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INVENTORY OF HISTORICAL POLYCHROME USING PHOTOGRAMMETRIC METHODS

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Summary

The inventory of a historic monument is carried out to create documentation that provides information on the up-to-date condition of the object. Preserving its original form and materials requires a minimally invasive approach to data acquisition. The implemented research project included an analysis of the possibilities of using photogrammetric methods in the inventory of wall paintings in the historic wooden Greek-Catholic Church of the Protection of the Holy Mother God in Miękisz Stary (Jarosław County, Podkarpackie Voivodeship). The research object is a wooden church from the 17th century with a three-part layout – sanctuary, nave, gallery – and a wide nave in an almost square plan. Inside, the walls and ceilings are decorated by numerous polychromes. Unmanned aerial vehicles (DJI Phantom 4 Pro) and a photographic camera (Canon EOS 1200D) were used for photogrammetric measurements of the polychromes. The results of the photogrammetric measurements were digital photos, which were used for photogrammetric processing. The photographic work involved generating high-resolution images in the Agisoft Metashape Professional software. A point cloud obtained from terrestrial laser scanning was used to render the geometry in the process of creating orthophotoplans. The results of photogrammetric work are orthophotoplans of polychromes with high resolutions. Two orthophotoplans of wall paintings were generated based on drone photos, while ceiling paintings and one of the walls were generated based on high-resolution photos taken with the Canon EOS 1200D camera. The obtained results demonstrated that measurements made using UAVs and digital photos processed with photogrammetric methods enable a comprehensive inventory of wall paintings for historic objects.

Keywords

inventory of historic buildings • polychrome • photogrammetry • orthophotoplan • UAV

1. Introduction

An architectural inventory provides information on the structure, shape and fixed equipment of buildings. The documentation prepared during the inventory accurately reflects the current condition of the building, which is the basis for any conservation or construction work. In a situation of partial or total destruction of a historic monument, it helps in the reconstruction process, so that the object can serve future generations and be a valuable source of historical knowledge [Kantorowicz 2022]. The practice of measurement of existing buildings and documentation of objects before the commencement of construction works dates back to the end of the 16th century, and the documentation prepared allowed for the reconstruction or renovation of many cultural heritage objects [Brykowska 2007]. Currently, the scope and methods of documentation are defined by the Act on the Protection of Monuments of 23 July 2003 (Journal of Laws 2003, No. 162, item 1568).

The most important materials resulting from an inventory of a historic site include orthoimages, three-dimensional models, vector drawings, and cross-sections [Kędzierski et al. 2008]. One technique for making such documentation is short-range photogrammetry using digital imagery [Kędzierski et al. 2008]. Terrestrial photogrammetry results in products that meet the high requirements of conservationists and act as basic material for cartometric development. Before starting the work, it is necessary to place control network (photopoints) on the object and to measure them in order to obtain the appropriate dimensions of the object during image processing. Photographs are taken at a set distance, perpendicular to the photographed plane, and processed at photogrammetric stations [Bar and Fałdrowicz 2010]. It is also necessary to determine the front and side overlap of the photographs [Boroń and Pastucha 2012]. Making orthophotoplans of polychromes or elevations of historic buildings is popular and in high demand, as evidenced by the number of publications on the subject. An example is the polychromes in the church in Michalice documented by Antoni Rzonca, for whom the basic parameter for the development of orthophotoplans was the field pixel size of 0.3 mm [Rzonca 2004]. In the case of the photoplan of the Byzantine polychromes in the apse of Sandomierz Cathedral, the resolution was 1 mm. This value was affected by the difficult conditions during the work, as described by Adam Boroń, Marta Borowiec, and Tomasz Pirowski [Boroń et al. 2010]. Józef Jachimski and Władysław Mierzwa made an inventory of the paintings in the library of the Cistercian Abbey in Libiąż using non-metric cameras, which yielded a position error of no more than 0.5 mm [Jachimski and Mierzwa 1998]. In their publication, Andrzej Boroń, Andrzej Wróbel, and Rafał Kocierz described the process of creating colour photoplans of the development of the paintings on the vault in the cloisters of the Carmelite monastery in Kraków, where they obtained a resolution of 0.4–0.7 mm [Boroń et al. 2006]. Photogrammetric methods are also commonly used to inventory historic objects in the form of carvings and figures [Lo Monaco et al. 2022], bas-reliefs [Kęsik et al. 2023], decorations [Leon et al. 2020] and paintings [Torres-González 2022].

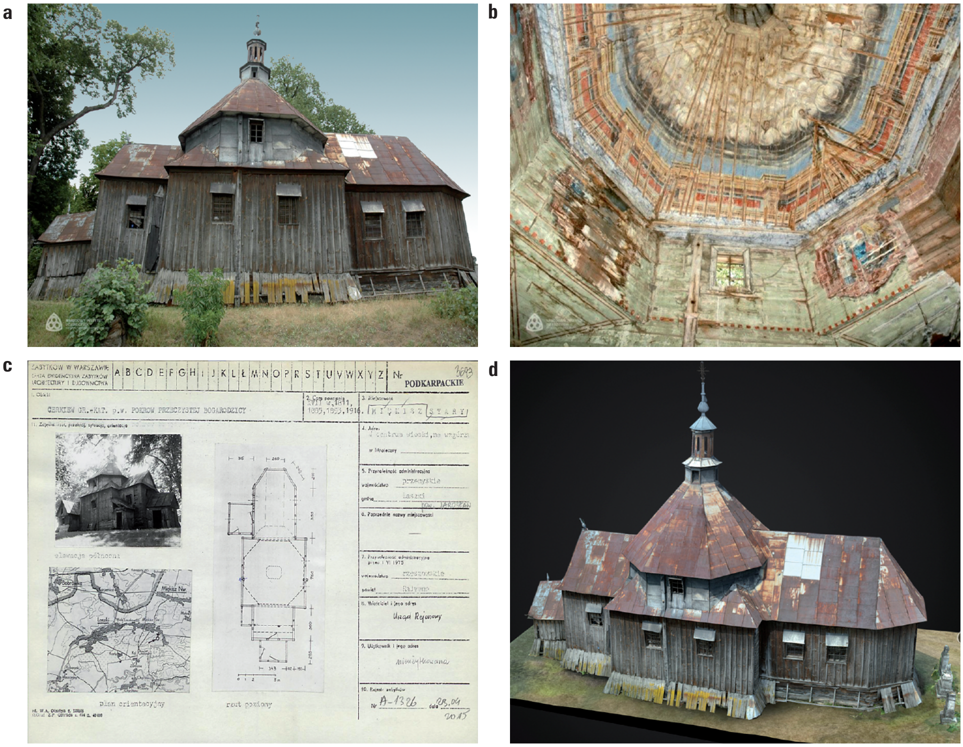
With the development of technology, it has become increasingly popular to document historic objects with laser scanning [Bassier et al. 2018]. The scanner emits a laser beam and, given the angle at which the beam is released and the distance to the object (calculated over time), determines a point with known coordinates. From a single position, it provides a multi-point data set called a point cloud [Lemmens 2011]. Based on such a dataset, documentation of architectural objects can be successfully created, as Tomasz Orłowski and Magda Tunkel have demonstrated using the example of the wooden church of St. Brykacjusz in Gościęcin [Orłowski and Tunkel 2022]. Meanwhile, Bednarz and his team [2016] discussed the suitability of the point cloud for inventorying a monument using the example of the Church of the Assumption of the Blessed Virgin Mary in Nysa [Bednarz et al. 2016]. In both cases, the inventory concerned the general geometry of the buildings. The integration of the results of different photogrammetric methods also proves successful. Data from different sources are combined during the inventory of highly detailed objects, as was achieved, for example, during the inventory of the tombstone of Anna Jagiellonka in Wawel Cathedral [Rzonca 2006].

2. Research object

The aim of the research was to take stock of the historic polychrome located in the Greek Catholic Orthodox Church of the Protection of the Most Pure Mother of God. The building currently serves as a Roman Catholic church (Fig. 1a). The wooden church from the turn of the 17th and 18th centuries has a tripartite sanctuary-nave-basil layout with a wide nave on a plan close to a square (Fig. 1c). Inside the building, there are numerous polychromies on the walls and ceilings (Fig. 1b). These are figural polychromies (some illusionist), which have been partially preserved on the walls of the nave, the tambour and the dome vault, the walls of the women's gallery and the balustrade of the singing choir [NID, Monument card].

The object, over the centuries, has undergone numerous renovations and repairs. One of the most extensive was carried out in the second half of the 19th century. According to a partially preserved inscription on the southern wall of the women's gallery of the church in Miękisz Stary, 'This church was built in 1883 under the patronage of Jan Czyrński, thanks to the efforts of Jan Furczyn and Wasyl Halas. It was polychromed in 1885.' The content of the inscription is not unambiguous; although 1885 is the year when part of the interior painting was made, 1883 clearly does not refer to the actual construction of the church, but at most to an unspecified renovation. Further renovation and rearrangement works took place in 1893. During this time, the shingle roofing was replaced with tin roofing in both churches. Meanwhile, in the church in Miękisz Stary, the porches at the women's gallery were added, the choir was rebuilt, the walls were boarded from the outside and the windows in the western wall of the women's gallery were made. The church in Miękisz Stary was damaged during the war in 1914, and in the following years (1916) the bullet-riddled roof covering was repaired.

The polychrome of the orthodox church in Miękisz Stary is composed of no less than two chronological layers. The first goes back to the construction of the church and refers to the Baroque style. The second chronological layer probably dates from 1885 and has eclectic features. The ceiling of the sanctuary depicts a starry sky with a dove in radiant glory, symbolising the Holy Spirit. On the eastern wall of the sanctuary, there is a large polychrome area with a rustication motif, belonging to the first chronological phase. The other walls of the sanctuary are covered with marmoration with geometric motifs inspired by folk cross-stitch embroidery. In the lower parts of the sanctuary, there is a red painted plinth. Nave: on the northern wall a large fragment of polychrome belonging to the first chronological phase is visible, with the motif of a column or pillar with a base on a plinth.



Source: National Heritage Institute. https://zabytek.pl/pl/obiekty/miekisz-stary-cerkiew-pw-pokrow-przeczystej-bogarodzicy

Fig. 1. Research object – Greek Catholic Church of the Protection of the Most Pure Mother of God, now a Roman Catholic church: **a.** exterior part (facade) of the church, **b.** the interior of the church – fragment of polychrome, **c.** first page of the Monument Card, **d.** 3D visualisation of the object

The polychrome of the second chronological phase consists of a grey plinth with marmoration, surrounded by an illusionist cornice. Above it, on the surface of the north, south, and west walls, there is a monochrome green coating supplemented by modest red accents on the pendentives and the stepped tambour ornament, and a purple border around the crossing between the nave and the women's gallery. A richer iconographic programme can be found on the walls of the tambour, where illusionist Baroque frames include representations of the four Evangelists and a symbolic depiction of faith, hope, and love illustrated, as a cross, anchor, and heart, interlaced with a sash, in radiant glory, emerging from the clouds. These symbols are flanked by two kneeling, adoring angels. The tambour and the ceiling above the nave are covered with an illusionist polychrome with a motif of architectural order with prominent consoles, above which is an open sky with piled up clouds, among which are putti. The women's gallery: on the ceiling is a painting of angels heralding the Day of Judgement. In the middle of the ceiling there is a large Latin cross in a radial gloria, emerging from the clouds. On the clouds at the corners are four angels blowing trumpets. On the north wall of the women's gallery, there is a composition entitled 'The Return of the Prodigal Son', captioned in Ukrainian with 'Father I Sinned'. On the south wall is a composition entitled 'The Good Shepherd', captioned in Ukrainian with 'Examination of Conscience'. Beneath it are the remains of a panel with an inscription from 1885, written in Ukrainian. On the choir balustrade, the remains of a polychrome with motifs of angels playing instruments. Sacristy: the walls of the sacristy are decorated with a simple polychrome in ochre (walls) and blue (ceiling), separated from each other by modest geometric ornamentation inspired by folk cross-stitch embroidery. The ochre and blue cavities show an earlier chronological phase in the form of pink monochrome [Kurek et al. 1989, Stojak 2011, Tomaszek 2013, Żygadło 2019].

3. Method and methodology of the works

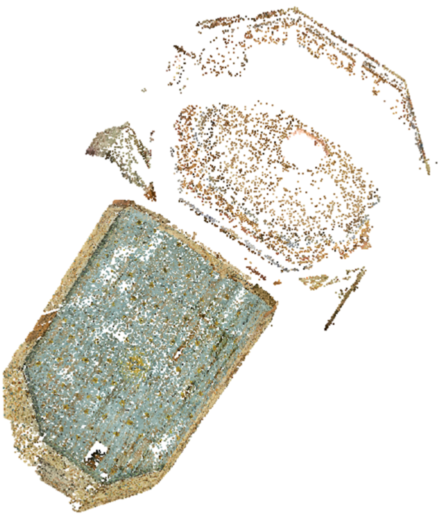
The fieldwork was carried out using a Leica P40 ScanStation terrestrial laser scanner. The point cloud from the TLS was used to provide geometry, shape, and appropriate size for the photographed polychromes. An unmanned aerial vehicle (DJI Phantom 4 Pro) and a camera (Canon EOS 1200D) were used for the photogrammetric survey. The work was performed with artificial lighting, thus ensuring even illumination of the entire painting. The work resulted in high-resolution digital images, taken for individual polychromes at front and side overlap of at least 80%.

The process of generating orthophotoplans for the wall paintings took place in Agisoft Metashape Professional. The two orthophotoplans of the wall paintings were generated from the drone images, while the ceiling paintings and one of the walls were generated from high-resolution images taken with a Canon EOS 1200D camera.

The first stage of the work involved the Align Photos process, which finds the camera position and determines the orientation for each photo using the algorithms to create a sparse point cloud model. During this process, the software creates tie points based on the feature points in the photos. The final result of this procedure includes the generation of a sparse point cloud model (Fig. 2).

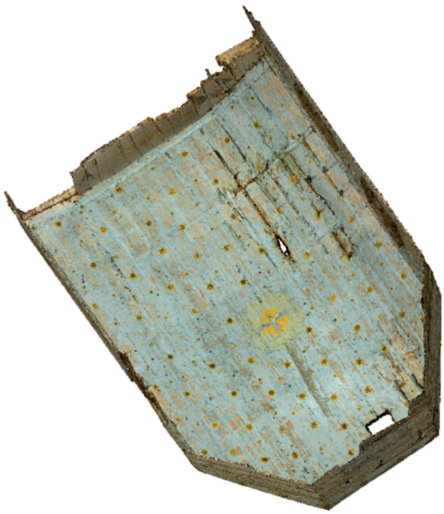
The next stage of work in Metashape was to develop a dense point cloud (Fig. 3). The dense point cloud is created from depth maps for each digital image. The point cloud generated from the images is, in terms of parameters, comparable to a point cloud acquired from a laser scanner.

The point cloud obtained from the digital images (Fig. 3) does not present the correct geometry or scale information for the study. A point cloud derived from terrestrial laser scanning was used to provide the appropriate geometry and scale (point cloud unified to 0.005 m). In order to give the above characteristics, 6 points were used, appropriately distributed across the study site. These points are feature points, easily identifiable on the point cloud from the TLS and the resulting Metashape software point cloud. The average fitting error of the control points was 0.014 m (Fig. 4).



Source: Authors' own study

Fig. 2. The generated sparse point cloud model



Source: Authors' own study

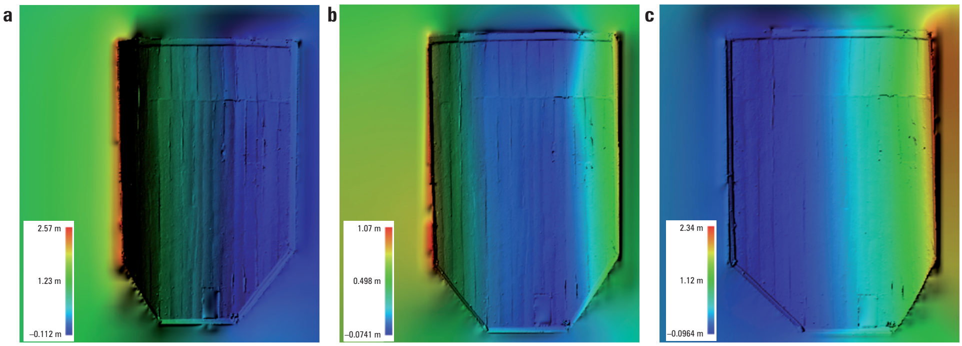
Fig. 3. The generated dense point cloud

Markers	X err (m)	Y err (m)	Z err (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
1	-0.019721	0.006932	0.004191	0.005000	0.021320	11	0.012
3	0.004900	0.000117	0.000849	0.005000	0.004975	10	0.004
4	0.013791	-0.007122	-0.006482	0.005000	0.016821	13	0.010
5	-0.010294	-0.000139	0.002374	0.005000	0.010565	13	0.006
6	0.011324	0.000212	-0.000932	0.005000	0.011364	12	0.007
Total Error							
Control points	0.012941	0.004446	0.003655		0.014163		0.008
Check points							

Source: Authors' own study

Fig. 4. Accuracy and error parameters at the control points

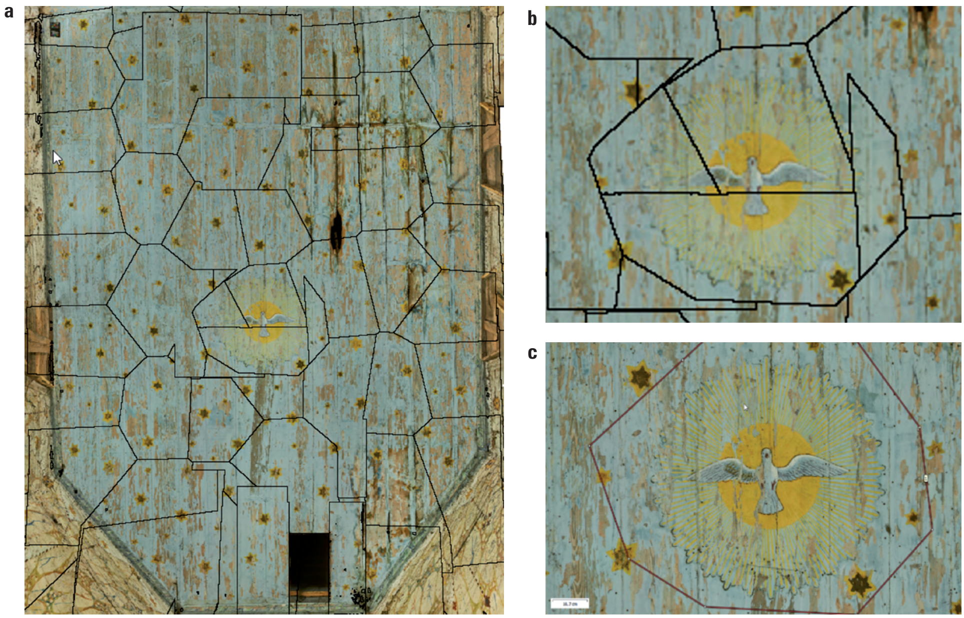
Generating an orthophotoplan of a polychrome requires the generation of a Digital Surface Model (DSM). This is a 2.5D model of the surface, represented by a regular grid and a coordinate value perpendicular to the projection surface. The DSM was generated for three surfaces, as the section being inventoried was on the ceiling, which had three different surfaces located on different planes. The generated DSM was based on matching the plane to the three points (Fig. 5). The basis for generating the surface model was the cleaned point cloud.



Source: Authors' own study

Fig. 5. DSM models generated for part of the ceiling: **a.** left, **b.** middle, **c.** right

An orthophotoplan was created based on the generated DSM models. The generated orthophotoplan, with a resolution of 1mm/pix, was subjected to mosaic editing during processing. This process consisted of editing the mosaic lines (Fig. 6) in order to optimise the selection of the photo fragments that form the final orthophotoplan and avoid blurring, fuzziness, orthorectification artefacts, etc.



Source: Authors' own study

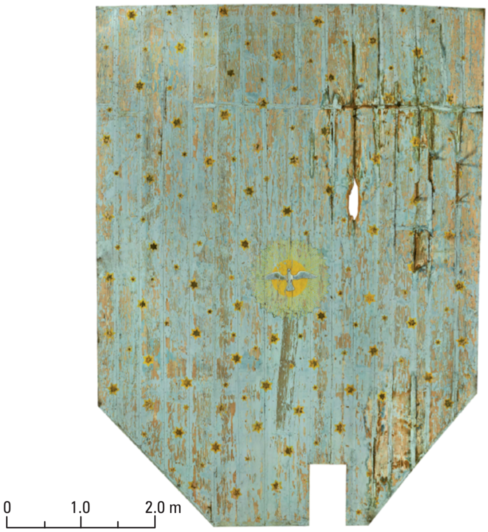
Fig. 6. Orthophotoplan mosaicking process for ceiling polychrome: **a.** mosaic lines, **b.** section of orthophotoplan subject to mosaic editing, **c.** a fragment of an orotophotplan after mosaic editing

4. Results and discussion

The final result is an orthophotoplan of the polychrome with a resolution of 1mm/pix. This product is a complete data source for conducting an accurate and comprehensive inventory of the painting (Fig. 7). Thanks to the high resolution, any cracks, paint separations, and structural damage are also visible.

An orthophotoplan of the wall painting was also generated for one of the interior walls (Fig. 8). The orthophotoplan of the wall filled with paintings was obtained with a Canon 1200D digital camera. The sparse point cloud model was created from 42 images and the generation accuracy was set to medium. The result of the photo orientation process (Align Photos) is a sparse cloud consisting of 70,000 points. The sparse point cloud was generated on the parameters 'medium' for quality and 'mild' for depth map generation. In order for the point cloud to have the right geometry and scale, reference points derived from ground-based laser scanning clouds were used. The orthophotoplan was created using the generated DSM and the resolution is 1mm/pix.

Images captured with a DJI Phantom 4 Pro unmanned aerial vehicle (20 MPix camera) were used to generate orthophotoplans of the polychromes above the altar (Figs. 9, 10). The creation of a sparse point cloud was carried out on 'medium' parameters. A dense point cloud of approximately 11 million points was then generated. The dense point cloud was given scale and geometry using point extraction from clouds acquired from terrestrial laser scanning. The error of fitting the points into the point cloud was 0.0155 m. The generated products were created using a DSM with a resolution of 2.09 mm/pix, and the output orthophotoplan pixel size was 1 mm/pix.



Source: Authors' own study

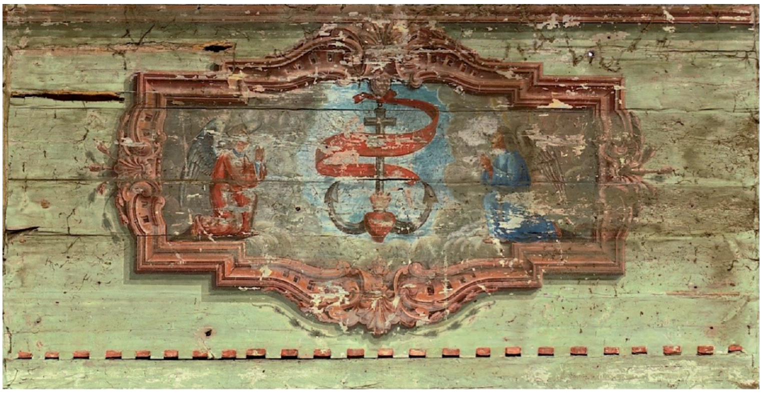
Fig. 7. Final result of generating the orthophotoplan of the painting

Source: Authors' own study

Fig. 8. Orthophotoplan of the wall painting obtained with the camera

Source: Authors' own study

Fig. 9. Orthophotoplan of a wall painting obtained with an UAV



Source: Authors' own study

Fig. 10. Orthophotoplan of a wall painting acquired from an UAV

The results of the research work, presented in the form of orthophotoplans, are consistent with the results achieved in the works of, among others, the team of Torres-González [2022] or described by Boroń et al. [2010]. The resolution of the studies, at 1mm/pix (and higher), is a value generally accepted by photogrammetrists for the preparation of this type of documentation [Rzonca 2004, Boroń et al. 2010, Torres-González 2022]. Polychrome inventories of historic buildings using photogrammetric methods provide an excellent source of data for this type of object. Such studies are particularly important for sites for which these types of measurement methods provide a non-invasive way to obtain comprehensive information about the monument object as well as the polychrome in it [Bednarz et al. 2016, Orłowski and Tunkel 2022].

5. Conclusions

Based on the results of the fieldwork and the carried out research, the thesis put forward in numerous scientific studies that photogrammetric methods are an excellent source of data for the inventory of historic objects, including polychromies, has been confirmed. This is because they offer a non-invasive way of obtaining information about the object, while maintaining high accuracy (resolution) of the results.

Photogrammetric studies (orthophotoplans) can be performed using both digital images taken with professional cameras and images from a camera on a platform of an unmanned aerial vehicle. While paintings on walls or low ceilings can be registered with ground-based photogrammetry, polychromes located at higher levels (high and difficult to access places) can be reliably inventoried on the basis of images taken by drones.

Based on high-resolution DSM models, it is possible to produce high-resolution photogrammetric studies, made for resolutions equal to and higher than 1mm/pix. In addition, using a point cloud obtained by scanning with a terrestrial laser scanner and by extracting the coordinate values of the registered characteristic points – distributed on the polychrome – it is possible to give to the generated study a precise and real shape, size, and scale. Orthophotoplans prepared in this way are a faithful representation of the polychrome, ensuring at the same time their accurate and comprehensive inventory.

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