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Photogrammetric reconstruction software as a cost-efficient support tool in conservation research

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Abstract

A crucial activity in architectural and archaeological conservation research is the process of synthesising information in which the researcher records collected field data in the form of a planar drawing. This labour-intensive stage is significantly improved by automated systems which support the measurement work. Some of these are programs that convert sets of photographs into virtual and spatial models.
The author compares the reasonably priced software options, shares the experience which was gathered during their use and presents the results of the research. The paper also presents the economic aspect and practical examples and highlights the development potential of these tools.

Keywords: measurements, conservation research, photogrammetry, 3D scan

1. Introduction

Photogrammetry is a technique that can be used to perform measurements based on photographs. It has long been used by cartographers to prepare maps. However, in the last decade, automated methods of computer-aided analysis of extensive collections of photos have been well developed and have been made more accessible. The most spectacular examples of this use are Google Maps and Google Street View. They combine LIDAR scans, satellite imagery and photogrammetric mapping to obtain spatial models. Such techniques are often used by film studios and computer game developers (RealityCapture, 2020). In addition to the obtaining of photorealistic representations of a location, methods of spatial analysis of images are used to capture the dynamics of movements of characters. Even the actor's facial expressions can be transferred into the digital dimension (Agisoft, 2020). This technology can also support robots on production lines and autonomous vehicle driving systems.

This futuristic technology is now within the reach of every designer and researcher. It allows full utilisation of the potential of the available equipment and also facilitates and accelerates documentary fieldwork. It enables the reduction of the costs incurred by such tasks. Over the past few years, the tools have become significantly improved and much more user-friendly. The advancement of developed algorithms (Snavely, Seitz and Szeliski, 2006) and access to increased computing power is reflected in the comparison examples presented in Fig. 1. The first author's point cloud, done in 2010, was used as an underlay to prepare the chronological stratification of excavated walls of the Kruszwica Castle basement (Małachowicz and Karnicki, 2010) (Fig. 1c). The last part (Fig. 1d) shows the results of a recalculation of the previously used photoset in the currently used software (Agisoft, 2020).

Point clouds are commonly associated with costly and specialist appliances. The cost of equipment and the short-range laser scanners used in a mapping is considerable[1]. It often exceeds the financial capabilities of non-specialised operators. The technology of budget optical scanners[2] is still underdeveloped. There are noticeable limitations of the software and processing power of popular hardware to use them widely. There is still no consistent processing system and no easy to use tools to manage the datasets available to ordinary users.

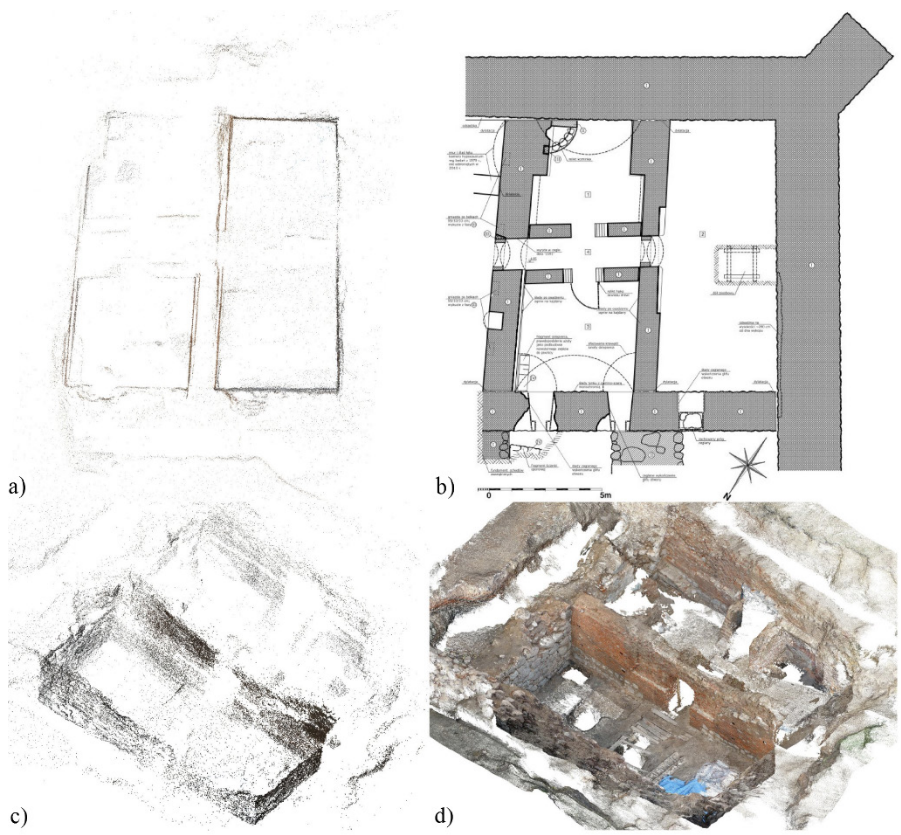

Fig. 1. Kruszwica, Castle, a fragment of the palace cellars excavated during archaeological works in 2010 (Małachowicz and Karnicki, 2010); a) photogrammetric reconstruction (Microsoft PhotoSynth) of the basement projection; b) inventory drawing with chronological stratification of the walls; c) isometric view of the excavation area – a point cloud (about 65,000 points) made from 136 photos (4 Mpix) created in 2010 with Microsoft PhotoSynth, calculation time was approx. 4 hours; d) isometric view of the place – point cloud approx. 4.5 million points, an comparable set of photographs, created in 2017 with Agisoft Metashape software, calculation time was approx. 10 min

[1] The cost of a laser scanner varies. It depends on type and range. The entry handheld SLAM-based 3D solution is priced at around €16,000 (Leica BLK360) or mobile LIDAR mapping at $40,000 (Paracosm PX-80).

[2] The cost of simple optical short-range or SLAM scanners is in the range of $500 to $3,200, e.g. Google Tango, Structure Sensor, Kinect, Matterport etc.

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The availability of parallel data processing tools[3] on graphics processing units (GPU) has stimulated the development of methods for the processing and analysis of large image sets[4]. This is used by modules supporting computer aided design (CAD) software[5] or software specialised in photograph processing[6]. The cost of specialised, commercial software, although lower than hardware solutions, often exceeds the budget of smaller projects[7]. A possible solution is to temporarily rent software or the computing power of remote data centres[8].

However, it is worth noting, there are several much less advertised programs that allow improving one's workshop for a low-cost or practically cost-free. These tools have been created within research centres[9] and organisations[10] supporting innovative solutions within the context of open-source software and crowd-funding. There is also a set of three open-source tools such as Bundler, PMVS and CMVS (Bundler, 2020), which are integrated into OpenMVG (OpenMVG, 2020) and VisualSFM (Wu, 2013; Changchang Wu, 2020). Another solution, which is the most complete, is the AliceLabs Meshroom (AliceVision, 2020), which is also available as open-source software. Until 2015, the community was developing the operational system ArcheOS (ArcheOS, 2017). It was based on Linux (Debian) and supported the preparation of archaeological documentation with some CAD, geographic information system (GIS) software and simple photogrammetric applications.

2. Generals and practical hints

Two devices are required to perform a photogrammetric reconstruction: a camera and a computer to run the chosen software. Additionally, the coordination of geodetic measurements or LIDAR scans can also be used to improve results. Practice shows that for research and design purposes, it is sufficient to perform linear scaling measurements. This allows for preparing a proper underlay. Linear scaling measurements should be taken between the most distant and marked points of the site.

The camera should record images that are as sharp and detailed as possible. The optical resolution has an impact on the effective range of the scan and the accuracy of the match. The best results in terms of the number of images and the effective range were obtained using a digital SLR with a wide-angle lens with a focal length of 10–20 mm (the equivalent of 15–30 mm for a full-frame). This does not exclude telephoto lenses nor mobile cameras. The digital photo should be as unprocessed as possible. The image EXIF metadata where the lens settings are recorded enables the software to calculate an accurate estimation of the camera location. Distortion correction of images performed in photo editors may result in errors during the model building. Perfect complements to the terrain photos are those taken from a mast or drone. They make it possible to document a geometry that is out of sight from the ground level.

The process of using photogrammetric software is realised in successive steps. Initially, the user uploads a set of collected images to the program.

3 The software uses the Nvidia CUDA (CUDA, 2017) or OpenCL (OpenCL, 2013) libraries.

4 The next step in the development of 3D mapping technology are tools that utilise the advantages of neural networks and artificial intelligence in image recognition.

5 Ex.: Bentley ContextCapture (ContextCapture, 2020), Autodesk ReCap (ReCap, 2020).

6 Ex.: Agisoft Photoscan Pro (Agisoft, 2020), RealityCapture (RealityCapture, 2020), etc.

7 The license costs for full and PRO versions of software start at around $650 and reach nearly $15,000 with additional technical support.

8 Temporary licenses can be purchased (e.g. Autodesk ReCap (ReCap, 2020) and RealityCapture (RealityCapture, 2020)). With the use of remote data centres, it is possible to use mobile solutions, even a mobile phone, for mapping purposes in the measured site (Locher et al., 2016; ReCap, 2020).

9 It is worth mentioning the people who laid the foundations for the development of the problem of digital image analysis here, they are Marc Pollefeys and Jan-Michael Frahm from UNC-Chapel Hill, and Noah Snavely, Steve Seitz and Brian Curless from the University of Washington.

10 Cooperation and support of the Microsoft Research and the Google Research Center allowed the development of some innovative technologies as the PhotoSynth or Bundler (Bundler, 2020).

In the following step, the program algorithm finds common points between uploaded images, calculates spatial cameras locations and builds a sparse point cloud of the common recognised parts. Depending on the calculation method obtained, dense point clouds or depth maps can be converted into a textured mesh in the next step.

The detail of the reconstructed object may reflect the texture and roughness of the surface (Fig. 4). A 3D printed model may be based on this data. The possibility of applying material colours to the mesh perfectly reflects the real state of the object (Fig. 5). As a result of this, perpendicular projection (orthophotography) can be applied as a useful drawing underlay for detailed vector drawings or standalone inventory documents.

To properly prepare the reconstructions as accurately as possible, it is necessary to adhere to some essential guidelines (Agisoft, 2020):

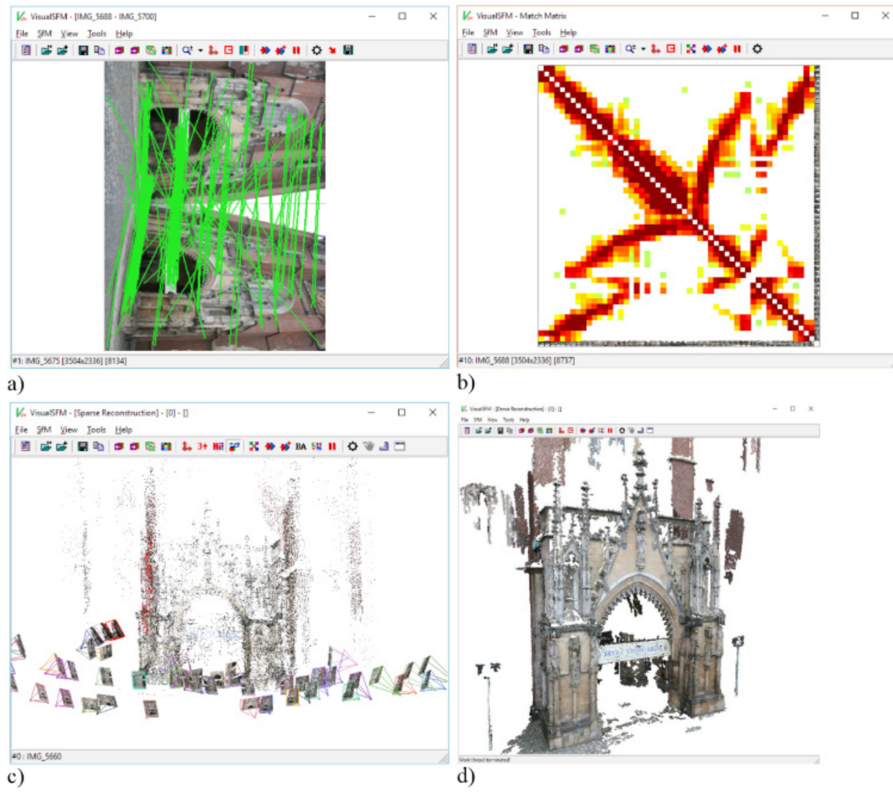


Fig. 2. Illustration of following photo reconstruction steps – VisualSFM (Changchang Wu, 2020); reference site – main western portal of St. John the Baptist Cathedral in Wrocław: a) visualisation of connections between recognised characteristic points of two matching images; b) matrix which shows relations grade between individual frames (bronze – best fit); c) spatial location of cameras stands and a sparse point cloud of characteristic points of the shots; d) dense point cloud obtained using CMVS+PMVS modules (approx. 4 million points, calculation time 3 hours, 2015)

- Sequential movements of the camera position between shots are essential. The recommended deviation should not exceed 15° to maintain optimal overlap.
- Frame coverage of about 80% ensures a high accuracy of the reproduction. The author suggests that a particular plane on each side of the object's corner should be registered with a minimum of five photos each in order to reduce the "noise" effect[11].
- It is recommended to use one camera and keep the focal length fixed within the photo set. This significantly reduces the possibility of deformation accumulation and mismatches from optical distortions. The correct results can be obtained from objects of an irregular texture and shape[12].

Computer hardware dedicated to run this specific software is similar to that which is typically used for gaming or 3D modelling. A dedicated Nvidia graphics card is recommended because most of the programs use the hardware acceleration of estimations based on CUDA libraries(CUDA, 2017). ATI cards only support calculations based on OpenCL(OpenCL, 2013), so the availability of software is limited[13]. A vital element of the system is the storage capacity; this is due to the significant number of photo files and even more sizeable result models.

[11] Two is the absolute minimum number of photos. However, there is a high probability (certainty) of the occurrence of geometric deformations.

[12] For smooth, homogeneous, transparent or glossy surfaces, it is advisable to use markers to reduce misalignments. Non-inventoried objects, such as moving people or vehicles, should be excluded from the frame. Trees in the foreground should also be cropped or masked to save processing power and memory.

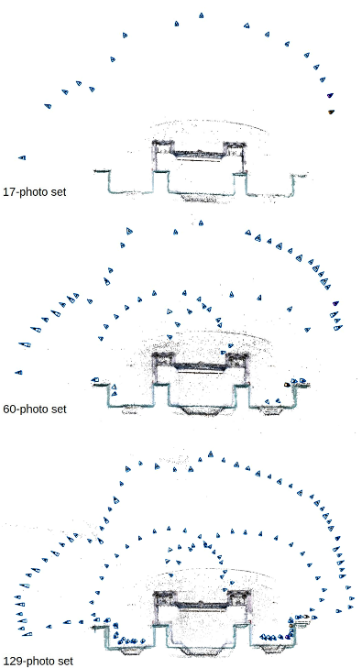
[13] Agisoft Metashape (OpenCL, 2013; Agisoft, 2020) works on ATI and MacOS cards among the tested programs.

3. Review of photogrammetry software

Most of the compared programs are capable of performing complex tasks, from the initial matching and adjustment to the export of final models and orthophoto maps. Some of the programs have extra features that make them more attractive for a specific group of recipients. The performed analysis of selected programs aimed to identify cost-friendly systems supporting the preparation of conservatory documentation and supporting the architect in the process of making measurements or design underlays. The presented comparison was prepared in September 2019 (Karnicki, 2019).

Photographs were captured with a Canon EOS 30D camera; Sensor size APS-C (22.5 x 15 mm), 18 mm lens, resolution of 8 Mpx. Photos were saved directly as JPG files. Reconstructions were computed on a moderate PC[14] – CPU – AMD 1600, 32 GB of RAM, GPU – Nvidia GTX 1080, 8 GB of VRAM, (estimated value of the computer was ~3,500 pln).

The software was selected and evaluated in terms of availability, affordability, technical support, relative user-friendliness and the degree to which the results were satisfactory. Three sets of outdoor photographs from a demanding location were chosen. They simulated a variety of site conditions. The sets were prepared according to the following specifications: the main set of 17 photos shows the general situation; the extended set of 60 photos contains an additional walk around; the full set of 129 photos that were enriched with close-ups (Fig. 3). It allowed the preparation of a calculation speed test to compare the size and quality of the computed models. The obtained results were additionally visually evaluated (Figs. 4 and 5). The final results were summarised in comparative charts and tables (Fig. 3). Differences between the software in calculation time depending on the size of the input data sets and the preferred quality are presented.



The benchmark results

software name / computed photos / settings	point cloud [Mp]	textured model [Mf]	cumulated computing time [s]
Agisoft Metashape / 17 / Medium	1,6	0,3	234
Agisoft Metashape / 17 / High	6,4	1,0	575
Agisoft Metashape / 17 / Ultra	27,7	4,2	2005
Agisoft Metashape / 60 / Medium	3,8	1,0	776
Agisoft Metashape / 60 / High	20,3	4,2	2434
Agisoft Metashape / 60 / Ultra	58,2	17,4	12188
Agisoft Metashape / 129 / Medium	7,0	1,3	1639
Agisoft Metashape / 129 / High	39,0	5,1	5663
Agisoft Metashape / 129 / Ultra	128,0	23,0	26967
Autodesk ReCap Photo / 20		1,5	2400
Autodesk ReCap Photo / 100		4,4	9000
Meshroom / 129 / Normal		3,3	4011
Meshroom / 129 / Custom		9,8	14400
RealityCapture / 17 / Normal	1,1	3,3	192
RealityCapture / 17 / High	6,5	13,1	554
RealityCapture / 60 / Draft	0,19	0,38	175
RealityCapture / 60 / Normal	4,9	9,9	581
RealityCapture / 60 / High	19,5	39	2100
RealityCapture / 129 / Normal	7,5	15	1135
RealityCapture / 129 / High	29,5	58,9	2468
3DF Zephyr Free / 50 / normal	0,57	1,1	1366
3DF Zephyr Free / 50 / Custom	10,7	4,6	4936

[Mp] - millions of points
[Mf] - millions of faces

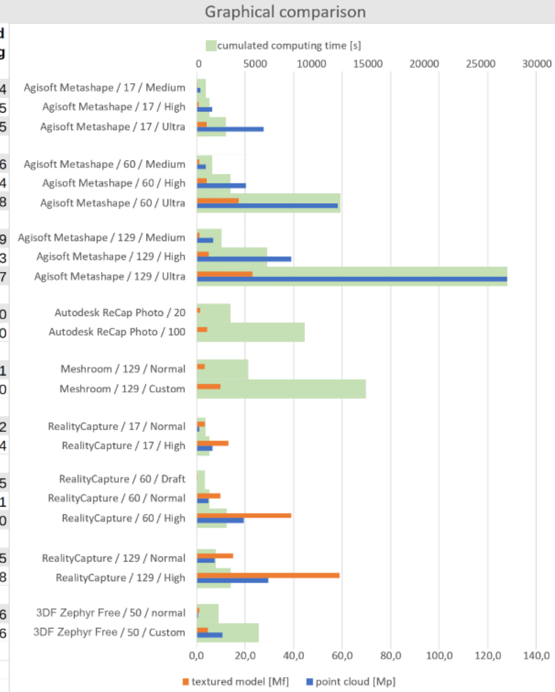


Fig. 3. Benchmark results – three photo sets were prepared: 17, 60 and 129 pictures. As a reference object, the author chose the western portal of St. John the Baptist Cathedral in Wrocław. The locations of the camera stands are shown on the illustrations on the left. The effects and timings of different default settings were compared within the programs. The graph on the right graphically presents the results. Navy blue shows the size of the obtained point cloud [Mp], orange shows the complexity of the mesh model [Mf] (the longer bar, the bigger model). The green bar in the background shows the total computation time (the shorter the bar, the faster the computation). Used units: [s] seconds, [Mp] million points, [Mf] million faces

[14] The author would like to thank the Autorska Pracownia arch. Macieja Małachowicza for support and access to archival documentation and hardware resources used to prepare this publication.

General summary of the tested software features:

OpenSource software:	
Meshroom (AliceVision, 2020) (OpenSource (Mozilla, 2020), the licence allows commercial use)	This has a simple default computation process. The program allows tweaking and the use of additional modules. The final effects are a little worse than Agisoft Metashape. The program allows for obtaining textured 3D models. Points clouds are storied in the Alembic file format (*.abc). The program is storage space-hungry (a project of ~300 photos can take > 50 GB). The complete open-source solution is available at no cost and offers surprisingly good results. Further post-processing of 3D models is possible in MeshLab or CloudCompare (CloudCompare, 2020).
Commercial software:	
3DF Zephyr (3DF Zephyr, 2020) (Free (3DF Zephyr Free, 2020) – for personal use, 50 photo limit; Lite-€149 (500 photos), Pro €2,400)	The program is relatively easy to use. The quality of the textured mesh model is average (similar to Autodesk ReCap photo level). It can also be used as a 3D model viewer. 'Lite' version is an acceptable deal.
Agisoft Metashape (Agisoft, 2020) (Standard – $179, Profesional – $3,499)	Both versions were compared, and no significant differences were noted in the speed and accuracy of calculations. The pro version supports the use of markers that improve the speed and accuracy of image matching, alignment with geodetic data and wider export formats. The deviations do not usually exceed 0.5%. There is a batch process option. Smaller chunks can be matched and merged. The user can use pre-edited models. Occasional geometry mismatches and texturing errors appear. The standard license is a satisfactory choice. Updates have not yet been limited to a one--year support period.
Autodesk ReCap Photo (ReCap, 2020) (rental price: 214.51 pln per month – 1,798.54 pln per year)	This tool is dedicated to integrating laser scans with a photographic and reconstructive part. The program performs calculations on remote servers. It recognises general planes and edges well and correctly sets the initial scale of the object. The positioning and measuring tools work satisfactorily. The results are comparable to the 3DF Zephyr. The number of processed images is limited to 100.
RealityCapture (RealityCapture, 2020) (rental price one month – €175, one year – €1,743, permanent €2,800–15,000, optional PPI licence – paid per input ~€49.90 for 1,000 photos, 20 Mpx)	The program is easy and intuitive to use. Detailed options allow for quality improvement. It is extremely flexible and effective. Excellent results can be achieved even with a small number of photos. It computes large sets of even over 100,000 photos. Laser scans can be integrated with photogrammetry for accurate metric correction. The quality of the obtained models exceeds the quality of laser scans known to the author. This is the absolute leader in terms of processing speed and obtained results.

The achieved structure and textures show the complexity of the process and effectiveness of algorithms at particular stages. The output results are shown below in the comparative illustrations (Figs. 4 and 5).

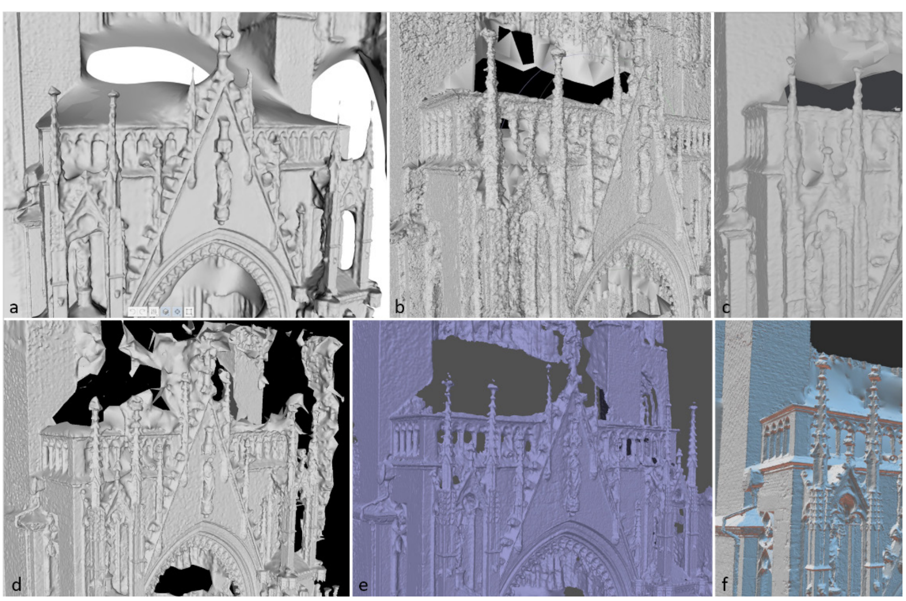


Fig. 4. Comparative comparison of texture--free meshes to judge the quality of geometry representation – all models are shown in the highest quality offered by the software: a) Autodesk ReCap Photo – good representation of wall planes but some simplifications in the perforation area; b) Meshroom, mesh before optimisation, good visible detail and significant noise; c) Meshroom, mesh after denoising process, visible loss of geometry detail; d) 3DF Zephyr Free, good quality mesh with good detailing; e) Agisoft Metashape, a high-quality mesh with a good detailing and perforation coverage – at the uprights there are some detailing problems but captured profiles and wall material texture are recognisable; f) RealityCapture, perfect reproduction of geometry and complexity of the detail where small-size elements are also shown

Programs vary in results and processing times. Increasing the set of images and the preferred quality of the final result leads to an exponential increase in the calculation time. In the described situation, an optimal set of photos for making "fast" models was used. The set of 100–150 images allows

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Fig. 5. Comparison of selected fragments of orthophoto maps of the western elevation of the portal: a) Autodesk ReCap Photo, visible distortions within complicated geometry and significant deformations around perforations; b) Meshroom, certain visible imperfections of geometry caused by high noise reduction parameter and "ghosting" imperfections of texturing; c) 3DF Zephyr Free, problems with perforated and eclipsed elements; d) Agisoft Metashape, correct geometry mapping, minor texture distortions and occasional ghosting in multi-plan situations; e) RealityCapture, great mapping, minor problems with small perforations, credible completion of hidden geometry

inventorising a somewhat complicated room or a small building. Documenting larger targets requires more resources and time. To select the optimal strategy, the author recommends dividing the photo-making routes into overlapping sections/loops.

4. The utilisation of results

Point models better reflect the geometry in space than meshes, due to the independence of the dots that form them. Greater or lesser noise within the measured area indicates the estimation accuracy. Moreover, due to the inter-point spaces, X-ray-like projections are possible. This method allows use of such underlays as a good base for routing the geometry of the plans and cross sections of the building or its investigated part.

Photogrammetric imaging methods, in comparison to laser scanning, allow obtaining dense clouds at a significantly lower cost, even from hard to reach areas. Dense point clouds can also be used as a reference for façades. However, projections of a textured mesh model without perspective deformations provide

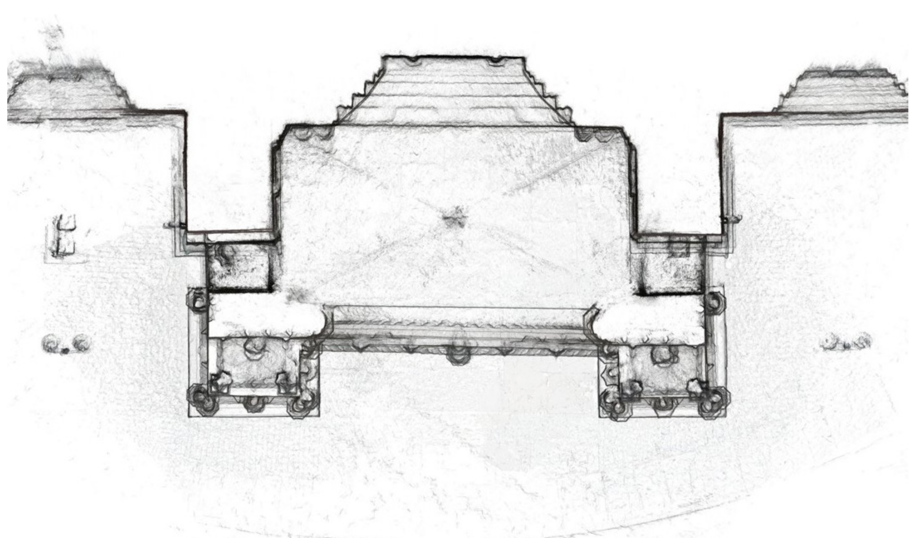

Fig. 6. Wrocław, St. John the Baptist Cathedral, an example of using a point cloud as a semi-transparent underlay for plan drawing (by author, 2019)

the chance to obtain an even higher resolution of a referential underlay image. The highly detailed façade views are an excellent basis for preparing the chronological stratification of walls. They make it easy to trace the location and type of phase contacts investigated. This method reduces the investigator's effort in preparing an accurate representation of the complexity of the building's structural transformation (Fig. 7).

The quality requirements are also essential for the results of the research publication. Maintaining the readability of the plans is crucial. The choice of

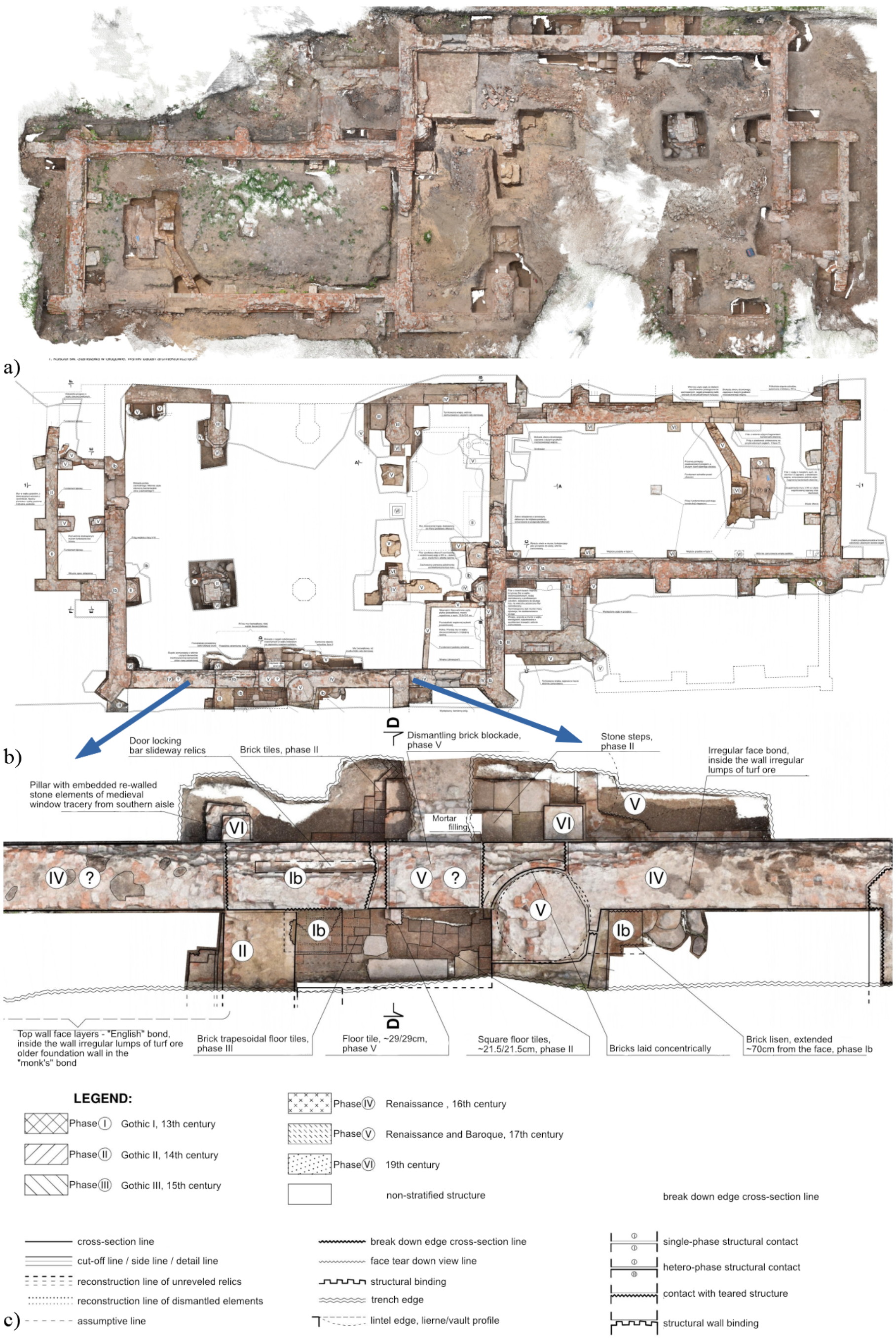

Fig. 7. Głogów – ruins of the foundation of St. Stanislaus Church (Małachowicz et al., 2017; Karnicki, 2018): a) the raw photogrammetric reconstruction image of the archaeological excavation, site size about 54 x 23 m – set of 740 ground level photos, Agisoft PhotoScan, calculation took approx. 14 hours, point cloud ~78 Mp, 2017; b) measurement drawing of the relics with chronological stratification of the walls – it uses the exported raster as an underlay; c) fragment of the drawing that shows used markings, descriptions and legend

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the input data should depend on the expected final effect. Three-dimensional models often contain much more information and are more accurate than can be transferred to the printed paper version. Achieving a high resolution where 1 pixel corresponds to 1 mm of the real object is easy and depends only on the quality of the input photo documentation. It enables the preparation of high--quality drawings. Difficulties occur during the printing process in situations in which the image contrast or the resolution of the printer is insufficient. Colour reproduction demands expensive photo papers and better inks, and they significantly increase documentation costs.

The clear connection of a schematic drawing with a raster underlay is a significant challenge. Adequately contrasting drawing makes it possible to maintain readability. It is recommended to adjust the resolution and size of the used markings to the output scale of the prepared drawing. In general, there are three types of marking and labelling: descriptive, hatches and edges. The size of descriptions and line types should match the scale of the drawing. In the case of surface markings (hatches) used with a raster background, both 1:50 and 1:200 scale drawings would be readable when surfaces are highlighted with a tinted colour or coloured hatch. This allows for a translucent effect. Edge markings of phase contacts with excellent print quality remain visible at < 1:100 scale (Fig. 7c). On a picture less than 1:200, it is reasonable to limit contact markings to the main building elements relevant for the described area.

The growing popularity of electronic publications allows the more liberal placement of high-resolution plans or vector drawings. This enables the recipient to enlarge the chosen fragment freely. Photogrammetric reconstructions will enable the preparation of three-dimensional objects, which can be described in a qualified manner and attached to the publication in the form of an interactive 3D illustration (Acrobat, 2020). This method allows free enlargement, rotation and even taking measurements of the spatial model[15].

5. Observed limitations and proposed solutions

Various cameras were used during the implementation of the photogrammetric enhancements. Practice shows that the optical resolution of the photos taken affects the quality of the models and the effective scan range and resolution. A decent cellular camera (~12 Mpix) allows the obtaining of a reasonably detailed reconstruction of facades of up to 4–6 m high and yield reasonably accurate geometries up to a distance of 25 m. A DSLR camera (~24 Mpix) with a sharp lens allows doubling the effective range preparation of a good base for a tower helmets model (Łuniewicz, 2017). Lenses with a wide field of view are key for easy scanning and reducing the number of images that are necessary to compute. The author points out that a lens in the range of a focal length of 15– 30 mm (the equivalent of full-frame) is the most effective[16].

Smooth, monochromatic surfaces, which are texture-free, transparent or reflective, are a severe challenge for the mapping algorithms and cause misalignments. In such cases, it is necessary to apply a temporary texture or put other markers on the measured surface. In challenging situations, a wide lens is the best ally. Its broader field of view allows the capture of more edges of geometric planes.

The obtained models sometimes need to be adjusted in other applications. The commercialisation of the software has resulted in a significant selection of tools with a wide variety of features. The PRO versions, in most cases,

[15] The chance to view 3D content in *.pdf files except the leading browser (AcrobatReader) is quite limited because of the complicated 3D file preparation process, which often requires the use of third-party software.

[16] Almost any imaging device captures useful photos. However, the quality of the output models depends on its optical resolution and not being processed (straightened). The author used images obtained using a low-end Chinese drone (from 1 Mpix), various mobile phones with cameras, popular handheld cameras, and a high-quality DSLR (24 Mpix photos).

provide better accuracy by combining photo scanning methods witch verifying markers, geodesy tools and laser scans. Nevertheless, the potential of the basic software is sufficient for the researcher's daily work, for documentation of the archaeological site or the facade articulation.

All programs can quite accurately determine the position of the surface using more than three photos as a minimum. In places where information is insufficient, it is possible to observe some imperfections as bumpy or distorted surfaces. Doubling the amount of the images can also eliminate some reconstruction weaknesses caused by sensor noise or compression artefacts. The software cannot correctly build a model from insufficiently documented or undocumented areas[17].

Sometimes the accuracy of scans may provoke some complaints. The used method does not release the investigator from critical evaluation and the possible verification of errors. When photographic documentation is unreliable or blurry, mismatches can be challenging to avoid. To verify the model, check measurements performed between characteristic points should be simultaneously recorded. It is advised that any distances relevant to the construction of prefabricated elements be separately checked with appropriate tools. In cases requiring extraordinary accuracy, the photogrammetric reconstruction could be used to complement the context conditions.

A routinely applied photogrammetric measurement enables reaching a level of precision of the measured distance (between planes) of 99.9% (±1 cm / 10 m). This accuracy is noticeably lower than that of a laser scan, but for conservation investigation purposes, for drawings at a scale of 1:50 or even 1:20, it is sufficient. The observed deviations usually occur within the edges, thin bars or perforated elements. The specific behaviour of the presented systems proves that they base more on analysing the textured surface of an object than on plane detection or edge adjustment.

The need for higher scan resolution increases the need for computing power. The computer should have more memory, an even faster CPU and a stronger GPU. The need for calculation time increases exponentially with the number of processed views. Therefore, it is recommended to divide the model into smaller chunks. For optimisation purposes, it is recommended not to exceed 300 photos limit for each section loop to rationalise processing time.

6. Summary

The basic application of the photogrammetry method is easy due to the fact it is based on existing equipment. The software allows revealing its enhanced value.

The methods shown can be used in a variety of documentation processes, from a small detail, like a stove tile reconstruction and its 3D printout, to a large scale urban complex analysis (Klingner, Martin and Roseborough, 2013; Rahaman and Champion, 2019). Archaeologists can easily document and visualise the progress of excavation work. It allows them to "go back" to a virtual location reconstructed from previously made photographic material.

The portability of the measuring device allows documenting places that are difficult to reach or even immeasurable with more expensive, stationary hardware. It also significantly reduces the time and costs of site inventory work.

However, it is wise to remember specific tool limitations. The shown method, despite its extraordinary usefulness, does not release the researcher from thinking at every step and does not replace the work of a draftsman. It is only a helpful tool that allows the significant improvement of the research techniques.

[17] In the step where the 3D model is constructed, the program algorithm must calculate some averages and occasionally try to estimate the location of inaccessible surfaces. Sometimes such misalignments may cause bubbles or geometry distortions on reconstructions. Spatially complicated solids with a large amount of perforations are a serious challenge.

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Programowa rekonstrukcja fotogrametryczna bliskiego zasięgu jako narzędzie wspierające w badaniach konserwatorskich

Streszczenie

Kluczowym działaniem w badaniach konserwatorskich architektonicznych oraz archeologicznych jest proces syntetyzowania informacji, podczas którego zebrane dane terenowe zapisywane są w postaci płaskiego rysunku. Ten pracochłonny etap można znacząco usprawnić, wykorzystując zautomatyzowane systemy wspomagające prace pomiarowe. Wśród nich są programy przetwarzające zbiory zdjęć na modele przestrzenne.

W niniejszym opracowaniu autor, bazując na przeprowadzonym porównaniu dostępnego oprogramowania i doświadczeniach zbieranych w trakcie jego stosowania, przedstawia efekty wykonanego rozpoznania, ekonomiczne i praktyczne wskazania użytkowe oraz zwraca uwagę na potencjał rozwojowy stosowania tych narzędzi.

Słowa kluczowe: pomiary, badania konserwatorskie, fotogrametria, scan 3D