Karol Czajkowski

Modern Technologies in the Documentation of Cultural Heritage:

A Coherent System of Data Collection, Processing and Presentation as a Basis for Conservation Activities

National Institute
of Cultural
Heritage

Narodowy Instytut Dziedzictwa
ul. Mikołaja Kopernika 36/40
00-924 Warszawa
nid.pl

Managing Editor
Maria Wierzchoś

Graphic Design
Piotr Berezowski

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Foreword

The need to create and collect documentation on historic monuments is without doubt essential in the process of their conservation. Any activity that affects the structure of a historic building must be preceded by an inventory of its existing condition. This documentation, which is then subjected to analysis and architectural interpretation, ensures that the conservation work is carried out correctly. The aforementioned procedure has always been used in the conservation of historical monuments. Irrespective of the period, the measurement technique used and the method of publication, the documentation produced should be reliable, objective and adapted to the perceptive capabilities of its recipients.

As measurement technology has developed, so have inventory techniques, including methods of data collection and presentation. Today, a large number of researchers use the digital environment for its interpretation. Access to low-cost hardware, software and services has provided the conservation community with many tools to quickly and accurately obtain measurements of historic architecture. In addition to the obvious advantage of speed and accuracy of measurement, digital techniques give us the opportunity to document reality on a macro scale. This world consists of the entire cultural context, recorded in subtle traces that are not overlooked in the process of photogrammetric data collection. These traces make it possible to study not only the typological features of a structure, but also the technological process used to make its individual elements, or even the personal characteristics of the craftsman. Recording as much information as possible about an object seems particularly important, especially in the context of the analytical capabilities of neural networks, which are developing at an increasingly rapid pace.

Despite a decade of widespread use of the method and a wide range of instrumentation, there is still no consistent procedure for the acquisition, development and publication of the information, nor are there any guidelines for minimum map resolution, data quality or recording formats. One of the reasons for this is that there is no clear definition of the final processing of digital data. This is because it is neither a refined point cloud embedded in a coordinate system nor a mesh model. It is simply data that has been suitably prepared for further analysis, and as a source base it can be used in the future for further studies and collections of information based on it. It seems, therefore, that the basic question that determines the parameters of the documentation is: for what kind of analyses do we need the survey data? The answer to this question will vary according to the specialist and the line of research. The aim of this article is an attempt to describe the basic minimum parameters of the study and the elementary methodology of its implementation, necessary for the preparation of inventory documentation of historical architectural objects.

Land surveying

The digitization and documentation of architectural monuments involves the use of non-invasive measurement methods – terrestrial laser scanning and digital close- and medium-range photogrammetry systems – for the purposes of architectural inventory. The work is divided into an on-site part – related to measurements and analysis carried out directly on the object, an administrative part – during which the data collected on site is processed, and a publication part – in which the basic scope of analysis (a drawing in the form of an interpretation of the architectural structure) becomes part of the systematized information about the object.

At the National Institute of Cultural Heritage, the main purpose of a digital inventory is to create a 3-dimensional digital copy of the object, in order to store in a digital environment a precise inventory of its characteristics – geometry, state of conservation of the structure, all the traces that allow a more in-depth historical and architectural analysis. These traces concern, among other things, the technology used and the time of its construction, defects, structural deformations. Of particular interest to us is the possibility of periodic monitoring of damage associated with the disturbance of the structure, e.g. as a result of warfare.

At the same time, we do not forget about the digital copy of the architectural details, stuccowork, which are historical elements of the interior design, and are measured, precisely reproduced in terms of their shape, characteristics, colour and three-dimensional surface structure. In the context of the policy of pillaging pursued by the occupying forces, it is particularly important to make their digital copies for identification purposes. Of course, the aforementioned examples do not exhaust the wide range of applications of inventory data. Depending on the field, we can use the same source data for both basic (e.g. design and costing) and

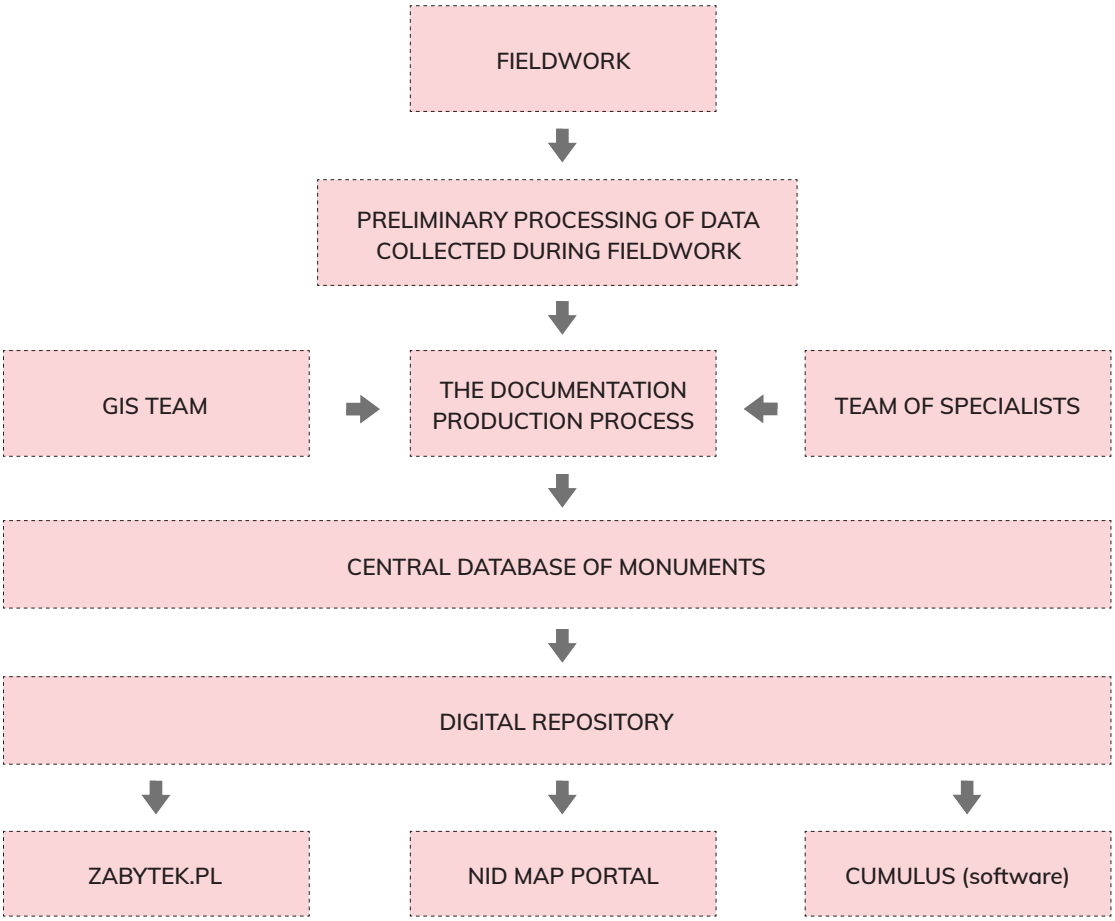
1 Tacheometric survey of the ruins of the synagogue in Tarłów (photo: K. Czajkowski)

specialized (e.g. acoustic) analyses. The scope and parameters of the study we select must take into account the prospects for the development of the analytical database and software, as well as the feasibility of depositing and storing the source data in a repository.

Specialists of the National Institute of Cultural Heritage prepare documentation of the current state of preservation of the architectural structure based on the original survey. Its universal form is based on a standard

that has been defined for years and can be used by people without specialist software. It consists of two-dimensional drawings made on the basis of 3D scans, models in the form of point clouds – as basic measurement data in full resolution and simplified forms, and mesh models – in multi-polygonal form and simplified forms for visualization and popularization purposes.

The stages of data collection, the drawing up and publication of documentation are shown in the diagram below:



2 Laser scanning of the church of St Barbara in Solec nad Wisłą (photo: K. Czajkowski)

The first and most important element of systematic data collection and compilation is an interdisciplinary team to carry out fieldwork. Such a group should include, in addition to a surveyor, equipment operators (drone, camera, scanner) and data modelling specialists, in particular architectural historians. An interdisciplinary team is essential for the successful collection of data on site. The architectural historian understands the building he or she is dealing with, is able to assess the value of the objects that are found, for example, elements of the furnishings, and thus modify the work methodology or data collection technology used on site.

Systemic data collection also determines the methods of fieldwork on site. By fieldwork we mean the physical measurement of the object in the form of a digitization project lasting several days, during which tacheometric measurements, measurements with an RTK receiver, multi-view terrestrial laser scanning, drone (UAV) flights, the acquisition of images with non-metric cameras, both hand-held and mast mounted, are carried out in order to produce three-dimensional photogrammetry models and

360-degree panoramic images. Basic data processing is also carried out during the fieldwork to check the quality and completeness of the data.

The minimum set of parameters of the on-site material to be used for the inventory should include:

1. **Point cloud** – base model at a resolution of not less than 9 points/cm^2, with recorded RGB and intensity values. The measurement should cover at least 90% of the object's volume.
2. **Photogrammetric images** taken by drone or camera – should be taken from such a distance from the object that the accuracy of the surface representation measured in GSD (Ground Sample Distance) is not less than 0.12 cm/px for architectural objects and 0.05 cm/px for architectural details, sculptures and street and landscape furniture.
3. **XYZ geodetic data** of all control points distributed on the site with reference to the global geodetic coordinate system.

These source datasets should be backed up and a copy deposited in a repository.

3 The drone is an indispensable tool for collecting photogrammetric data in inaccessible places. St Bartholomew's Church in Poręba Wielka (photo: K. Czajkowski)

Processing of data collected during fieldwork

The core processing stage takes place during the administrative work carried out in the office on the acquired materials, using dedicated software. The results are comprehensive models of the buildings composed of partial laser scans, in the form of a refined and filtered point cloud, embedded in the global coordinate system. Such models constitute the basis for structural analysis and the drawing of cross-sections and projections of buildings.

Developments of projections, cross-sections and views, in the form of two-dimensional vector CAD drawings, have been the basic architectural documentation on which specialists from most fields have been working for years. In addition to the measurement value, they contain the most important thing – an architectural interpretation of the structure. For this purpose, the presence of an architectural historian in the team is necessary.

The materials produced in the process of such a study constitute the basic package of information about the historic building. Once completed, it should be published and simultaneously deposited in a repository. These materials should contain a minimum set of data and their parameters, which we have developed together with the team as a set of good practices for the needs of the Competence Centre of the National Institute of Cultural Heritage.[1]

1. **Point cloud** in a filtered, refined, registered and geo-oriented form. The points should have an RGB and a reflectance parameter in

1 Document entitled 'Dobre praktyki w zakresie wykonywania dokumentacji architektury współczesnymi metodami rejestracji cyfrowej', eds: Karol Czajkowski, Klara Kantorowicz and Ryszard Zimek

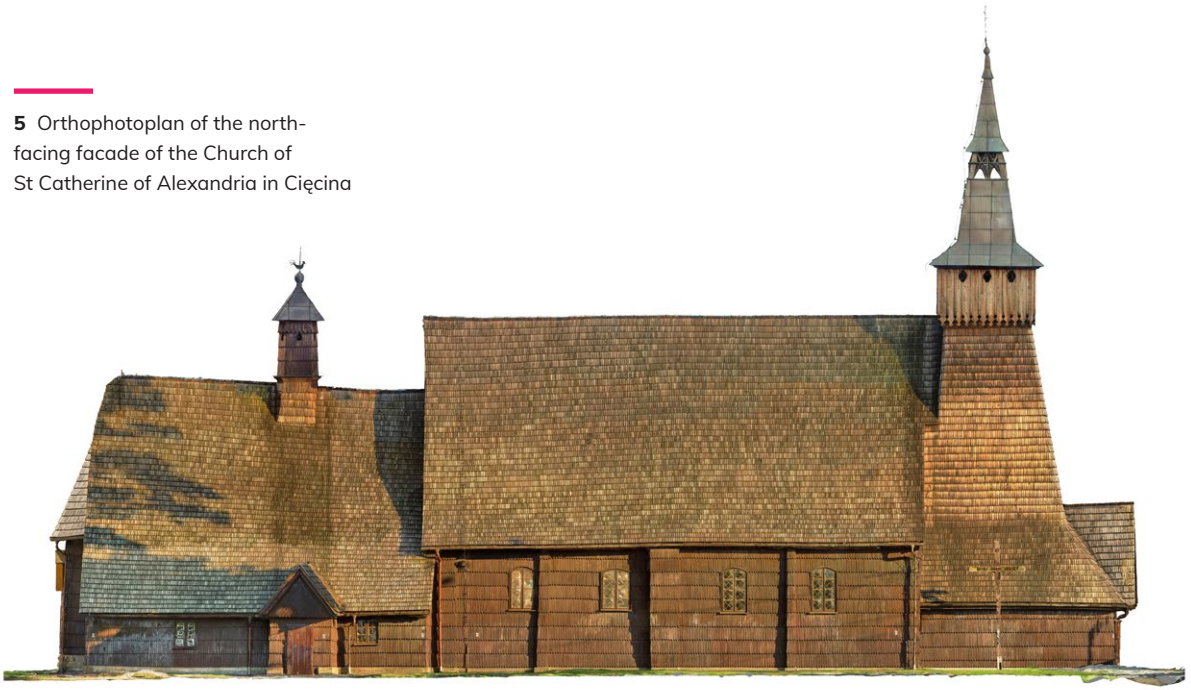
4 Measurement in the form of a point cloud showing St Bartholomew's Church in Poręba Wielka

addition to the coordinates. The model should be exported into one of the commonly used formats: PTS, PTX, E57 with an accompanying assembly report as a TXT / PDF file.

It is also worth exporting the point cloud from the project in the form of separate files corresponding to individual scanner positions. This makes it easier to work on objects with large, complex volumes. The individual files should first be filtered, refined, registered and oriented in the geodetic system and saved in one of the following formats PTS, PTX or E57 with an accompanying assembly report as a TXT / PDF file.

2. **Orthophotographs** of walls, elevations, with a resolution measured in GSD of not less than 0.12 cm/px and of polychrome, paintings with a resolution of not less than 0.05 cm/px, in TIFF format together with a georeference file.
3. **Location and elevation plan**, in DWG and PDF formats, including: plan (roof projection or external outline at the ground floor level of the building) with surrounding elements, marking of characteristic

5 Orthophotoplan of the north-facing facade of the Church of St Catherine of Alexandria in Cięcina



levels (at entrances to the building), nearest neighbouring buildings and landforms. Made on the basis of a current geodetic map.

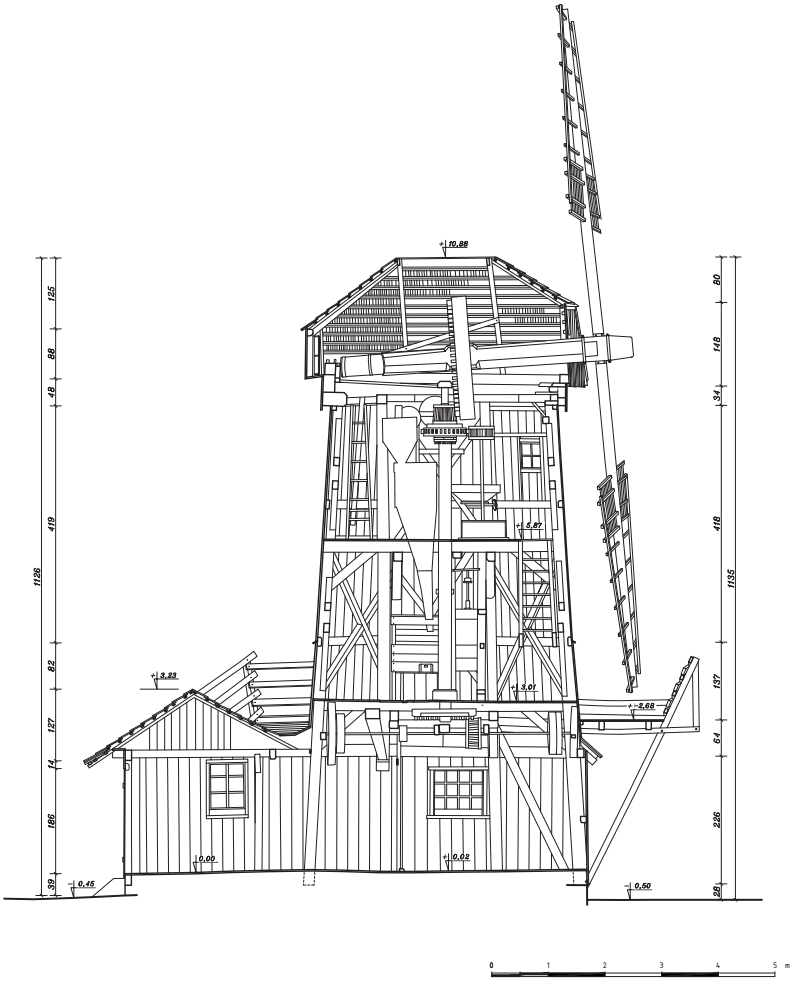
4. **Drawings of the elevation** on a scale of 1:50–1:10, depending on the type of study, in DWG and PDF formats. These shall be prepared on the basis of cross-sections and slices of the point cloud, projected relative to the axis of the building. Similarly, drawings of elevations should include views of all the walls in the building. For complex buildings, views of walls 'obscured' by other elements of the building elements should be shown on the relevant sections. It is important that any voids, damage, cracks or dampness in the walls be marked (mapped) on the elevations. It is sometimes advisable to produce a separate drawing showing these, e.g. at a larger scale. On the elevation drawings, visible building elements should be drawn (at least in part): bricks, stones, roofing elements, etc.
5. **Cross-sections and projections** of the building, floors, depending on the nature of the study, should be prepared on a scale of 1:50–1:20 (1:100 in justified cases), in DWG and PDF formats.
6. **3D models** of buildings and details, composed of triangle meshes, based on non-metric camera shots, at the GDS resolutions described above.

For historic architecture, the scope of the survey should include all floors, roof trusses and a roof plan. The level of the horizontal sections should be drawn at a height of one metre above the floor, but slight variations are permissible in order to give as complete a picture as possible of all elements of the building and its furnishings. At the same time, each room should be described with its own number, floor number, function, area, height and type of flooring. In addition, all projections should be marked with cross-sectional planes.

The dimensions on the drawings should indicate the length and width of the rooms, diagonals, sectional dimensions and wall thicknesses. We mark the characteristic levels, the height of the rooms (in vaulted rooms the height at the vault arch and the height of the vault base), the height of the window sills and the clear openings. The plans should show, with accuracy appropriate to the scale used, all visible elements such as recesses, differences in the offsetting of the walls, projection of the vaults with the elements of their construction and stuccowork decorations, projection of the ceilings with ceiling beams or stuccowork decorations (for better readability of the presentation it can be made on a separate drawing), drawing of the floor with fragmentary marking in characteristic places, differences in the floor levels, window and door joinery (marked schematically with an indication of the type and possible way of opening), land adjacent to the object: surfaces, stairs (with an indication of the direction), terraces, balustrades, bands, etc., landscape architecture associated with the object and permanent fixtures drawn in detail that is clear for the intended scale of the drawing.

Longitudinal and transverse cross-sections of the object through its characteristic elements (vertical communication, window and door openings, differences in levels) should give as complete a picture of the building as possible. However, a minimum of two cross-sections perpendicular to each other is necessary. Stepped section lines may be used for more complete identification of the building. Levels should be marked on the cross-sections with spot heights with absolute ordinates (or relative to an assumed reference level). The cross-sections should be supplemented by views of walls showing fixed furnishings.

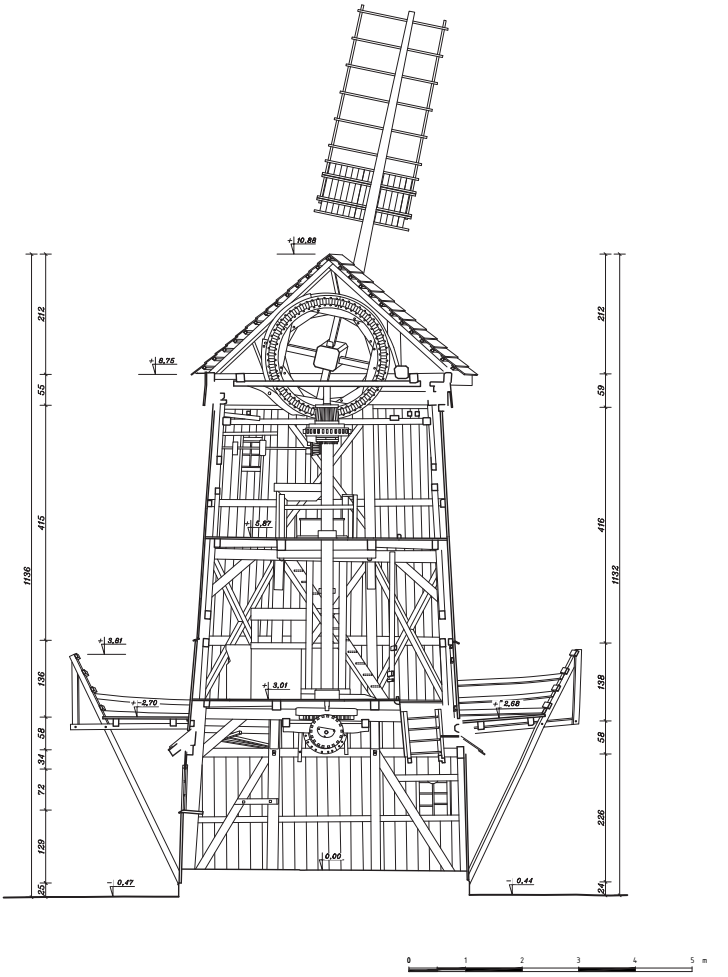
For the purposes of the repository, the model should be exported to a file in .fbx format at its maximum resolution (i.e. the maximum number of vertices captured during the model generation process, together with information about vertex colour). Another way of exporting models



Narodowy Instytut Dziedzictwa

TEMAT:	WIATRAK HOLENDERSKI W KORYCISKACH
TYTUŁ RYSUNKU:	PRZEKRÓJ AA
OPRACOWANIE:	KLARA KANTOROWICZ KAROL CZAJKOWSKI BOLESŁAW KOBIELSKI RADOSŁAW TROCHIMIAK MONIKA RUSTECKA RYSZARD ZIMEK TOMASZ ŻEBROWSKI
DATA:	Wrzesień 2022
SKALA	1:50
RYSUNEK NR:	4

6, 7 Inventory drawings of the windmill in Koryciska based on laser scanning (drawing: R. Trochimiak)



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TEMAT:	
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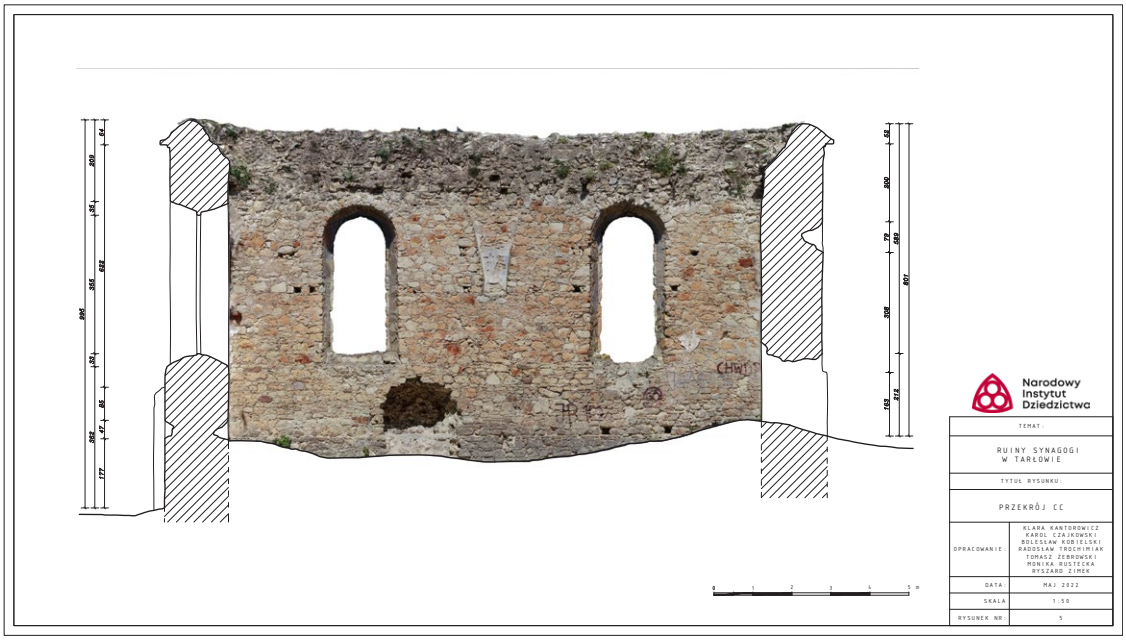
OPRACOWANIE:	KLARA KANTOROWICZ KAROL CZAJKOWSKI BOLESŁAW KOBIELSKI RADOSŁAW TROCHIMIAK MONIKA RUSTECKA RYSZARD ZIMEK TOMASZ ŻEBROWSKI
DATA:	Wrzesień 2022
SKALA	1:50
RYSUNEK NR:	5

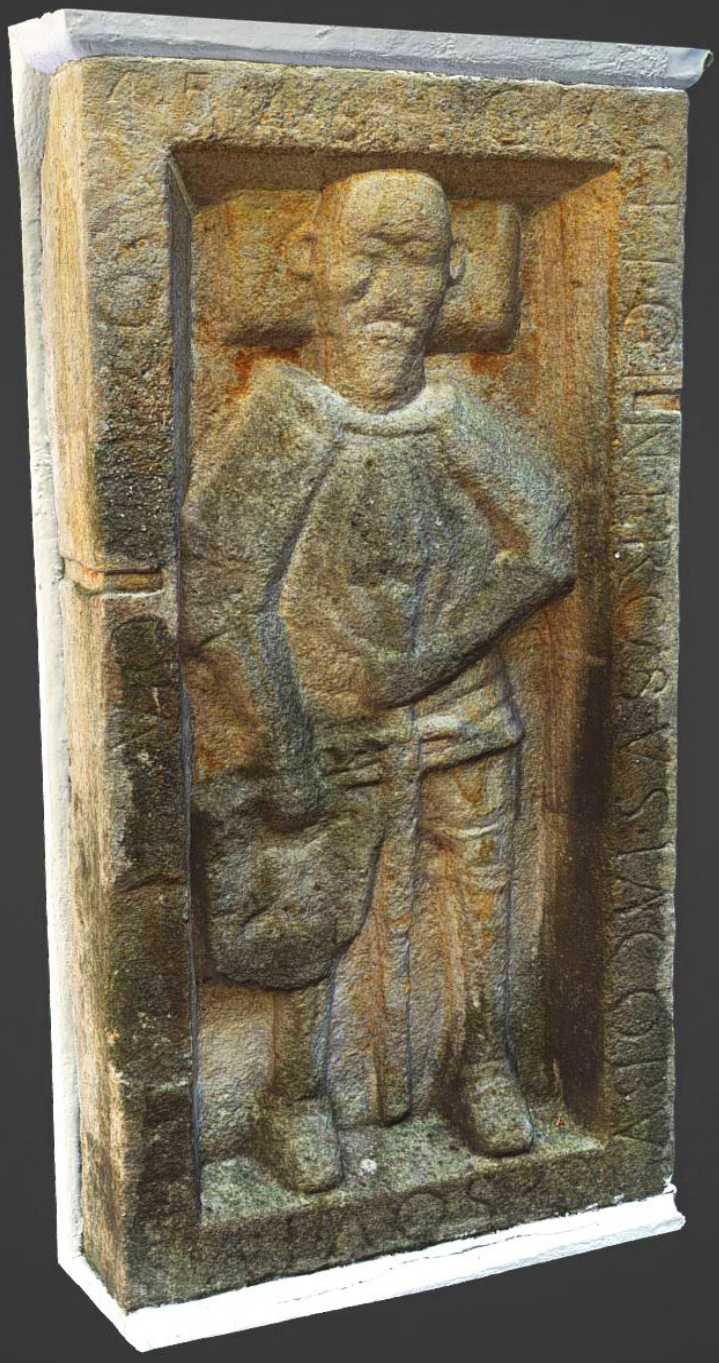
8 Polygonal model of the windmill in Koryciska based on photogrammetric measurements

for visualization and analytical purposes is to perform a process called retopology – reducing the number of vertices together with cleaning up the edges and modelling areas not visible during registration. Such a model should be exported as an .obj or .fbx file with generated UV coordinates (a UV map) and all the textures. The maximum number of vertices in the model depends on the capabilities of real-time visualization engines or online browsers of 3D files (e.g. Sketchfab with up to 4 million, ensuring smooth operation of the web browser).

The model texture should contain one or more images in uncompressed format (TIFF, TGA, PNG) with a resolution of 8192 x 8192 pixels and a colour depth of 8 bits per channel or higher. The set of textures generated by the photogrammetric process consists of a colour map – *color map*; *normal map* with micro-surface information; *displacement map* (optional) and *AO map* (optional). A model can have more than one texture set. However, each must have UV coordinates (a *UV map*) for an object that supports one or more images or texture sets.



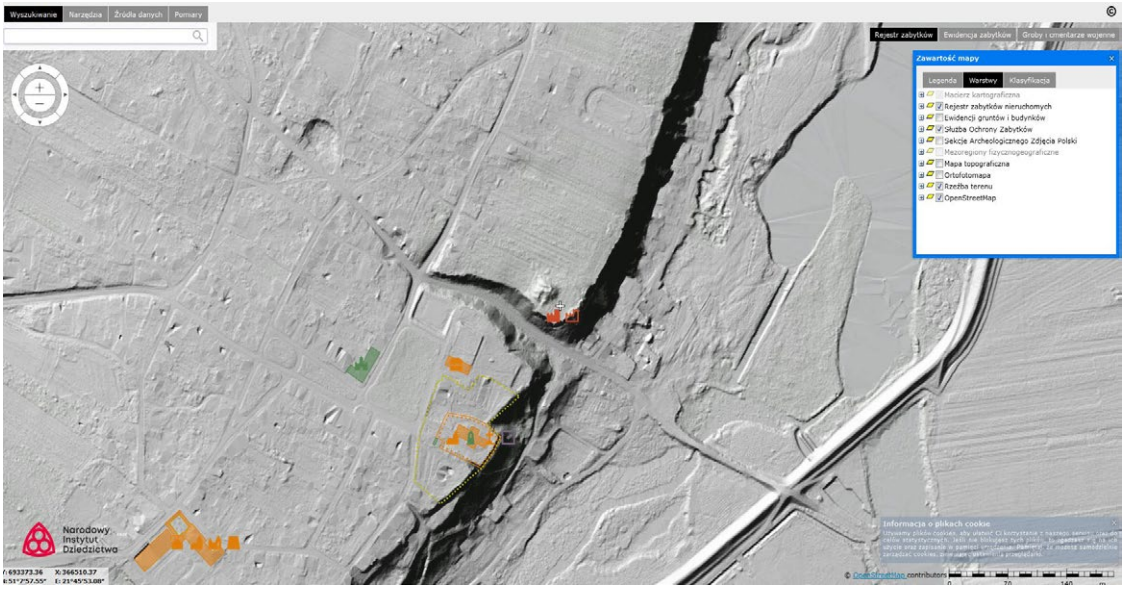
9 Hybrid inventory, ruins of the synagogue in Tarłów.
The documentation, which is a combination of a drawing (cross-section) and an orthophotoplan (view), was made on the basis of laser scanning and short-range ground-based photogrammetry



10 Polygonal model (mesh) of the stonework detail. Epitaph of Jakub Gierałtowski, located near the Church of the Blessed Virgin Mary of Carmel in Głębowice

Ways of archiving and presenting data

The storage of the acquired and compiled documentation into a digital repository in the form of a reference copy, takes place at NID through the Central Database of Monuments. Our system has a database system we call the Production Environment, which is consistent with the register and records of Polish monuments that have been in place for many years. This environment consists of the Central Database of Monuments and the Digital Repository. All information about historic buildings, including their geolocation and features, is continuously acquired into the Central Database. The Repository, on the other hand, receives the documentation complete with metadata, source files and all multimedia acquired during

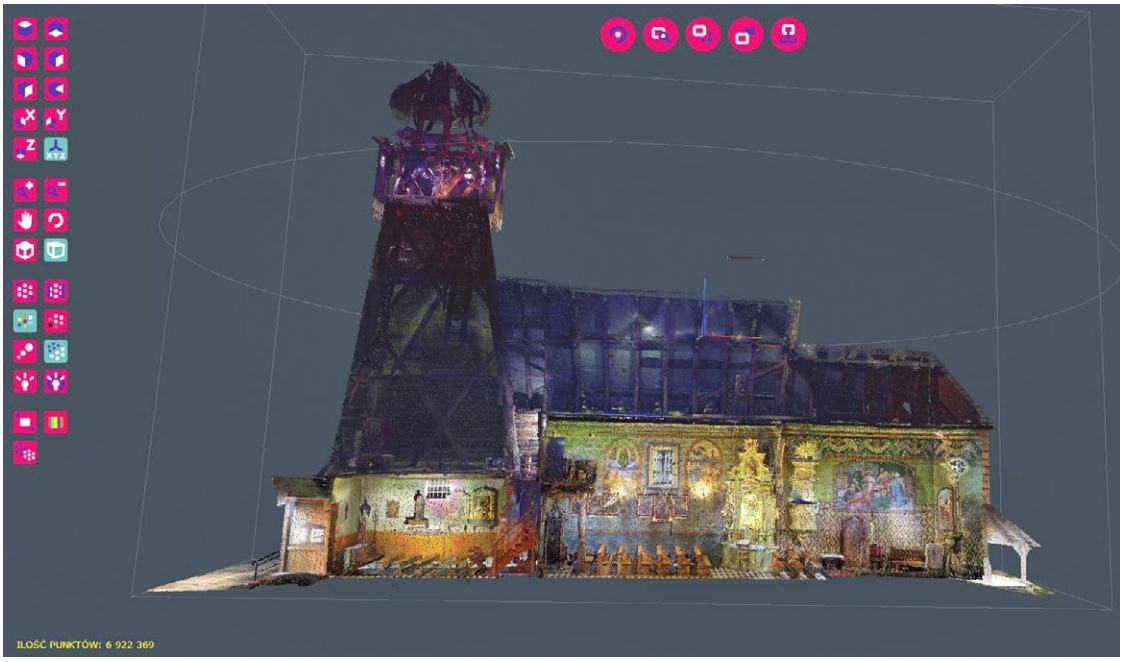


11 NID map portal. Surface model with the range of registered and recorded objects

the digitization project in situ. The storage of each of these elements is extremely important, as each of them has documentary value. The batch processing is managed by a purpose built application, which allows different categories of data to be loaded, described with metadata (chronology, object category and type, material, etc.) and stored on servers. The data entered into the geoinformatics system is managed by a team of GIS specialists.

For the documentation to have a useful dimension, we need to consider a method of publication. While two-dimensional documents in the form of DWG / PDF files are relatively easy to read and print, spatial data poses some difficulties. At the National Institute of Cultural Heritage, we practise the publication of documentation in three web environments that are coherently designed around a single database.

The first of these is the Map Portal (mapa.geoportal.nid.pl), which is a cartographic representation of the features of historic buildings collected in the registers and property records – including their location along with the appropriate assigned scope of conservation protection, category, chronology, etc., allowing simultaneous use of data provided by public institutions (e.g. Land and Mortgage Register, Digital Terrain Model of the Nation Protection IT System). The second is the portal zabytek.pl. On it we



12 Cumulus application. Longitudinal section of the laser-scanned point cloud of St Bartholomew's Church in Poręba Wielka

13 Documentation of the no longer surviving church in Tychówek

can present the digital documentation of any object listed in the register or property records in the repository – i.e. orthophotoplans, inventory drawings, archive documentation and mesh models. The latter use the Sketchfab viewer function, which in itself is a splendid, evolving environment for presenting plane models.

The third environment is Cumulus, proprietary point cloud management software developed and implemented in collaboration with the Institute of Mechatronics at the Warsaw University of Technology. Integrated into the Zabytek.pl portal, the Cumulus application meets the needs of those who do not have appropriate, often expensive, point cloud viewing software. It allows for the visualization of laser scan data in a web browser window, giving the possibility to independently analyse the architectural structure by making any cross-sections through the building, perpendicular projections, orthophotoplans and exporting them as bitmaps at the desired scale.

The above procedure, together with the mapping parameters, should be understood as a minimum level of inventory development, regardless of the external situation – the degree of devastation or obstructed access

to the building. It seems that in the case of an extraordinary situation – e.g. the need to inventorize objects in a war zone – such technology and the adopted working methodology would be optimal. In such circumstances, a number of external factors should also be taken into account, such as: the short duration of access to the object (i.e. minimizing the risk to the health/life of the team by using the technique to collect data as quickly as possible); the sensitivity of the object to indirect destructive activities (changes in ground stability, vibrations, landslides as a result of artillery fire); limitations on the use of certain types of data collection equipment (e.g. limitations on the control of equipment supported by RTK satellite communications, GPS, drones).

Not least of these will be the element of the team operating under stress, as well as the crucial need to provide a method of backing up the data collected on site – in case of loss of mass storage, for example due to an emergency evacuation.

Conclusion

In recent years there has been a growing trend towards the use of digital documentation techniques. This trend goes hand in hand with an increase in the funds allocated by state institutions for the digitization of historical monuments. In such a context, it is worth mentioning what should be included in the document defining the subject of the contract for digitization services. The most important element in this case will be the selection of the appropriate technology for the specific object. In the field of monument conservation we deal with many different types of monuments, each with an individual character; they differ in the complexity of their shape, the material from which they are made, the presence of sculptural details and their interior decoration. The inventory of each of these types will have its own peculiarities and will require the modulation of techniques or the use of hybrid methods in the inventory process. It is therefore advisable to specify at the outset the data and materials that are to be the result of the on-site survey and study, i.e.: specify what is to be the result and what type of data we are to obtain at the end (survey only, survey plus processing); specify the resolution of the scans and photographic materials; specify the arrangement of the reference points and the coordinate system, the accuracy of the tachymetric distance measurement of the control points and the permissible values of registration errors; specify the minimum field resolutions for orthophotoplans and 3D model textures. It is also worth adding to the specification framework guidelines for lighting/sunlighting of sensitive areas (e.g. roof trusses, elevations) and specifying the formats of the files to be transferred.

Once the basic minimum parameters have been defined, we can be sure that the data obtained during the digital inventory process will be reliable, consistent with the databases operating in the conservation environment, and reusable. Digital documentation is an expensive process, sometimes only possible once in the life of an object. It is worth remembering that what is missed on site may be lost forever.

14 Documentation of the church of St Jacob in Mieronice

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