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RESEARCH ARTICLE

CASE STUDIES ON THE USE OF UAV'S FOR DOCUMENTATION OF CULTURAL HERITAGE

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ABSTRACT: In material cultural heritage documentation, the use of measurement methods, i.e. photogrammetry and laser scanning, is becoming more and more common. The increasing availability of hardware and software allows to create the photorealistic models of objects documenting the heritage and the state of its preservation. The virtual object model can carry information about the dimensions, shape, color and texture of the documented object and it can be the basis for the documentation of the archaeological site, architectural and construction inventory, architectural and conservation studies and monitoring the condition of the object. In the paper presented an overview of the most important measurement techniques and methods for acquiring spatial data used in the documentation of monuments, with particular reference to photogrammetric documentation generated on the basis of data obtained from photographs made with the use of UAV. The heritage documentation presented in the paper were created using the Agisoft Photoscan software. The use of geographic information systems in storing, analyzing and sharing information about monuments was also discussed.

1. INTRODUCTION

In recent years, due to the dynamic development of digital measurement techniques, an increasing number of advanced geomantic methods can be observed in documentation of cultural heritage objects. The use of especially photogrammetric methods and laser scanning in the documentation of various types of facilities has become popular - museum collections, archaeological sites, technical monuments and large-scale objects. Each of the objects possesses its specificity and method of documentation depends on many factors, i.e. the required measurement accuracy and the possibility of measuring devices and availability of the facility, assumed time-consuming and cost-consuming (software, hardware), the value of the historic object, its formal complexity, the expected scope of spatial development - 2D, 3D or 4D (time), necessary data exchange formats (raster, vector, hybrid), range of attributes and other user's expectations (Bac-Bronowicz *et al.*, 2018).

The aim of the paper is to present the possibilities related to the documentation of material cultural heritage, primarily with terrestrial photogrammetry methods using the Unmanned Aerial Vehicle (UAV). The paper presents also the course of action of creating

3D models of historic objects developed on the basis of data obtained from UAV, as well as the assessment of their usefulness in the development of monuments inventory and their presentation using the Geographic Information Systems (GIS).

Cultural heritage is an element of the geospatial, and its recording requires the use of modern measuring techniques (Tomaszewski, 2007). In the case of endangered objects, the issue of "preservation through documentation" seems particularly important. The scientific record of the spatial form of the monument serves to save it in scientific awareness and in social memory. In the last century, photographers Bernd and Hilla Becher made phenomenal work - they documented disappearing industrial architecture around Europe and North America, trying to reflect the appearance of the building as faithfully as possible. They revolutionized the documentation of industrial landscape and created a unique collection that, apart from artistic values, is a catalog of industrial facilities with very high scientific and historical values.

2. GEOMATIC METHODS OF SPATIAL DATA ACQUISITION

Geomatics is a scientific discipline, which deals with the collection, analysis, interpretation, dissemination and practical use of all geospatial information (geoinformation) (Gaździcki, 2001). Geomatics is interdisciplinary and is used in many areas such as administration, spatial management, environmental protection, agriculture, transport. In the context of cultural heritage preservation along with the development of digital data acquisition techniques, the necessity to record the spatial form of the monument in a scientific manner has been noticed: precise, reflecting the actual state and providing research materials.

The most important measurement techniques and at the same time methods of obtaining spatial data are (Longley *et al*., 2008; Bac-Bronowicz *et al*., 2018):

- direct geodetic/ field measurements,
- measurements of satellite navigation devices Global Navigation Satellite System (GNSS),
- radar interferometry (aerial and satellite) - Interferometric Synthetic Aperture Radar (InSAR),
- laser scanning (terrestrial and aerial),
- satellite images,
- aerial photographs - taken from the ceiling of manned aircraft and UAV,
- terrestrial (stereoscopic) images - metric and non-metric,
- vector-raster / raster-vector conversion,
- photogrammetric method (digital photogrammetric workstations),
- cartographic method (processing of existing map studies),
- state data resources, e.g. materials from the geodetic and cartographic resources, maps and local plans,
- geographic databases (available on the Internet) - Geographic Information Systems.

Laser scanning and photogrammetry are commonly used in the documentation of monuments (Guarnieri *et al*., 2004). The method of laser scanning is not a new, but fast developing technique allowing for very high precision results. Surface laser scanning achieves accuracy of up to 1 mm, higher than standard field measurement techniques. It is successfully used in the preservation of monuments and archeology (inventory of complex

monuments and archaeological sites for the needs of research, archival and design documentation) as well as in spatial planning and management of urban complexes. Laser scanning reproduces the surrounding space in the form of a very accurate point cloud, in which each point, in addition to spatial coordinates, also has color information (based on the acquired images). This allows to visualize and measure geometry using dedicated computer programs.

Laser scanning is being capable of direct acquisition of a huge amount of 3D data and it is widely use in cultural heritage documentation (Boehler and Marbs, 2002; Kościuk, 2012, Lichti *et al*., 2002), It is very common in documentation of wide variety of heritage, like large scale objects and archeological sites.

Photogrammetry can be an alternative to laser scanning. Due to technological progress (digital photography, advanced computer software and the UAVs) photogrammetric measurements received tools that took them to a new level of development, making them competitive in relation to laser scanning. By applying drones in obtaining data in usually inaccessible places, making 3D models of large scale and tall objects with photorealistic representation has become easier and quicker.

UAV-based photogrammetry for documentation of heritage should be specially justified as a relatively fast and low-cost technique to create 3D models for a wide range of objects. During the flight, it is possible to obtain data from places, i.e. roofs, towers and other high-placed elements, which are often inaccessible to the laser scanner and terrestrial photogrammetry. The data obtained this way allows to create complete 3D models of many types of objects. In many cases, from the user's point of view the building model is attractive when it is complete and possible e.g. to being published on the Internet - on geoportals or websites providing virtual tours.

3. THE POSSIBILITY OF USING GIS PLATFORMS IN HERITAGE DOCUMENTATION

The development of the monument's documentation is mainly archaeological research, the study of written and iconographic sources (plans, maps, drawings, paintings, photographs, projects), classical measurement, laser scanning, terrestrial photogrammetry (metric, non-metric) and with UAV usage. All kinds of monuments of material culture (movable and immovable), such as museum collections, monuments of archeology and architecture, require a meticulous inventory and current cataloging. GIS, which allows to present this context in virtual space (presenting information i.e. photos, films, documentation) in an accessible form for users to research and promote heritage. A very good example of the use of GIS systems in documentation and popularization of cultural heritage is the Spatial Information System of the Wilanów Palace Museum (http://gis.muzeum-wilanow.pl). The geoportal presents information on the area, buildings, park, architectural objects, garden sculpture, elevation, interiors, trees and shrubs as well as the results of archaeological research. All spatial objects were created on the basis of architectural and geodetic documentation using the ArcGIS software from ESRI.

Digital 3D models of monuments in the form of a set of objects, presented on the appropriate GIS platform, can be documentations that can facilitate the work of restorers, historians, municipality services. When compiling the documentation of historic buildings, especially those with a complex form and rich history and building complexes, large amounts

of spatial data are often generated. Therefore, a very important task in gathering information needed for the inventory of historic objects is the selection of appropriate types and structures of databases to store geometric and descriptive attributes about the spatial objects under study.

The preservation of cultural heritage and its documentation, especially regarding building complexes and urban planning assumptions, requires today appropriate tools for collecting data on the studied spatial objects, and then for their analysis and presentation. Currently, the most popular geoinformation tool for the above purpose is GIS. Geometric representation of objects in the GIS database has coordinates of all points specified by measurement in the adopted reference system, which allows to determine the neighborhood and contextual study of the impact of the environment, terrain shape and coverage. Many historians and historical geographers believe that GIS is mainly used for cartographic representations. The map is of course one of the basic GIS products. However, the analysis of quantitative and qualitative data of collected objects is an equally important GIS product, which is supported by their attribute representation (Bac-Bronowicz and Wojciechowska, 2016).

In recent years there has been an increase in interest in the use of GIS systems in historical research. Historical GIS (HGIS) is an interdisciplinary field of study of the past, based on the technology of geographic information systems. The main area of HGIS are issues from the borderline of geographic and historical sciences extended by the possibility of conducting spatial analyzes based on old maps and other sources (collected statistics, texts, images or films, etc.) (Gregory and Healey, 2007). In HGIS, GIS tools were adapted, while not only the possibility of spatio-temporal analysis was considered, but also the possibility of storing data in various stages of the "life" of a specific object, such as the time of erection, conversion, reconstruction or liquidation.

In GIS environment spatial and non-spatial data can be integrated. It gives restorers and architects opportunity to integrate many features and access various type of data e.g. different datasets such as photographs, textual descriptions, and 2D thematic drawings (Saygi *et al*., 2013).

4. PHOTOGRAMMETRY IN THE DOCUMENTATION OF MONUMENTS

Spatial information, in the form of coordinates, is the basis of every project. Gathering and processing data into a coherent form when creating a spatial model is often a long and complicated process. Photogrammetric studies with the use of non-metric digital cameras have gained particular popularity in the documentation of monuments. The development of technologies and the increasing availability have made these advanced technologies widely used. Model's textures are generated directly on the basis of photos, which allows to get much more content than traditional measurement.

The accuracy of developing a 3D structure model with photogrammetric methods depends primarily on: the correctness of image registration, camera parameters and correctness of its calibration and rectification, the achieved overlay of subsequent images in the block, the shape of the measurement network or the number of control points (Jaud *et al*., 2016). The Agisoft PhotoScan software, which was used in the paper is based largely on automatic image matching algorithms and is a very effective tool for processing entire blocks of both metric and non-metric digital photographs (Preuss, 2015). The program uses the SIFT

algorithm (Scale-invariant feature transform), pixel by pixel analyzing and comparing their parameters to determine local features in the image, generating so-called image descriptors. They are next used to detect identical points in images which comprise a common block (all de-fined in the project, not only between two neighboring stereopairs) (Wojciechowska and Łuczak, 2018).

The procedure of creation of 3D model of an architectural object using Agisoft PhotoScan Professional software comprises of eight main stages (Wojciechowska and Łuczak, 2018). The models created in the documentation of monuments are very diverse, but the applied procedure is basically the same. The first stage is obtaining of photogrammetric data and optional structure surveys. Next step is image masking - at this stage in order to optimize modeling process a bicolour image (1-bit) should be overlaid on the picture in order to mark areas which are to be omitted. Subsequent action is to import control points (preferably in defined geodetic coordinate system) and then, bundle-adjustment which is an assignation of basic calibration parameters and their automatic distribution. The outcome of this process is sparse point cloud (tie points) and collection of camera positions (exterior orientation). Further action is generation of dense point cloud basing on the collection of camera positions and images. Next stages are re-construction of a 3D model (generation of 3D polygon mesh representing the structure surface basing on dense point cloud) and model texturing based on reconstructed geometry (mesh). Final step is to export 3D model in commonly applied external formats - de-pending on further needs (only preview or further edition in graphic software).

The result of the process is a model that brings information about shape, size, texture and colors. When the main assumption is to obtain a photorealistic model (a virtual copy of a real object) the photogrammetric method works very well.

4.1. Materials and instruments

In the paper images were obtained by low-altitude photogrammetric flight of UAV DJI Phantom 4, equipped with dedicated camera FC330. The aircraft weights approx. 1.4 kg, has gimbal with 3-axis stabilization (pitch, roll, yaw), GPS and GLONASS satellite positioning system. The camera is of HD resolution with 12MP and 1/2.3” CMOS sensor.
To build textured 3D model from obtained still images Agisoft PhotoScan Professional Version 1.2 was used.

4.2. Documentation of an architectural object

The problems with the inventory of high cubic capacity historic objects are i.a. elaboration of high located architectural details and measurements of inaccessible elements. Certain structural elements, i.e. pillars and vaults may require periodic monitoring for evaluation the occurrence of deformations. The interiors of sacred buildings are often characterized by a considerable degree of detail complexity. Other methods of inventory and other requirements for documentation are set depending on i.e. the type of facility and the required accuracy of the study. A full inventory of historic objects requires the development of measurement methodology combining classical inventory methods and modern technologies, i.e. laser scanning, photogrammetry using UAV.

The case study surveyed in the paper is Parish Church in Pożarzysko in Lower Silesia (southwestern Poland). The church is from mid-13th century and was built of crushed granite and stone joints used in corners and for details. In 19th century an octagonal tower was added. The church fell partly into ruin due to the post-war neglect and was rebuilt in 1970s. An early Gothic portal of high artistic value has been preserved in the southern wall (Fig. 1.).

For the purpose of making a 3D model documenting the state of preservation of the church in Pożarzysko only images obtained by low-altitude photogrammetric flight of UAV were used (Wojciechowska and Łuczak, 2018). The axis of the camera was set perpendicularly to the façade of the building, at an angle of approx. 45º, as well as perpendicularly to the ground. 156 images were used for the alignment. Around 115 000 tie points were obtained, and dense point cloud of 42.8 million points. Mesh, shaded coloured and orthoimages textured models were generated. The inventory drawings of facades in the scale 1:100 and selected architectural de-tails were created on the basis of facade orthoimages (Fig. 1.). The metricity of the model was assigned using external software (MeshLab) basing on the real dimensions of the structure. The accuracy of the model was determined to be on the level of 2.5-3.2 cm.

There were several problems that occur while using the method: difficulties with generating textures hidden behind plants and other objects in front of the façade (additional shooting was needed in that areas) and reconstruction of reflective sur-faces (metal elements of building drainage system and some flashings that were better illuminated during the shooting). However, in this study it was not the subject of documentation - contemporary elements were not included.

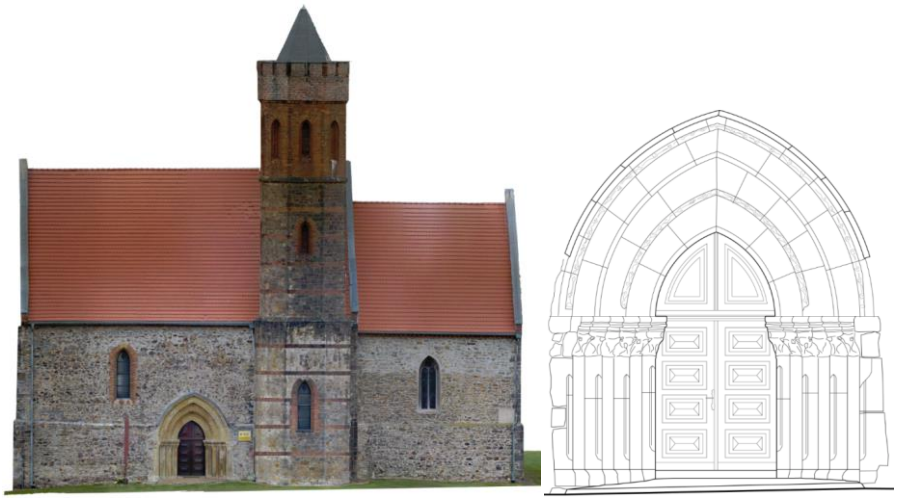

Fig. 1. Orthophoto of southern facade church in Pożarzysko and inventory drawing of the Gothic portal

4.3. Documentation of the archeological site

Using an UAV to make a textured 3D model allows to quickly and relatively cheap document the state of archeological excavations, which after researches usually becomes covered. It is a very useful tool that allows to permanently save the excavation model in the form of a virtual copy. The developed documentation very often remains the only information about the archaeological site and is an invaluable source for future researchers.

The excavation model in Ruszowice was made as part of a project implemented in 2014-2018 at the Institute of Archeology of the University of Wrocław under the direction of dr hab. Justyna Baron. The hypothesis of researches was to verify assumes the Kłodzko valley was not an empty communication zone connecting both sides of the Sudety mountains but a stable settlement region with its own original cultural and settlement properties. As the result of covered archive queries, surface survey, geophysical and geomagnetic prospection the excavations were performed at the site of Ruszowice (Baron *et al*., 2018).

In the development of a spatial archaeological excavation model with dimensions of 20x20 m, 240 photos were obtained during low-altitude photogrammetry flight of UAV. The photos were taken in the vertical axis of the camera. As a result, a sparse cloud of around 162,000 points was obtained, in the next stage a dense point cloud was generated (70 million points), a mesh model and a textured model (Fig. 2).

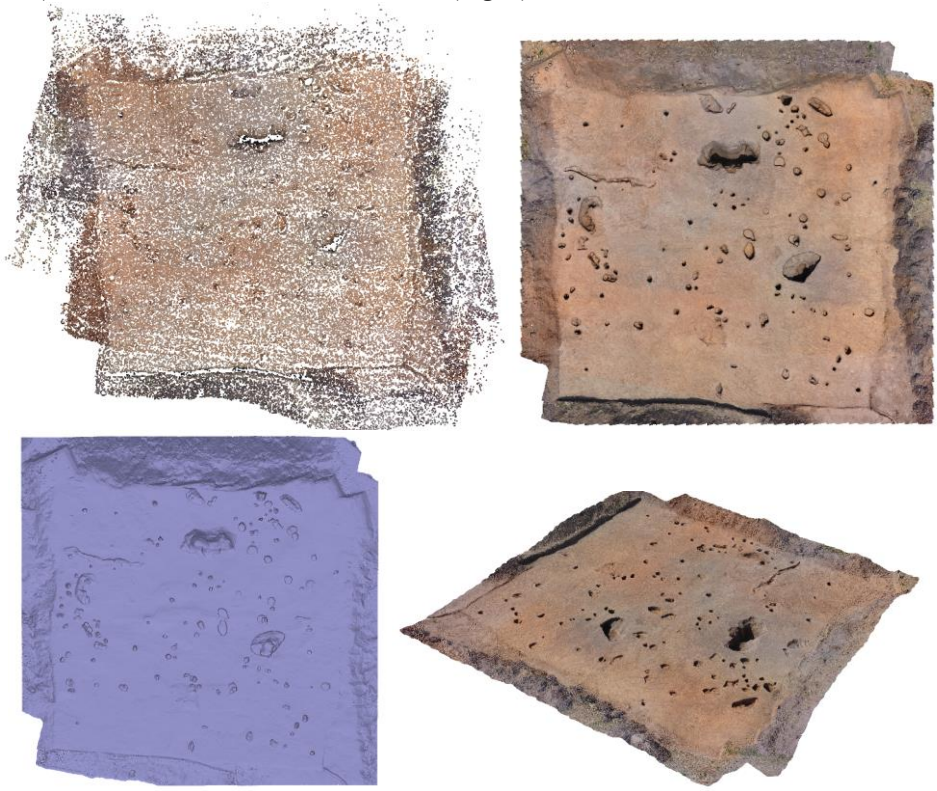

Fig. 2. Archaeological site in Ruszowice (from left: 1- sparse point cloud, 2 - dense point cloud, 3 - mesh model, 4- textured model)

The metricity of the model was obtained on the basis of geodetic data from staking excavation points. The coordinates were assigned to the appropriate markers marked on the photographs, which became the adjustment points.

5. CONCLUSION AND FUTURE WORK

There are very large possibilities of using geomatics to acquire, store, analyze, pre-sent and share spatial data about monuments. The use of geomatic tools in the preservation of cultural heritage is particularly evident in two basic areas: scientific description of objects in the form of inventory documentation and in the popularization of knowledge about cultural heritage by means of geographic information systems and geoportals. The use of an appropriate measurement method for the inventory of monuments - and not only - still depends on many fixed elements, which primarily include: accuracy requirements, technical conditions (size, complexity and availability of the object, area of study), as well as economic factors (time, cost and labor consumption). It is necessary to be aware of the advantages and disadvantages of the measurement methods used. The final effect of the study always depends on the purpose determined by the user and the choice of the appropriate measurement method. An optimal way to carry out the inventory of items such as roofs and towers seem to be pictures made through the UAV, which allows to build whole geometry of the objects based on photogrammetric solutions.

Documentation is the basis for dissemination of knowledge about cultural heritage. The possibility of graphical recording and presentation of documented objects on GIS platforms allows to transfer heritage protection to a new dimension. Com-prehensive tools for storing and managing large amounts of spatial data create new possibilities for documentation of historic objects.

Future work will concern the development of 3D model of the church in Pożarzysko – photogrammetric model of interior of the monument can be used as a form of virtual tour on the designed webpage and visual material for researchers of medieval architecture. A database containing information about the object's history, materials used, conversions, archives, inventories and archaeological research will also be designed. Knowledge of previous activities (inventories, researches, archival photographs, etc.) is extremely important during working on the documentation of a historic building. Gathering information in one place avoids doing the same work repeatedly, which unfortunately happens relatively often in the documentation of monuments, e.g. re-inventorying. The designed database could be a support for architects and restorers who will deal with the topic in the future and could be adapted to other monuments with similar characteristics.

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