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PROTECTION OF CULTURAL HERITAGE

LASER SCANNING OF THE WOODEN CHURCH OF THE ASSUMPTION OF THE BLESSED VIRGIN MARY AND ST MICHAEL THE ARCHANGEL IN HACZÓW, POLAND

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ABSTRACT: The continuous destruction of world heritage prompts us to ask if more can be done to reduce the consequences of the loss. Disasters, such as the recent partial destruction of Notre-Dame cathedral in a fire, put us at risk of losing world heritage sites forever. The article points to the role of technologically advanced method of documentation - 3D laser scanning in keeping world heritage "alive" in a virtual world. The visualizations generated as a result offer exciting research applications for the scientific community. Beyond that they can be shared with audiences around the world, using online platforms. The monument chosen to carry the 3D laser scanning documented in this article was a medieval wooden church of the Assumption of the Blessed Virgin Mary and St Michael The Archangel in Haczów, Poland. The temple is listed on the UNESCO World Heritage List which confirms the recognition of its value on the global scale.

KEY WORDS: Laser scanning, virtual reality, heritage, 3d documentation, scans

1. Introduction

Art conservation aims to preserve the precious artefacts including architecture for future generations. Traditional techniques used commonly until today in art conservation are generally based on science and craftsmanship. But there are limits to these approaches. No matter how well we protect our heritage, we are losing historical artefacts of great importance. We have to face the fact that we are not able to protect monuments completely and forever against continuous destruction.

Sudden losses of world heritage are particularly tragic and prompt us to ask if more could have been done to reduce the consequences of the loss. In 1992 a romanesque stave church in Fantoft, Norway was completely destroyed by fire in a few hours. Giotto's frescos in Assissi were severely damaged in an earthquake in 1997. Hundreds of ancient temples were ruined in an earthquake in Bagan in 2016. And recently Notre-Dame made headlines when it was partially destroyed by fire. In Poland, the priceless wooden churches in Libusza[1] and Mileszki[2] have burned down in recent years. Disasters like these shake the global public and put us at risk of losing world heritage sites forever.

A key element of minimising the consequences of such devastating losses is proper documentation[3]. Traditional documentation methods, such as line drawings and photography, however, have many disadvantages. They can be very time consuming to produce and are prone to human error[4]. The advent of digital technologies has opened new possibilities for art conservation[5]. One of these new digital tools available to us is 3D laser scanning. By providing realistic, digital 3D models of artefacts and monuments, laser scanning gives us a chance to keep our world heritage "alive" in a virtual world.

2. Other examples of 3D scanning in Poland

3D laser scanning of historical buildings started in Poland at the beginning of the 21st century. Two of the earliest objects documented with this tool were: the wooden church of St. Michael the Archangel in Michalice and the Sigismund Chapel in Wawel[6]. In the following years, documenting historic architecture using 3D laser scanning was progressed by the Interdisciplinary Research

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1 https://dzieje.pl/dziedzictwo-kulturowe/jest-opinia-bieglego-ws-pozaru-zabytkowego-kosciola-w-libuszy as read on 2020-10-29..

2 https://dzienniklodzki.pl/pozar-drewnianego-kosciola-w-mileszkach-splonal-zabytkowy-kosciol-zdjecia-film/ar/6517598 as read on 2020-10-29.

3 https://www.theartnewspaper.com/news/interpreting-a-laser-scan-that-may-one-day-aid-notre-dame-s-restorers as read on 2020-10-20.

4 Drobek K., Szostak B., Królikowski W., *Metody inwentaryzacji obiektów w stanie ruiny, Stocktaking methods of facilities in a state of ruin*, [in:] Budownictwo i Architektura, Lublin 2018, pp. 76, 78, 84.

5 Prarat M., Schaaf U., Inwentaryzacja pomiarowo-rysunkowa zabytków architektury drewnianej w procesie konserwatorskim – problemy i propozycja standaryzacji, [in:] Budownictwo i Architektura, Lublin 2015, pp. 100-108.

6 Mitka B., *Możliwości zastosowania naziemnych skanerów laserowych w procesie dokumentacji i modelowania obiektów zabytkowych*, Archiwum Fotogrametrii, Kartografii i Teledetekcji, Vol. 17b, 2007.

Laboratory, whose main focus was researching the palace of King Jan III in Wilanów[7].

Recently, The National Heritage Institute has also noticed the urgent need to carry out an increasing number of laser scans of monuments to create modern documentation of them[8]. The National Heritage Institute implements the provisions of the "Program for the digitization of cultural goods and the collection and sharing of digital objects in Poland 2009-2020" and acts as a Competence Center in the area of digitization of monuments.

Many point clouds and 3D models of monuments are published on a platform managed by The National Heritage Institute. The images of the 3D representations are published online on zabytek.pl[9]. Laser scanning is carried out for an increasing number of protected buildings and places across Poland. One of the recently performed scans of a valuable and at risk object was the 3D laser scanning of a wooden church in Obórki, commissioned by NID and carried out in August 2020. Thanks to this, digital data describing the three-dimensional space of the church will be archived and will become the basis for modern documentation of the building. The National Heritage Institute has also developed and published recommendations for creating architectural inventories using digital methods, including laser scanning[10].

3D laser scanning of monuments has several applications. Creating accurate, objective, detailed and complex, three-dimensional documentation is priceless for scientific research purposes. Thanks to laser scanning technology, researchers can not only study a chosen phase of a building's history, but they can also track subsequent stages of its change in the past. But 3D laser scanning offers applications far beyond the scientific community. Visualisations obtained from the point-cloud can be shared with audiences around the world, using online platforms[11]. Regardless of their language or background knowledge, thanks to laser scanning, audiencies can engage with world heritage from any place in the world for education purposes[12]. Finally, scanning of historical artefacts can play a significant role in reconstruction efforts if a building gets destroyed. 3D scans of historic buildings are of invaluable help to architects working on reconstruction.

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7 Gołembnik A., *Rola nowych technik dokumentacyjno - pomiarowych w interdyscyplinarnych działaniach badawczo - konserwatorskich*, Wiadomości Konserwatorskie no. 40, 2014, p. 83.

8 https://nid.pl/pl/Informacje_ogolne/Aktualnosci/news.php?ID=3790 as read on 2020-10-13.

9 https://zabytek.pl/pl/obiekty?media=cumulus as read on 2020-10-13.

10 https://www.nid.pl/pl/Informacje_ogolne/Digitalizacja_zabytkow/ZALECENIA%20DIGITALIZACYJNE/ as read on 2020-10-13.

11 https://zabytek.pl/pl/obiekty?media=cumulus as read on 2019-12-25; https://sketchfab.com/store/3d-models/cultural-heritage-history?ref=header as read on 2019-12-25.

12 Petty G., *Teaching Today. A practical guide*, Cheltenham 2009, p. 178.

Fig. 1 The laser scanning is performed (photo by Wojciech Markowski)

3. What is a 3D laser scanner and what are its advantages

Put simply 3D laser scanning of architecture means determining the location of millions of points with millimeter accuracy from a distance of several hundred meters. Precisely measured three-dimensional scans provide a fully objective representation of an object or building at a time of its capturing. This kind of permanent, detailed and accurate documentation is priceless in preserving the worlds of generations past.

There are many reasons why 3D scanning is an appealing opportunity for art conservation. To begin with, it does not pose any risks to the objects that are being scanned. 3D scanners look like cameras on a tripod and the equipment never touches the object of scanning nor does it pose any other kind of risk to it. This technique offers a non-invasive approach to preserving objects and buildings. Secondly, 3D scanning offers an extremely accurate representation of the object. It objectively documents irregularities and deformations created in the building process or in the course of its use. Additionally, 3D scanners are able to document the colours and textures of scanned surfaces, which makes it useful when paint layers occur. In the case of architecture, the surveyed building is always scanned in relation to its environment. Finally, this method is extremely fast and efficient, especially when compared to other methods of surveying, such as creating a 3D model from scratch based on photos or other types of often much less precise documentation. The time needed to get a point cloud of even a very complicated building, is just a few days or even a few hours depending on the production pipeline. For simple and small buildings, laser scanning would typically take up to one day. Once the 3D scan is completed, any number of horizontal projections and cross-sections can be created from it. Permanently

archived, 3D scans become the best documentation of the monument that we are able to create today.

4. Exploration of 3D laser scanning of a medieval wooden church in Haczów, Poland and lessons learnt from the process

Haczów church and why we chose it

The wooden church in Haczow is one of the oldest and largest wooden Gothic churches built using a log construction in Europe. The temple is distinguished by a monumental body, outstanding quality of structural solutions and a characteristic architectural form[13]. The wooden church of the Assumption of the Mother of God and Saint Archangel Michael in Haczów, erected at the beginning of the second half of the fifteenth century, is one of the most valuable wooden buildings in Poland.

The unique scale of the temple, the high quality of the building materials and the excellent level of technical and architectural solutions used suggest that it might have been commissioned by King Casimir IV Jagiellon himself and carried out by a professional and highly specialized construction guild. The figurative painting decoration discovered inside the church is currently the largest collection of Gothic wall paintings from the 15th century in Poland. All this puts the Haczów temple among the most valuable sacred buildings not only in Poland but also in Europe[14]. The church's addition to the UNESCO World Heritage List (as one of six wooden churches in southern Lesser Poland) confirmed its recognition on a global scale.

The temple has been studied for decades. Various research methods, available at the time, were used to examine the church, including measurements and freehand drawings, photography, dendrochronology and others. However, it wasn't until 2018 that a 3D laser scanning of the temple was carried out. The digital 3D images of the temple are published for the very first time in this article.

Further processing of the collected data will allow for the development of detailed documentation enabling the assessment of the state of preservation of the structure and paintings. The authors of this article are currently seeking funding for the continuation of research on the object. Planned activities include a comparison of the images from the scanner with photographic documentation taken during past conservation projects of the church in order to detect potential changes in the condition of the object. The team also plans to publish visualizations documenting the Haczow Church to ensure wide on-line access to these materials.

It is also worth mentioning that the laser scanning technique perfectly archives the measurement data of the object and the tested surfaces in terms of their textures and colours. Together with other research, to which it is complementary, laser scanning should be the standard of modern archiving of the monuments we want to protect.

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[13] https://zabytek.pl/en/obiekty/haczow-kosciol-parafialny-pw-wniebowziecia-nmp-i-sw-michala-ar as read on 2019-12-25.

[14] Łopatkiewicz, P., *Drewniany kościół w Haczowie*, Kraków 2015.

Description of the church

The church is situated in the historical centre of the Haczów village and stands on the west bank of the Wisłok River.

Fig. 2 Point-cloud with texture depicting the church from the north-west (image by Wojciech Markowski)

The temple in Haczów was built at the beginning of the second half of the 15th century, not earlier than in 1459[15]. Such precise dating of the object was made possible by dendrochronological analysis carried out in 1998[16].

The church area also includes a historic, wooden granary. The building consists of a chancel set on an elongated rectangular floor plan, terminating in a semi-hexagon in the east, with a sacristy in the north, and a wider nave corpus erected on a floor plan approximating that of a square. The 18th-century Chapel of Our Lady of Sorrows, erected on a rectangular floor plan, and a treasury located between the sacristy and the abovementioned chapel, adjoin the nave in the north. A tower, erected on a near-square floor plan, adjoins the nave in the west. The church and tower are circumscribed by a cloister-type walkway added in the 17th century, covered with a shed roof resting on wooden pillars. The nave and chancel walls are embellished with Gothic figurative and ornamental wall paintings of 1494, which contribute to the importance of the object and were an important factor in the decision to add the Haczow Church to the UNESCO World Heritage List.

[15] Łopatkiewicz, P., *Drewniany kościół w Haczowie*, Kraków 2015, p. 20.

[16] Krąpiec M., *Dendrochronologia. Kalendarz dziejów*, [in:] Ochrona środowiska, turystyka i dziedzictwo kulturowe Pogórza Dynowskiego. Materiały V Konferencji Naukowo - Technicznej "Błękitny San", Jabłonka 24 - 25 kwietnia 2008, Rzeszów 2008, pp. 116 - 117.

The northern wall of the chancel presents a multi-panel Passion of Christ cycle, composed in a zonal arrangement, while the southern wall includes, among others, scenes of St Stanislaus murder, coronation of the Blessed Virgin Mary (Fig. 3.) and an image of St Michael the Archangel.

Fig. 3 The coronation of the Blessed Virgin Mary. The fragment of Gothic wall painting (picture from the scanner camera, photo by Wojciech Markowski)

The nave contains representations of saints and scenes from Genesis. On the presbytery ceiling and, partially, on the nave walls, there is a 19th-century wall painting which refers to the Baroque tradition of illusionistic decoration. Numerous historic elements are displayed in the church, among others, a sculpture of Mother of God with the Child from mid-16th century[17], stone baptismal font with a wooden Baroque cover from the 16th century and an altar of Merciful Christ from the late 17th century[18]. Part of the historic interior was moved to a new church erected nearby, including the sculpture of the Pieta from the beginning of the 15th century and the crucifix from the chancel opening of the church from the end of the 17th century. A copy of the medieval Pieta is currently in the wooden Haczów Church in the Baroque altar of Our Lady of Sorrows[19].

[17] Łopatkiewicz, P., *Drewniany kościół w Haczowie*, Kraków 2015, p. 120.

[18] https://zabytek.pl/en/obiekty/haczow-kosciol-parafialny-pw-wniebowziecia-nmp-i-sw-michala-ar as read on 2019-12-25.

[19] Łopatkiewicz, P., *Drewniany kościół w Haczowie*, Kraków 2015, p. 121.

History of the architectural change of the church

At the time of its creation, the church consisted of two basic architectural elements: a rectangular presbytery closed on the east with a three-sided aisle, and a nave, wider than the presbytery, built on a square plan. The sacristy, adjacent to the presbytery from the north, also belongs to the original architectural program. The tower was added to the west facade of the church in the 17th century. At the beginning of its existence, probably until the 16th century, the roofs and external walls of the church were not covered with expensive shingles. It can be assumed that initially the roof was covered with straw.

The most important changes in the silhouette of the Haczów temple were the addition of a bell tower to the west facade, the construction of a cloister-type walkway and the introduction of the bell tower in the roof ridge. The cloister-type walkway had to be transformed at least three times. In the construction of the oldest walkway system, there was no chapel or treasury. The addition of these elements in the second half of the 18th century and the enlargement of the sacristy in the second half of the 19th century forced the walkway to be rebuilt.

Further construction works took place in the 18th century. There were two new windows cut in the apse walls and a third one, illuminating the music choir, in the southern wall of the nave. In the second half of the 18th century, a chapel of Our Lady of Sorrows and a treasury were added to the nave from the north. 18th century reconstructions caused irreversible destruction of fragments of the Gothic paintings. The culmination of the renovations carried out at that time was the whitening of the interior of the temple, which for about 150 years hid the medieval decorations under the whitewash.

In the 19th century another enlargement of the sacristy and the introduction of a new double-wing entrance from the presbytery took place. At that time, the medieval ceilings were replaced with new ones, and the illusionistic-ornamental polychrome of the interior was made.

Selection of laser scanning equipment

Due to its excellent technical specification[20], we selected the Faro Focus 350 Laser Scanner to carry out scanning of the church of the Assumption of the Mother of God and St Archangel Michael in Haczów. The use of this modern tool guaranteed capturing a point-cloud which enabled us to create high quality three dimensional representations of the building.

The laser scanning process

Laser scanning enables quick capturing of straightforward and accurate measurements of complex objects and buildings. A built-in HDR-camera captures detailed imagery while providing a natural color overlay to the scan data.

The church was scanned on 7/31/2018. The body of the church (along with its immediate surroundings) and most of its interior were scanned in just 6 hours of work on a cloudy and a little rainy day. We used a tripod, Faro Focus 350 Laser Scanner, hard drives and a powerful PC. The scanning process can be initiated even in extreme weather conditions.

In order to capture the whole area and the church itself properly we had to scan the building from several points of view. We chose 45 points around and inside the church to get the optimal results. We put the scanner in each point for about 8 minutes. The scanning time depends on the accuracy and amount of details selected in the settings. We opted for a precise but also quick scanning process. Based on the laser measurements and detailed imagery, we were able to create a detailed model of the church with textures. After the scanning process was complete, data was captured and backed-up on hard drives. We then started to compose the 3D model of the area. We imported the 45 scans using a dedicated software, processed and registered them to connect all of the scans into a single overview 3D map and complete environment of the site. Interestingly, at that point, it was possible to see the model on-site, which allowed us to determine whether additional scanning was needed. We were able to see the first results of the

[20] Faro Focus 350 laser scanner and scanning process specifications from
https://www.faro.com/ ias read on 2019-12-25 2019-12-25:
Range FocusS 350: 350m using advanced sensor technologies
High Dynamic Range (HDR) - Photo recording 2x/3x/5x
Measurement speed: Up to 976,000 points per second/up to 2 million points per second
Ranging error: ± 1mm
Sealed design Ingress Protection (IP) Rating Class 54 Against environmental influences, scanning possible in challenging temperature conditions
Scan Group Feature - Rescanning of distant targets in higher resolution
On-Site Compensation and Registration - Real-time scan processing and registration, providing efficiency and time savings
Angular Accuracy 19 arcsec for vertical/horizontal angles
Integr. color camera - up to 165 mio. pixel
Weight 4,2kg, Size 230 x 183 x 103mm
Laser class 1
Multi-Sensor: GPS, Compass, Height Sensor, Dual Axis Compensator
Scanner control via touchscreen display and WLAN.

scanning process at once on-site. It took us 6 hours to achieve a detailed 3d model and finished scanning project. Once scanning results were generated, we could easily share the scans via web cloud in real-time. It is possible to send initial scanning results immediately while still on location. The point cloud data captured with laser scanners can be used with various software packages.

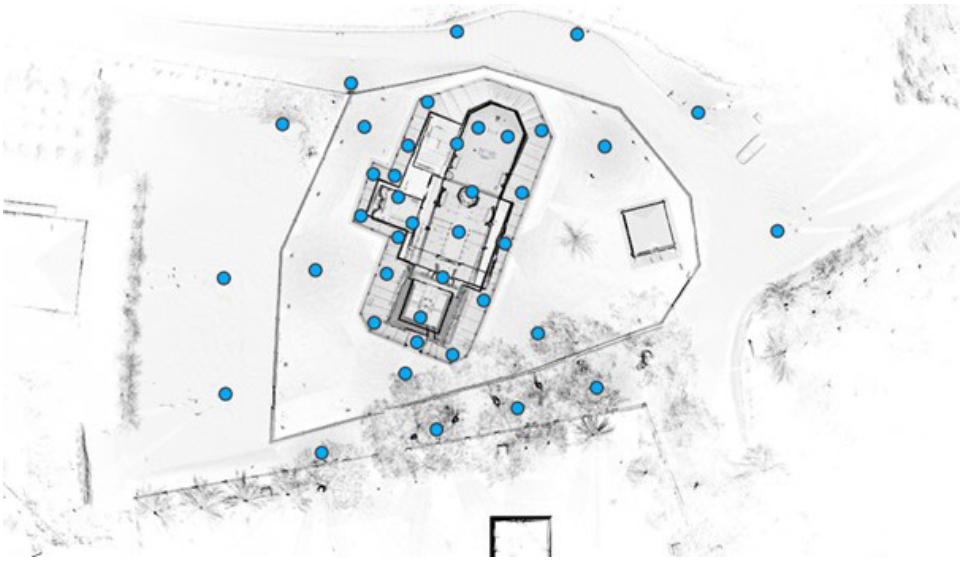

Fig. 4 Top view of the church with marked locations of the scanner (blue dots, image by Wojciech Markowski)

Fig. 5 The marker set on the border of two laser scanned rooms in the door leading from the tower to the nave (photo by Wojciech Markowski)

A laser scanning of a few parts of the church, among others the inside of the tower and the original truss-log-bracket covering of the structure, were postponed and will be conducted in the next stage of research.

Some locations of the scanner required the use of a marker. In those cases, we placed a white ball with a diameter of several centimeters in the scanning field. The ball served as a reference point to facilitate work at a later stage of data processing.

Scanning results

When creating documentation using a laser scanner, the most accurate way of sharing the results is in the form of generated visualisations. Avoiding descriptions containing specialized vocabulary allows sharing the results in a very democratic and accessible way, publishing them in the form of an image that is understandable to a wide, multilingual audience .

Fig. 6. The point-cloud with texture depicting the roofs of the church (image by Wojciech Markowski)

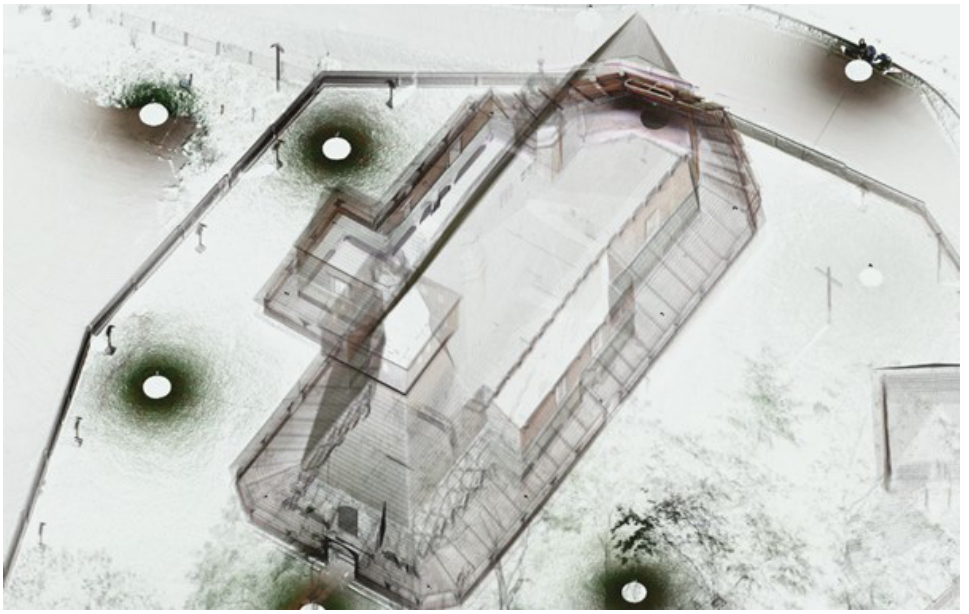

Fig. 7 Image of the church. A laser scan makes the images of the walls appear transparent. Since the scan is a collection of data points, different kinds of transparency are available. (image by Wojciech Markowski)

Fig. 8 The northern facade of the church (image by Wojciech Markowski)

Fig. 9 The southern facade of the church (image by Wojciech Markowski)

Fig. 10 The west facade of the church (image by Wojciech Markowski)

Fig. 11 The east facade of the church (image by Wojciech Markowski)

5. Possibilities offered by laser scanning 3D when creating documentation of historic architecture

A visualization i.e. 3D model processed from a point-cloud may at once both support the complex specialist knowledge and at the same time make it easy to be intuitively accessible and engaging to a non-expert audience in a way that a text or photography never could.

There are several possibilities offered by 3D laser scanning such as: restoration or scientific analysis purposes, protecting buildings, virtual reality presentations of historical sites .

Fig. 12 360 degrees VR preview, (image by Wojciech Markowski)

Laser scanner devices offer the possibility of creating detailed 3D documentation of historical structures and excavation sites. Thanks to the integration of the scanned data with the texture and color provided by the camera, photo-realistic representation can be created in real-time. A few possible uses of 3D scans are mentioned below:

- Reconstruction: Detailed 3D data for reconstruction of lost appearance of components of historical sites or archeological objects.
- Restoration: Creation of 3D models for conservation programs including the restoring purposes.
- Conservation: Precise 3D CAD documentation for preservation and protection of historical material and objects.

6. Conclusion and plans of using collected data

Data obtained in the scanning process has not yet been used as planned due to lack of funding for the next stages of the project. Further work of the VR Heritage team depends on finding funding to process the data and share our work online. The plan is to create specific outputs from this work that can be used in research, education and promotion of monuments.

Thanks to innovative, interdisciplinary approach and cooperation between an art conservator, programmers, graphic designers and computer animation specialists, the collected data will be used to create technologically advanced images of the church.

Virtual and augmented reality will be used in this process. Thanks to 360 degrees photography, which was part of the scanning process, there is an unique opportunity to publish virtual walkthroughs inside and outside the church on a website dedicated to Haczow Church and on Google Maps.

The use of these technologies will also enable the viewers to see detailed images of the wooden construction parts of the church as well as the paintings from any distance. This opens new possibilities of analyzing and monitoring the state of the building.

The team plans to create the following applications for the church in Haczów.

1. Mobile augmented reality application – "Model of the church in your smartphone"

An augmented reality application for a mobile device (based on IOS and Android operating systems) would enable users to see an interactive model of the church on a smartphone or tablet.

When launched, the application would recognize the terrain using its in built camera. The user would then be able to "insert" the model of the church in any place on the screen of their mobile device. The user would be able to adjust the size of the image and access additional information about elements of the church using a touchscreen. Certain parts of the church would be highlighted after touching the screen. In this way the user would be able to access information about the chosen fragment of the temple. Such mobile application could be used for educational purposes as well as for the promotion of the church.

2. Virtual reality application – "Historical reconstruction"

An application dedicated to virtual reality head mounted displays, such as Google Virtual Reality, would allow the user to "fly" freely through the indoor and outdoor spaces of the church and explore every detail up close and from any angle.

Thanks to virtual reality, the user would be able to appreciate the details of the church, scanned with a precision of 1 mm. Such VR application could be used for educational purposes and for the promotion of the monument. It could also be used in art conservation and similar disciples as a research tool.

3. Website – "Virtual walkthrough and digital sightseeing of the church"

A website dedicated to the church in Haczów would offer those who opt out of augmented and virtual reality applications the ability to digitally sightsee the monument. Website users would be able to navigate the digital sightseeing experience using arrows on the keyboard or with a mouse. There would be an opportunity to discover additional images and information in specific places, called hot-spots. Downloading the 3D model of the church would unlock additional options, such as rotating the building, zooming in and exploring a map of the model. Another option could be moving between selected points of the church and opening windows with extra information about the monument.

Fig. 13 The 3D laser scanning team (from the left): Wojciech Markowski, VR Heritage; Tomasz Janas, Faro Poland; Anna Wierzejska, VR Heritage, (photo by Wojciech Markowski)

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