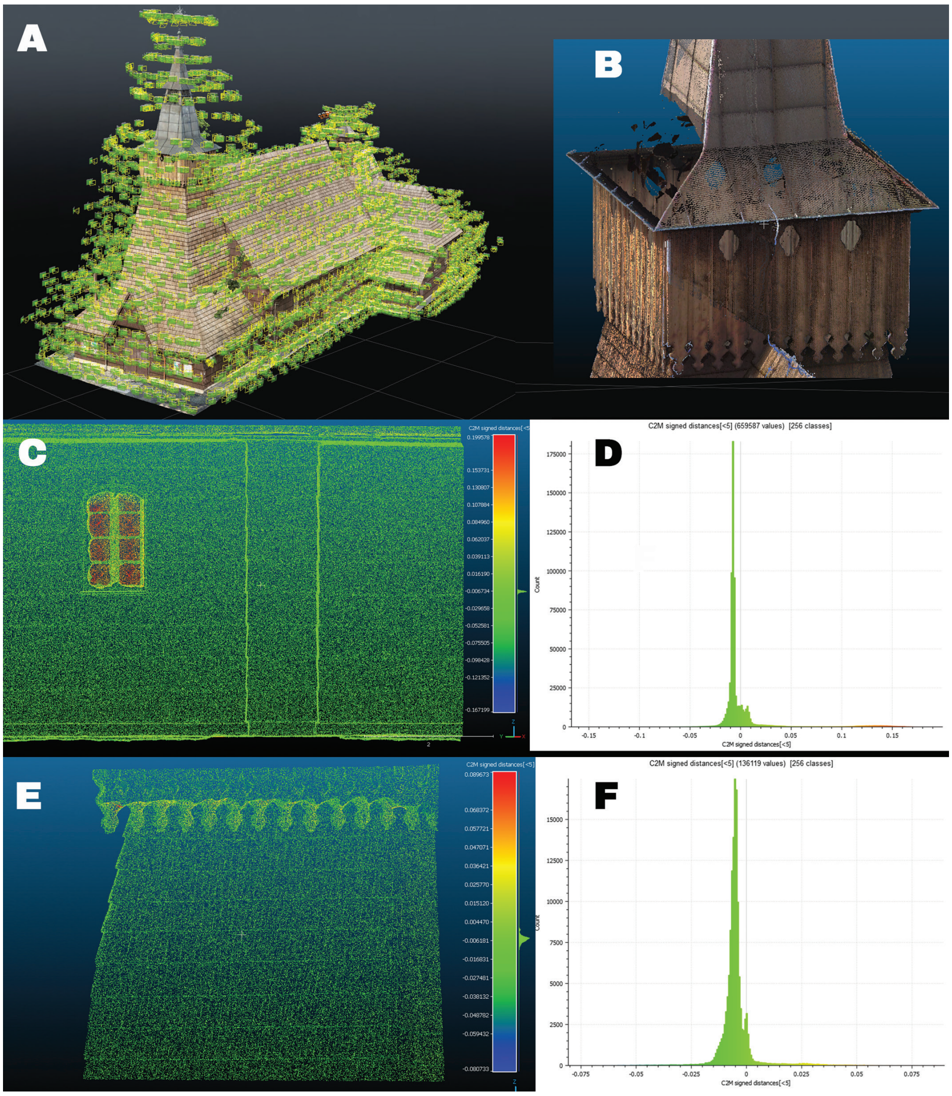

Fig. 6. Church in Cięcina: A – visualisation of camera poses for photogrammetric model, B – point cloud registered by laser scanner – blind spots, C, D, E, F – accuracy analysis of parts of point cloud generated in photogrammetric process in comparison with measurements registered by laser scanner with histogram (elaborated by R. Trochimiak, K. Kantorowicz, NID)

Il. 6 Kościół w Cięcinie: A – wizualizacja zdjęć do modelu fotogrametrycznego, B – chmura punktów z naziemnego skanera laserowego – martwe pola, C, D, E, F – analiza dokładności fragmentów chmury punktów uzyskanej z fotogrametrii cyfrowej porównanej z pomiarem ze skanera laserowego z histogramem (oprac. R. Trochimiak, K. Kantorowicz, NID)

beam from reaching surfaces of all of the elements that constitute the structure (Fig. 8). In particular, when placing the scanner on a different level than truss-floor is not possible.

As the survey drawings should contain the fullest possible information on the structure of the facility, the surveyor cannot rely solely on the information obtained from automated spatial recording. In order to produce a complete survey, it is vital that the surveyor be present on the site, conducting detailed analysis of the carpentry joints, placement of individual elements as well as identification and documentation (with methods available) of locations that are inaccessible for the scanner (Fig. 9).

Conclusions

When comparing the results of the measurements conducted with traditional and digital methods, the undeniable advantages of using the modern surveying techniques ought to be emphasised. However, it should be taken into account that such methods are imperfect, thus leading to errors in final documentation that could occur from the inconsiderate use of technology. First of all, laser scanning and photogrammetry are entirely safe for historical structures. Since they collect data contactless, they do not pose any danger to the sensitive matter of a historical building. Moreover, they allow us to obtain the accuracy of measurement unattainable with traditional methods, whilst collecting data very fast. Additionally, a given facility's scan (or its photogrammetry model) contains information on the fully visible spatial structure of the facility at the time of the documentation, and not – as it is in the case of traditional methods – arbitrarily defined plans, sections or façades. Thanks to that, on the basis of a singular measurement, it is possible to produce a three-dimensional model of the facility or generate any section or view. The increasingly accessible digital photogrammetry technique, allowing for reconstructing architectural shapes in three-dimensional MESH models, results in wide visualisation possibilities. It permits not only to document the existing state, but also to conduct virtual analysis of the proposed works in the historical building or its surrounding, as well as an excellent basis for generating digital reconstructions. Accuracy of photogrammetric mapping is usually sufficient for architectural analysis of the façades, especially in the wooden monuments, where the external formwork or shingle covering the façade is regularly changed. That is why the millimetre

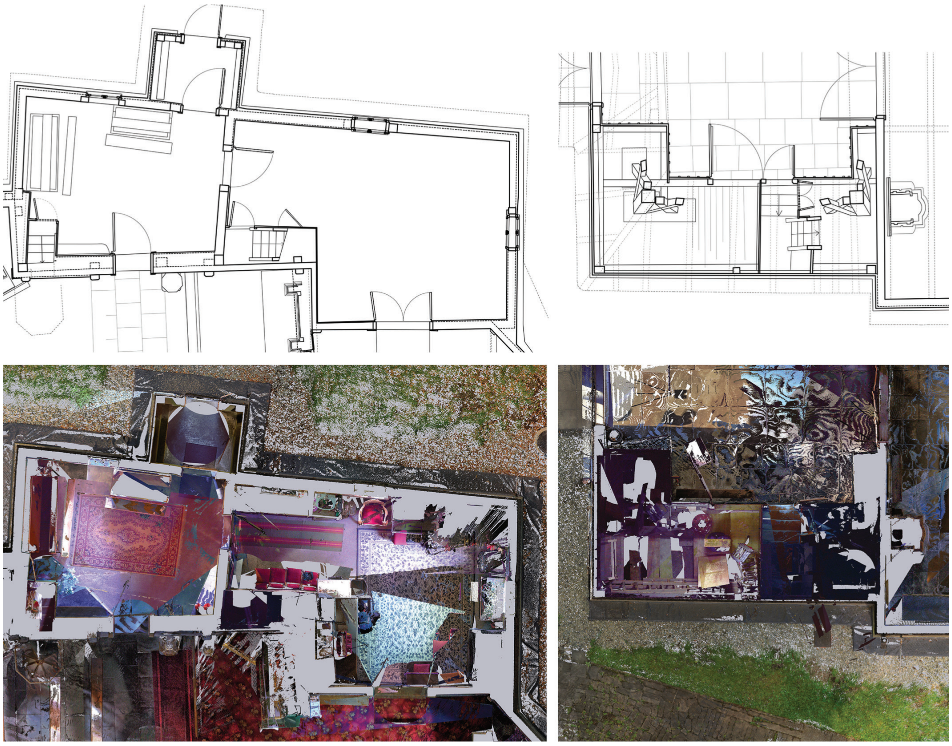

Fig. 7. Church in Cięcina – comparison of point cloud view and architectural drawings based on it, 2022 (elaborated by R. Trochimiak, K. Kantorowicz, NID)

Il. 7. Kościół w Cięcinie – fragmenty skanu i wykonanego na jego podstawie rzutu, 2022, (oprac. R. Trochimiak, K. Kantorowicz, NID)

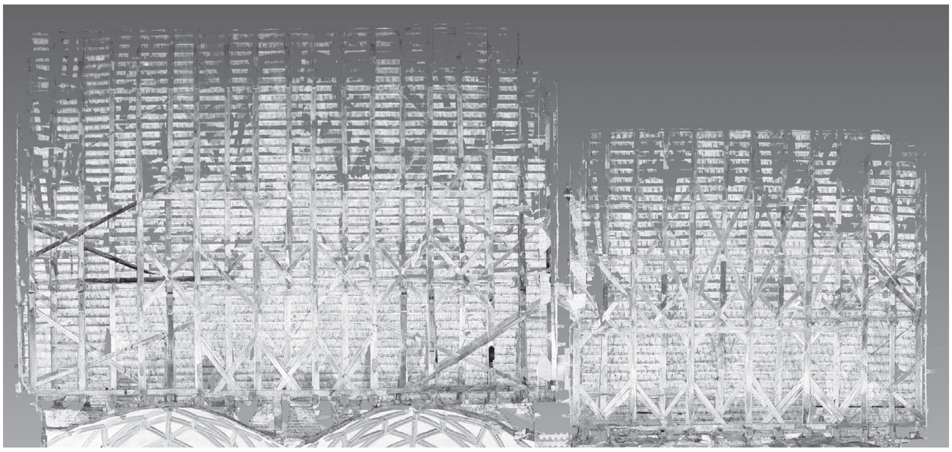

Fig. 8. Church of St. Procopus in Krzcięcice – point cloud of the roof truss with blank spots under the ridge, 2021 (elaborated by K. Czajkowski, K. Kantorowicz, R. Trochimiak, NID)

Il. 8. Kościół pw. św. Prokopa w Krzcięcicach – fragmenty skanu więźby dachowej z widocznymi brakami w chmurze w strefie pod kalenicą, 2021 (oprac. K. Czajkowski, K. Kantorowicz, R. Trochimiak, NID)

accuracy of the measurement, significant in measuring the original structure of the walls, towers or roof trusses, is not so important in imaging the external shape of the building.

Still, it is important to underline that the scanning process needs to be conducted with the awareness of the limitations and deficiencies in the imaging. Cloud points from a scanner, or generated from photographs, do not contain all the information necessary to produce an exhaustive architectural documentation intended as a basis for further research and designs. Due to simplification and automatisation of data collection, the operator should plan the scanning positions with minimising the blind spots, as well as test for the completeness of the data whilst still on location. Transferring the data processing stage into the office requires collecting the complete information during a relatively short period of field work. Since, as mentioned, part of the structure, details and layered structures will remain invisible to the scanner, it is a necessity during field work to identify and document (using alternative methods) all of these places. Otherwise, despite its accuracy, the survey conducted only on the basis of laser measurement could be less informative (Fig. 10B) than documentation carried with the use of traditional methods. Since the structure of a wooden construction requires analytical imaging of its individual elements – as well as how they are joined together – it could be depicted erroneously or in far-reaching simplification. Photogrammetric imaging of carpentry joints would allow for their proper interpretation, but insufficient lighting (underexposure) often remains an issue. Additionally, tight spaces do not allow for taking a sufficient number of images, thus making it impossible to reconstruct the detail in a three-dimensional model.

This is why the traditional documentation process (despite being less accurate and limited to a predetermined scope of drawings) still presents undeniable strengths. Notably, it is the need to produce drawings (survey sketches)

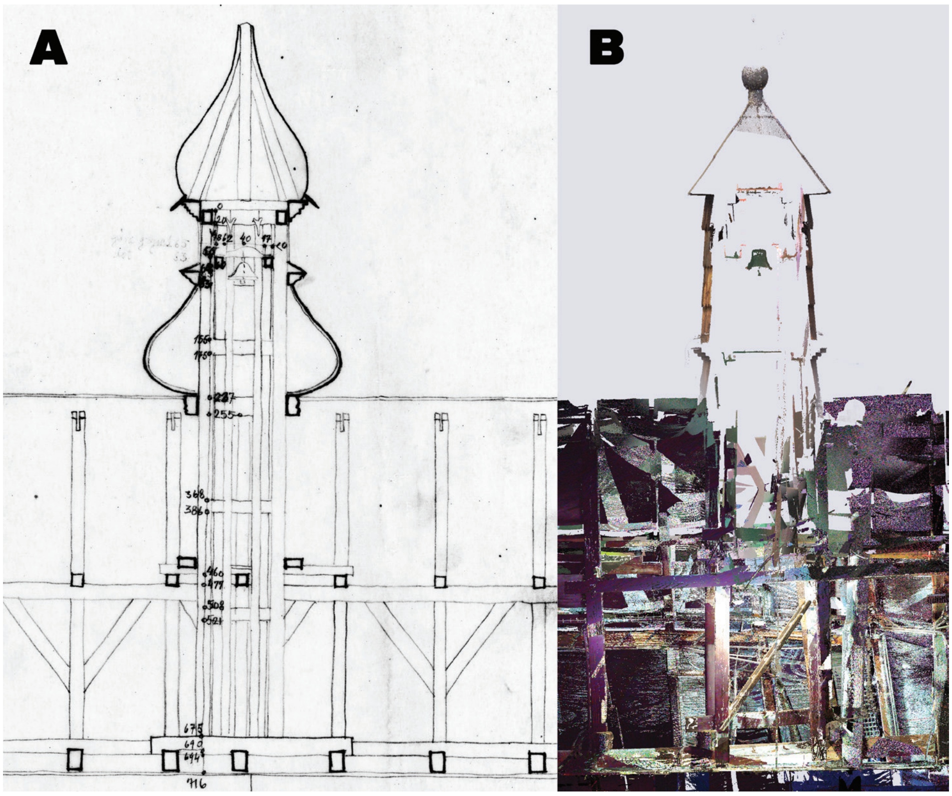

Fig. 9. Flèches:
A – piece of survey notes from church in Tum near Łęczyca, 1933 (Z. Zakrzewski, H. Tchorzewski, Reichert, WA PW Collection),
B – view of the point cloud from church in Cięcina, 2022 (elaborated by K. Czajkowski, K. Kantorowicz, R. Trochimiak, NID)

Il. 9. Sygnaturki:
A – fragment notatki pomiarowej z kościoła w Tumie pod Łęczycą, 1933 (Z. Zakrzewski, H. Tchorzewski, Reichert, archiwum WA PW),
B – widok chmury punktów ze skanu kościoła w Cięcinie, 2022 (oprac. K. Czajkowski, K. Kantorowicz, R. Trochimiak, NID)

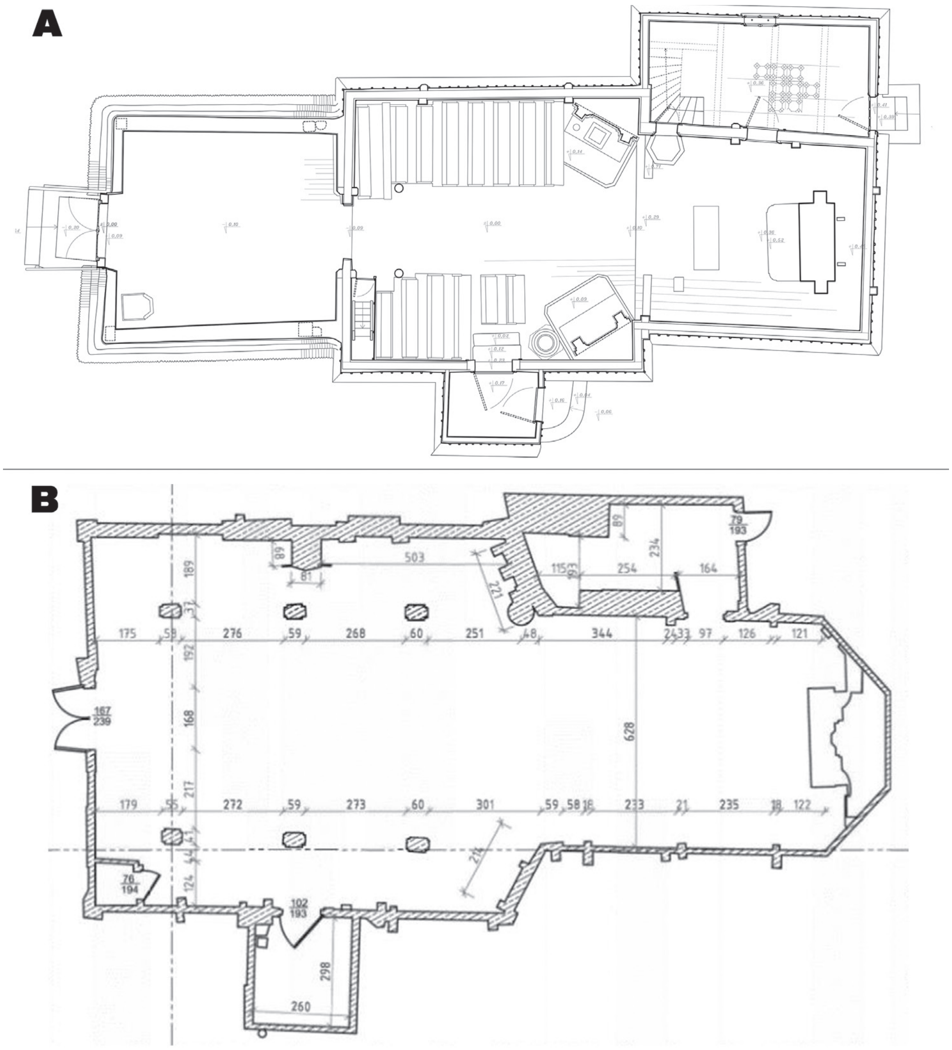

Fig. 10. Comparison of different drawings of wooden churches plans made on the basis of laser scanning:
A – Church in Graboszyce, ground floor plan, 2022 (elaborated by Czajkowski, K. Kantorowicz, R. Trochimiak, NID),
B – Church of St. Barbara in Magnuszewice, ground floor plan (source: [41])

Il. 10. Porównanie różnych opracowań rzutów drewnianych kościołów wykonanych na podstawie skanowania laserowego:
A – kościół w Graboszycach, rzut przyziemia, 2022 (oprac. K. Czajkowski, K. Kantorowicz, R. Trochimiak, NID),
B – kościół pw. św. Barbary w Magnuszewicach, rzut parteru, 2018 (źródło: [41])

directly by the surveyor whilst on location. Such sketches will contain all of the measured elements of the building. Whilst taking the measurements and producing sketches, the surveyor is "forced" to peruse the structure of the facility, analyse it and translate it into the sketches of the sections in determined planes.

Due to the fact that all of the techniques used in wooden buildings surveys have their shortcomings, it seems that the best approach is to use all of them in a complementary way. Combining laser scanning and photogrammetry together with traditional measurements allows for a complete – and at the same time geometrically trustworthy – visualisation of a surveyed building, thus allowing the data to be used widely in other research or designs.

Summary

The undeniable advantages of increasingly modern digital measurement techniques, allowing for the undertaking of very detailed and accurate documentation, provide increasing opportunities that should be, as much as possible, used in the surveying of historical buildings. For the particular heritage value, and complex structural design of the historical wooden sacral buildings, the demand on the surveyor requires much more effort than just an automated collection of spatial data that is later used for survey drawings or BIM (Building Information Modelling). In order to create a complete survey that contains all of the necessary data, it is essential to get familiar with, discern and properly (as in traditionally) document the geometry (including the elements inaccessible to the laser beam or camera) whilst on location. Similarly, it must also be done for the joining of individual elements that make up the structure of the entire facility and the detail.

Very rapid technological progress (continuous improvement of hardware and software using increasingly accurate algorithms, as well as the development of artificial intelligence) in the future will allow for ever increasing possibilities for usage of the collected data. This obliges us to preserve the best possible quality of the raw data (scans registered from the particular positions, or photos saved in the original resolution) amassed whilst carrying out measurements with digital methods. This is because most likely in the near future the secondary, fuller utilisation of this data will be possible. Maintaining the data can also allow for very precise monitoring of valuable wooden heritage monuments, which are in particular danger of suffering damage or deterioration.

Translated by
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Abstract

Usage of digital surveying techniques in monuments of wooden architecture. Example of documentation of churches on Silesia and Lesser Poland border

Monuments of wooden architecture are part of heritage which is particularly liable to destruction. That is why they need a detailed architectural survey. Architectural measurements of wooden churches in Poland have been conducted since the end of the 19th century. The digital methods of documenting monuments are becoming more and more popular and available, so they are replacing traditional measurements methods also in the monuments of wooden architecture.

Examining the documentation made with digital techniques in 2022 in comparison to historical drawings for five wooden churches on Silesia and Lesser Poland border helped to stress the advantages and disadvantages of using modern surveying techniques in wooden architecture.

It is obvious that using digital methods allows us to take the measurements faster. Also the geometry of the structure is registered more accurately. 3D documentation represents the geometry of the whole building, that is why it is fuller than the traditional architectural documentation, which only consists of predetermined plans and sections. The advantage of 3D documentation is also in the possibility to use it for visualisation purposes, e.g. special analyses or popularisation of heritage. However, while using digital surveying techniques in wooden architecture one must remember that these types of buildings require analytic documentation showing all elements of their complex construction. That is why creating competent documentation demands thorough study of the structure, especially in places inaccessible for scanners or cameras.

Key words: sacral architecture, wooden architecture, historic building survey, laser scanning, photogrammetry, 3D documentation

Streszczenie

Wykorzystanie metod cyfrowych w dokumentacji zabytkowej architektury drewnianej na przykładzie inwentaryzacji kościołów na pograniczu śląsko-małopolskim

Zabytkowe obiekty architektury drewnianej jako dziedzictwo szczególnie narażone na zniszczenia wymagają szczegółowej dokumentacji architektonicznej. Inwentaryzacje pomiarowo-rysunkowe kościołów drewnianych na terenie Polski wykonywane były od końca XIX w. Cyfrowe metody dokumentacji zabytków, stając się coraz popularniejsze i szerzej dostępne, zastępują pomiary wykonywane metodami tradycyjnymi, również w zabytkowych obiektach drewnianych.

Na przykładzie inwentaryzacji pięciu zabytkowych kościołów drewnianych z pogranicza śląsko-małopolskiego, wykonanych w 2022 r. za pomocą skanowania laserowego i fotogrametrii cyfrowej, przeprowadzona została analiza porównawcza z dokumentacją historyczną w celu uwypuklenia korzyści, ale jednocześnie możliwych braków czy błędów wynikających z zastosowania nowoczesnych technik pomiarowych w dokumentacji obiektów drewnianych.

Niewątpliwie wykorzystanie metod cyfrowych pozwala na przyspieszenie procesu dokumentacji, a także pozwala na bardzo precyzyjne odwzorowanie geometrii obiektu. Trójwymiarowe dokumentacje stanowią zdecydowanie pełniejsze zobrazowanie obiektu, nie ograniczając się tylko do zadanych rzutów i przekrojów jak w tradycyjnej inwentaryzacji. Ich zaletą są także możliwości wizualizacyjne – wykorzystania pomiarów jako modeli do analiz przestrzennych czy też w celach czysto popularyzatorskich. Wyzwanie wciąż stanowi złożona struktura konstrukcyjno-budowlana obiektów drewnianych, która powinna zostać odzwierciedlona na inwentaryzacji architektonicznej. Dlatego też inwentaryzator zobowiązany jest do wnikliwego rozpoznania struktury obiektu – szczególnie w miejscach, które pozostają niedostępne dla skanerów.

Słowa kluczowe: architektura sakralna, architektura drewniana, inwentaryzacja zabytku, skanowanie laserowe, fotogrametria, dokumentacja 3D