GEOMATICS AND ENVIRONMENTAL ENGINEERING • Volume 17 • Number 1 • 2023

https://doi.org/10.7494/geom.2023.17.1.35

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Verification of the Wołek Castle Model with the Actual State Using Digital Photogrammetry and Conventional Survey Methods[4]

Abstract: This paper presents the results of a study to assess the feasibility of using the Structure from Motion photogrammetric method to estimate what parts of Wołek Castle have survived from the 15th century to the present day. The photogrammetric measurements were made with a Nikon D5200 camera, and 249 mock-up images were obtained. Planimetry and altitude coordinates of the castle ruins were obtained using RTN GNSS measurements and the polar method. The measurements were made in the 2000 coordinate system in zone 6, the heights were obtained in the Kronstadt system. Two spatial models were made. The first one in the field scale was made using the ground control points measured in the terrain. The second one was made using ground control points measured on the model in the local system. The control measures were analyzed, the model compared with the actual orthophotomap, and it was estimated what part of the castle was preserved in reality.

Keywords: 3D model, SfM, survey measurements, Wołek Castle, history time

Received: 25 June 2022; accepted: 5 October 2022

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[4] The article was prepared under the research subvention of the AGH University of Science and Technology No. 16.16.150.545 in 2022.

1. Introduction

In recent years, public understanding about the value of history monuments has increased profoundly. By definition, a monument is material evidence of history in its broadest sense and it conveys knowledge of the times when it was created: about the culture of that period, achievements in art, science, and economy. It is a memorial of everyday life, but also a document of unusual events. This has important value for us in shaping our identity and aesthetic sensitivity, values we are obliged to pass on to future generations [1]. Therefore, the inspiration for this study was the remains of a medieval castle located in southern Poland. The current condition of the ruins is catastrophic, but it is worth preserving even small parts in their original state for future generations. In 2008, thanks to archaeological and historical research, the potential appearance of the castle from the 15th century was reconstructed. Consequently, Wołek Castle was visualized in the form of a mock-up which is now kept in the Aleksander Kłosiński Museum in Kęty in the Małopolska province. As mock-ups are, by definition, models made on a reduced scale, it was assumed that the model was made in this scale and that it would be possible to assess the damage and remains of the castle. The attempt to meet the assumptions was possible thanks to the use of modern measurement methods, where the research was based on acquiring a point cloud from the dense matching of images of the mock-up and field coordinates from measurements using the RTN GNSS method and the total station method.

2. 3D Model Acquisition

3D models can be acquired by numerous methods, starting from photogrammetric measurements using the dense photo matching technique [2–6] on which this paper is based, to terrestrial laser scanning of the object [7–11], to manual modelling of the objects [12, 13] we want to obtain. However, a question remains concerning the purpose of the acquisition. This is generally held to be that the obtained products facilitate interpretation, compared to two-dimensional studies, especially for people who struggle with spatial vision (stereopsis). Moreover, they faithfully reflect the surrounding reality, allowing the preservation of the appearance of objects that change over time. They also provide variety in viewing data by a potential recipient. A perfect example here is the Google Earth portal, which provides three-dimensional models of individual buildings and even entire cities, while allowing the user to add their own. Many such projects are still being rapidly developed, e.g. Geoportal 3D. Studies and projects of this type are a very good example of where technological and visualization development is heading. Three-dimensional models are the future in many professional fields, as well as in use in everyday life.

An inexpensive photogrammetric method that enables the representation of a 3D model is Structure from Motion (SfM) [2]. This method allows the reconstruction of a three-dimensional object based on a network of images taken at different distances and from different viewing angles (Fig. 1).

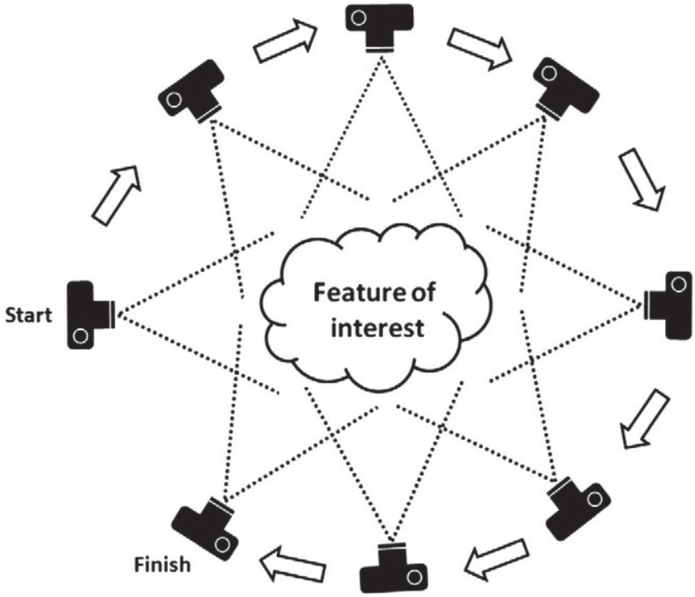

Fig. 1. The basic principle taking images in the method Structure from Motion

Source: [2]

The principle of performing the measurement is similar to the stereometric method, but it is not based on only two images, but requires taking several images around the object. Strictly speaking, SfM algorithms aim to generate 3D models of the scene (sparse point cloud), based on the orientation elements of the internal parameters of the camera (focal length, principal point) and camera external parameters from a set of overlapping images. The following steps can be distinguished in these methods. The first one is the selection of characteristic points, i.e. binding (homologous) points on adjacent images. The Scale-Invariant Feature Transform (SIFT) method [4, 14] or the VLFeat method [15] is often used. These points are used to relate images, which are added iteratively, to each other. The resulting camera parameters describe the spatial alignment of the images and a sparse point cloud. Then, with the camera parameters fixed, the dense 3D point cloud can be estimated using a process called Multi-View Stereo (MVS) or using the CMVS (Clustering View for Multi-View Stereo) or PMVS2 (Patch-based Multi-View Stereo) algorithm. The resulting dense point cloud preserves the proportions between the object elements, but the dimensions do not have the correct scale. Therefore, when using the SfM technique, additional scaling of the model [2] and georeferencing using photo points is required. A TIN-triangle mesh can be superimposed on such a cloud, and then rendering can be performed. This whole process makes it possible to faithfully obtain a digital 3D model.

The aim of this study was to make a spatial model based on the model of Wołek Castle and verify it with the actual state.

3. Study Area

The castle ruins which are the subject of this research are located in southern Poland in the Silesian Voivodship, Bielsko County, Porąbka Commune. The ruins of Wołek Castle are located in the picturesque village of Kobiernice on a mound, which is a naturally formed hill. The remains of the walls are a reminder of the existence of the only medieval fortress in the Beskid Mały. The exact location is shown on a map of Poland (Fig. 2).

Fig. 2. Location of the ruins
Source: Google Maps – Ruiny zamku Wołek [15.09.2022]

3.1. Historical Overview of the Castle

Construction was begun in the mid-14th century by Jan I Oświęcimski. Wołek was located in an exceptionally strategic place. The small castle, built as a border watchtower, played a very important role – it secured the southern and western borders of the former Duchy of Oświęcim, thanks to the narrow passage of the Soła River through the Beskid Mały mountain range. Moreover, thanks to its location on a hill, it was possible to control the trade route which ran along the foot of the mound – leading through the Żywiec Valley all the way to Hungary. Another, no less important aspect was the visibility between Wołek and the castle in Oświęcim, which was an extremely important fact for the dukes of Oświęcim. The castle was located in a hunting area, which at that time was a great advantage and made it easier to find food, among other things [16].

Wołek had a short, but very turbulent history. Even though seemingly it was only a small castle, it remained unconquered for a long time. This testifies to its excellent location and fortification and very good defensive potential. It was only after 1456 that the then owner Jan I Oświęcimski decided to sell the principality of Oświęcim to Kazimierz Jagiellonian. Thanks to this agreement, Wołek Castle became the property of the royal army. In later times, it passed through several owners, including the dukes of Cieszyn.

It is impossible to determine a clear date of the end of the castle's existence. Most probably it was demolished in the second half of the 15th century, then for many years fell into ruin and was plundered by local residents for building material. The Jagiellonian dynasty ruled in Bohemia and Hungary, so there was no real threat from that side, meaning that the castle lost its function.

It was not until the second half of the 19th century that archaeological research was carried out and the ruins of the castle were discovered. The credit for this project belongs to Stanisław Tomkowicz, the owner of Kobiernice at that time. Thanks to this research, information was obtained on the general outline of the castle, the layout of the surrounding walls, towers and gates, a well was discovered on its grounds and the dimensions of the various elements of the castle were known. During the excavations many fragments of ceramics and weapons were found. Currently, the exhibits can be seen in the collections of the museums in Kęty and Bielsko-Biała [16–20].

3.2. Characteristics of Terrain and Remaining Ruins

The mound on which the castle ruins are located is a naturally formed hill, the top of which, according to some sources, was leveled for construction purposes. Today, the area is heavily forested; only the top of the mound is clearly visible from the surrounding mountain ridges because there are almost no trees growing on it (Fig. 3). Wołek Hill is also very well visible from, among others, the Soła River valley because it is a characteristic single hillock lying on the eastern slope of Bujakowski Groń (Fig. 4).

Fig. 3. View of the mound from the Soła River valley

Fig. 4. The view of the mound from the perspective of Bujakowski Groń

Thanks to the archaeological investigations carried out, basic information about the castle was obtained, such as that it was built on a quadrilateral plan rounded on the western side (Fig. 5). The castle square can be approximated by a geometric figure with a semi-elliptical shape measuring 30 m × 42 m. Its estimated area is 1250 m^2. At first it was claimed that the castle walls were made of wood, but after a closer examination it turned out that everything was made of stone of local origin and to a small extent of Gothic brick [19].

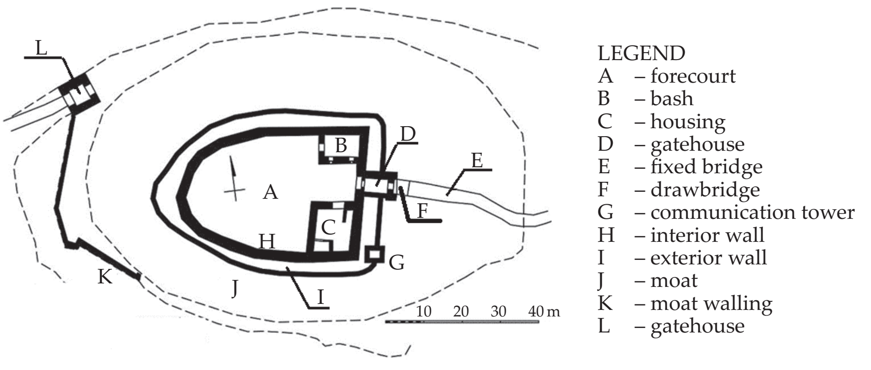

Fig. 5. Approximate location plan of the castle and ramparts
Source: based on [19]

The castle courtyard was surrounded by two rings of walls. On the western side there was also a third, incomplete ring with a tower. The second and third ring of walls was separated by a dry moat surrounding the fortification, which is estimated to have been 3.5–7.0 m deep. Inside the walls there was a tower and a residential building. The main gate and drawbridge faced east (Fig. 6) [21].

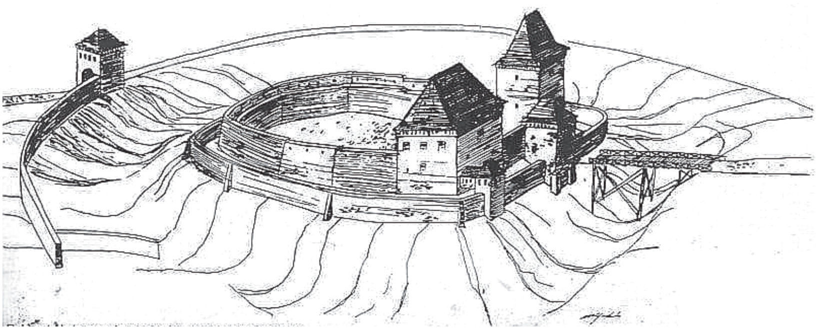

Fig. 6. Drawing reconstruction of Wołek Castle (drawing by Mariusz Godek)
Source: [21]

Unfortunately, the castle ruins are not preserved in a very good condition, and it is not possible to determine the exact location of most of the elements. The best-preserved fragments are the two buildings in the former courtyard (Fig. 7a) and the defensive tower on the western side. Some parts of the walls surrounding the castle and the main entrance to the castle can also be indicated. However, most of the ruins are barely outlined above the ground surface. On the other hand, part of the moat is clearly visible on the Digital Terrain Model acquired from the lidar data of 2012. The acquired dense model with a 0.5 m mesh gives a good representation of the terrain (Fig.7b).

a) b)

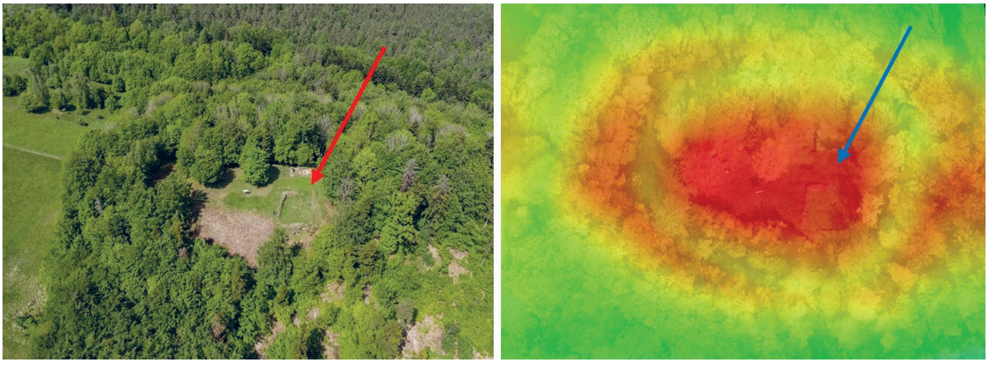

Fig. 7. View of the castle ruins from UAV (a) and orthophotomap with digital terrain model (b)

Fragments of the best-preserved ruins. The following images show the state of the ruins as of October 2021 (Fig. 8).

a) b)

Fig. 8. Current condition of the preserved ruins:
a) tower; b) fragments of the walls of a residential building

3.3. Mock-up of the Castle

The model of Wołek Castle is currently in the collection of Aleksander Kłosiński Museum in Kęty. It was made by the Polish artist D. Szemik in 2008. The dimensions of its base are 0.90 m × 0.60 m and 0.27 m high. There is no precise information about what materials were used in its creation but based on the author's observations, it seems that the base of the model is made of plaster, the walls and buildings of cardboard, and the drawbridge is of wood. The terrain is covered with artificial grass and the castle courtyard with sand. In addition to the buildings, the moat surrounding the walls is also depicted on the model (Fig. 9).

Fig. 9. Model of Wołek Castle in the collection of the Aleksander Kłosiński Museum in Kęty

4. Methods and Measurements

In the present research, an attempt was made to evaluate the actual remains of the castle, with the mock-up model. It was established that the 3D model of the Wołek Castle mock-up generated using the SfM method would be verified with the actual ruins of this object obtained from total station and GNSS RTN measurements.

Therefore, the research work was divided into two stages. The first stage was the photogrammetric measurement of the mock-up using images while the second was the field measurement of the castle ruins.

4.1. Photogrammetric Measurement of the Model

The photogrammetric measurement consisted of taking several hundred images of the model on the museum. The images were taken with a Nikon D5200 digital camera with a Nikkor 18–55 mm f/3.5–5.6 lens. The following parameters of the images were assumed: focal length – 20 mm, aperture – 5.6, exposure time – 1/2.5 s, and sensitivity – 125 ISO. The selection of individual settings was guided by indoor conditions, i.e. low light exposure, the size of the imaging object and the distance of shooting – about 0.5 m from the edges of the model.

The arrangement of all images took the form of a dome. The image started from the lowest row, at the base of the mock-up, and continued around the four sides, and finally the images were taken from the top, so that all elements of the mock-up were accurately imaging with high overlap (Fig. 10). A tripod was used to take the images. An effort was made to maintain transverse overlap of 80% and longitudinal overlap of 60%. A total of 249 images were used for final data processing.

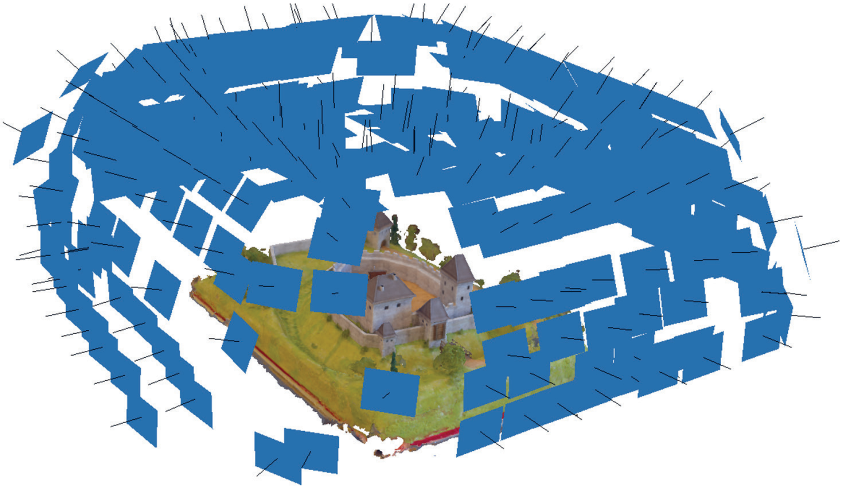

Fig. 10. Distribution of taken images relative to the mock-up

Additionally, 12 ground control points (GCP) were measured in the local layout of the mock-up, where one of the corners of the mock-up was taken as the starting point of the layout, while the shorter side was taken as the X axis and the longer side as the Y axis. On the basis of the mock-up, rulers were laid out along the axes taken. 12 characteristic points were selected, which were then projected onto linear measures and their X and Y values were read to the accuracy of 0.5 cm. Finally, the control distances between each GCP were measured. Only natural GCP was used in this study. The location and distribution of the GCP is shown in the figure below (Fig. 11).

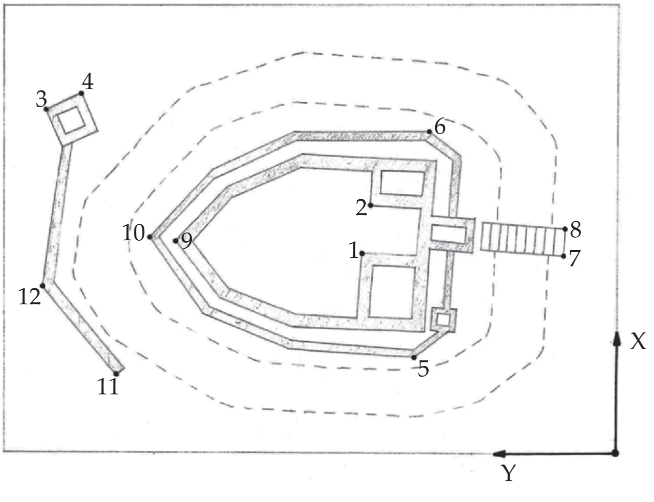

Fig. 11. Distribution of GCP in the local layout of the mock-up

4.2. Surveying the Castle Ruins

Unfortunately, only a few fragments of the ruins that can be unequivocally identified have survived to the present day, with just the remains of a building and two towers being identified. At the same time, these are the best-preserved fragments of the old fortification (Fig. 8). The full ring of walls could not be identified, while the double fortifications around the castle courtyard could only be partially identified. No well was found. After checking the present state of the site, it was decided which points would be adopted for field GCP (Fig. 12). The GCP were chosen so that they could also be identified on the model of the castle.

a) b) c)

Fig. 12. Selected natural GCP identifying corners of:
a) a residential building; b) a tower; c) a gate tower

Three natural GCP were field measured and shown in the sketch (Fig. 12). Point no. 11 is the outer corner of the residential building in the castle courtyard, point no. 12 is the outer corner of the tower inside the walls, and point no. 42 is one of the corners of the tower located to the west. Unfortunately, only three non-co-linear landmarks were selected that can be identified both in the field and on the model. Due to the condition of the ruins, it was not possible to identify more points clearly.

In order to measure the remains of the castle and the GCP's, a surveying coordinate network was established and assigned the numbers 1000, 1001 and 1002. The points of the coordinate network were measured with a KOLIDA K9-T GPS receiver, using the RTN GNSS technique. The coordinates of the points are in the Polish system 2000 zone 6. The Table 1 provides a list of points with coordinates and position errors.

Table 1. The coordinates of the points of the survey matrix

Points number	X [m]	Y [m]	H [m]	m_p [m]
1000	55 223 23.24	65 865 24.75	397.080	0.030
1001	55 223 17.16	65 865 46.64	396.630	0.023
1002	55 223 37.24	65 865 59.69	396.630	0.048

To estimate the area of the ruins, pickets were measured using a Leica FlexLine TS06 total station and surveying prism. Six survey stations were designed (Fig. 13) – two on top of the hill and four around the moat, the coordinates of which were determined using the resection method. The walls of the castle were measured along the axis and then their width was measured in the four best preserved fragments with a roulette. The average of the wall width measurements was 1.30 m. In the end, 89 survey points were measured, the location of which is shown in the sketch below (Fig. 14).

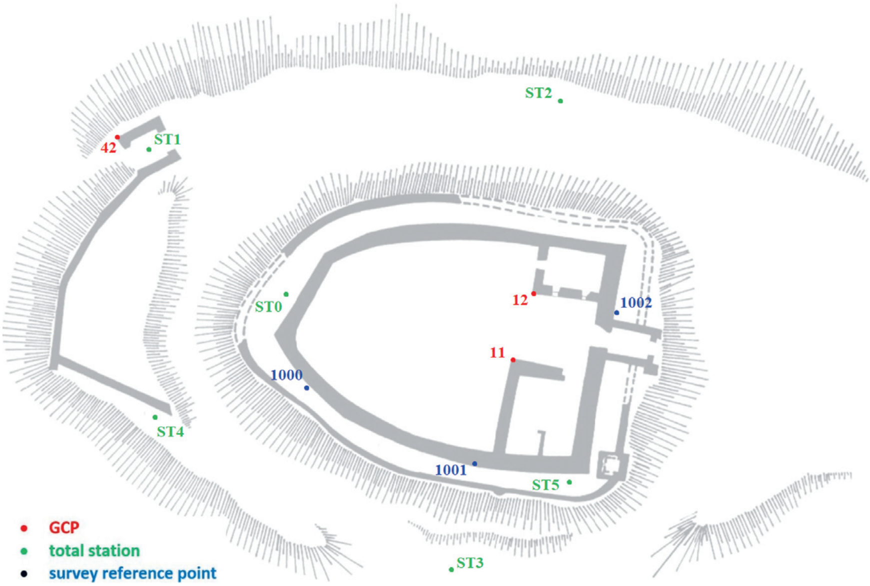

Fig. 13. Location of RTN GNSS survey network points, total stations and natural GCP's on the castle ground plan

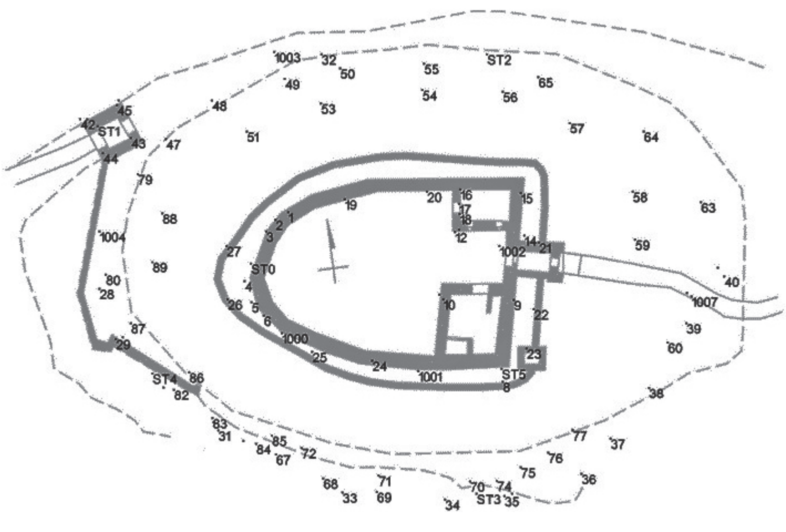

Fig. 14. Draft of measured field pickets

5. Results and Discussion

The main objective of the research work was to determine the damage done to Wołek Castle. In order to do so, an attempt was made in the first stage to determine the scale of the model in relation to the actual dimensions of the castle. For this purpose, the SfM technique was used to generate point clouds from a network of images covering the model. In the end, two-point clouds were generated: one based on natural ground control points obtained from total station measurements and the other using identical points like ground control points but measured in the local layout of the mock-up model.

5.1. Generating a Real Field Scale Model

In order to obtain a 3D model of the mock-up from the images, a self-calibration of the camera was performed, which gave internal orientation elements to all images. Then the SfM algorithm was applied, which searches for features in neighboring images by matching them. The camera position and orientation of each image was obtained, and then a sparse point cloud was constructed to represent the mock-up. On sparse points, gradual filtering was applied to remove noise, but without losing lots of points. The resulting cloud consisted of 125,042 points (Fig. 15).

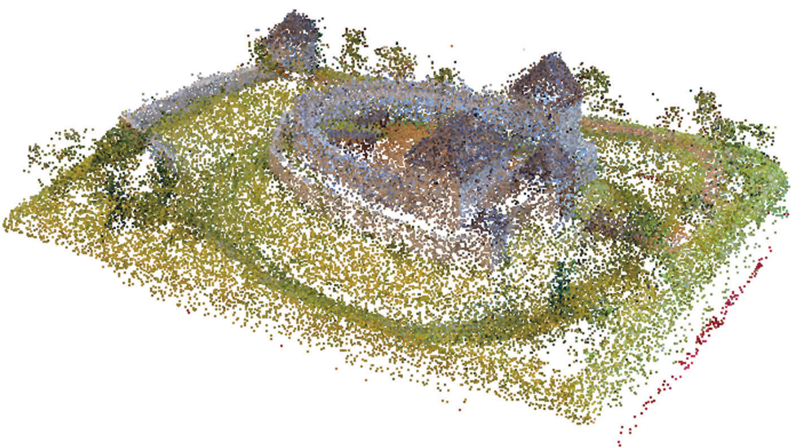

Fig. 15. Sparse points cloud extracted using the SfM method

The resulting points cloud is not metric, so it was necessary to enrich the input data with additional attributes that can provide scale to the model. One method to add scale to the model is to input the coordinates of feature points or GCP. In the present study, three GCP (No. 11, 12, 42) measured by the polar survey method in the field (Fig. 16) were used to generate a 3D metric model of the mock-up. This resulted in a model in the 2000 coordinate system. However, analysis of the accuracy of fitting the images into the point cloud showed large errors of about 1.5 m. The results were unsatisfactory. Nevertheless, it was decided to acquire a dense point cloud in order to analyze the control measures. Finally, a colorful, dense points cloud of 612,261 points was created (Fig. 17).

Fig. 16. Distribution of GCP's on a sparse points cloud

a) b)

Fig. 17. The view of the dense point cloud from:
a) south-east side; b) west side

Distances between GCP on the model and those obtained from field measurements were compared on the rescaled dense cloud of points. The differences were significant, and their values reached nearly 7 m (Tab. 2).

Table 2. Comparison of distance measures on the SfM-derived model and in the terrain

Reference lengths	Terrain distance [m]	Distance on 3D model [m]	Difference [m]
11–12	10.32	13.04	2.72
11–42	62.24	59.60	–2.64
12–42	62.91	56.20	–6.71

When starting the research, it was assumed that the model on which the measurements and subsequent analyses were to be made preserved the proportions of the distances in comparison with the castle's then dimensions. However, after generating the spatial model and scaling it to the real dimensions, it turned out that the proportions were not exactly preserved. Therefore, it was decided to scale the point cloud again, this time at a mock-up scale, in order to obtain a 1:1 3D model.

5.2. Generating a Mock-up Scale Model

In order to obtain a mock-up scale spatial model, 12 GCP (Section 4.1) were measured in the local system. Metricity was given to the sparse point cloud acquired in Section 5.1, as generating a new one would have no effect on the final results of the process. The rescaling was performed using 12 GCP (Fig. 18).

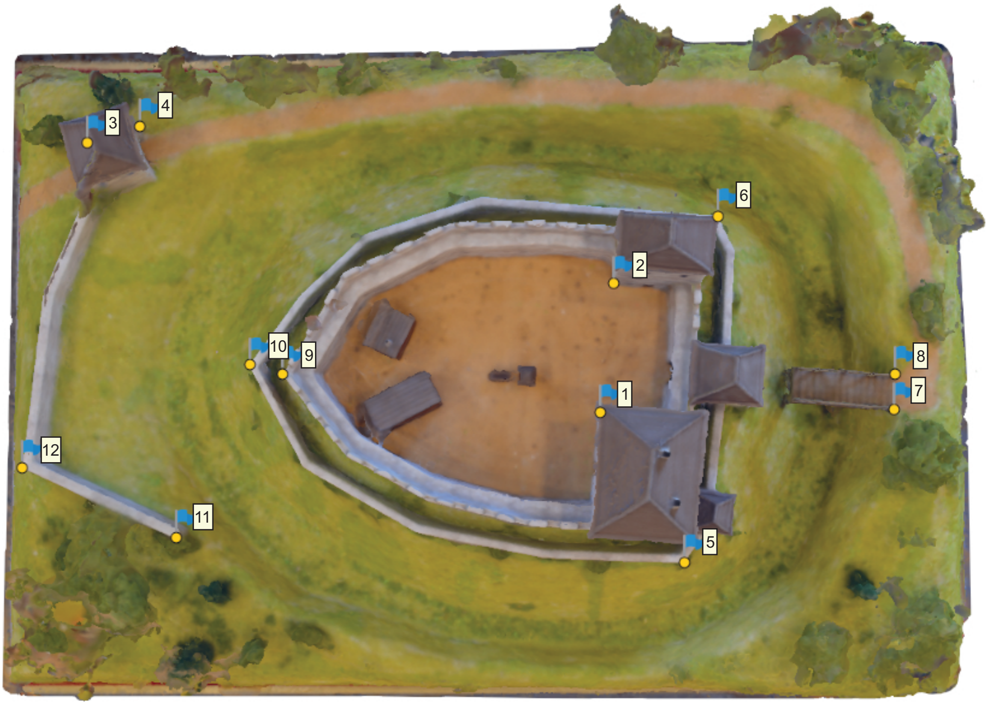

Fig. 18. Distribution of GCP's on the 3D model with texture overlay

Those points whose coordinates were measured in the field on existing ruins were also included during the measurement. After evaluating the quality and metricity, GCP no. 9 was rejected from further analysis due to a large fit error of about 5 cm. The other matching errors were within a few millimetres.

The next step was to extract a dense point of cloud with high quality (Fig. 19). The dense cloud consists of 12,855,403 points.

a) b)

Fig. 19. View of dense point of cloud:
a) from the south-eastern side; b) in orthogonal projection

Based on the dense point of cloud, a vector model consisting of a triangle mesh (Fig. 20) was generated and textures were overlaid on it (Fig. 21).

a) b)

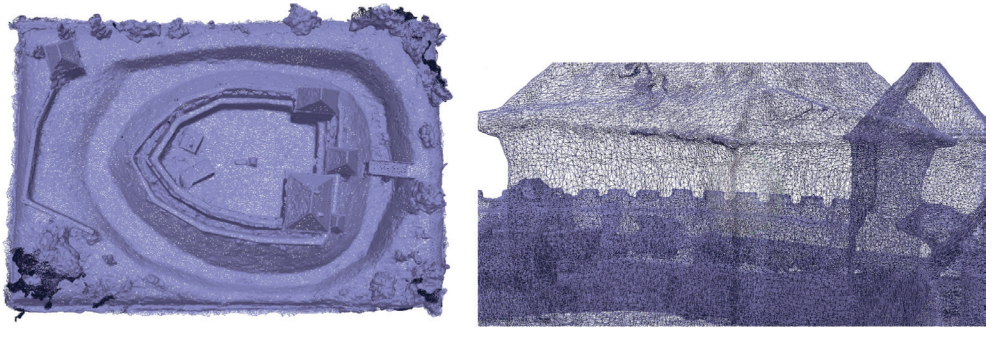

Fig. 20. Triangulate model:
a) in orthogonal projection; b) on an approximate fragment of the tower

As in the first case, the correctness of the model was checked by comparing three lengths identical to those measured on the model derived from field coordinates. The errors obtained did not exceed 5 mm (Tab. 3), so the rescaling of the model was performed correctly.

a) b)

Fig. 21. Textured model:
a) in orthogonal projection; b) on an approximate fragment of the tower

Table 3. Comparison of distance measures on the SfM-derived model and on the mock-up

Reference lengths	Mock-up distance [cm]	Distance on 3D model [cm]	Difference [cm]
11–12	11.7	11.5	–0.2
11–42	50.5	51.0	0.5
12–42	47.0	47.3	0.3

5.3. Comparison of the 3D Model with Orthophotos and the Calculation of Real Ruin Area

The main assumption of the research work was to estimate the area of the current ruins of Wołek Castle in relation to the actual castle area on the basis of the acquired 3D model of the castle mockup using the SfM method. However, due to the fact that the obtained model of the castle from dense photo-matching scaled up to field measurements did not retain appropriate accuracies, it was concluded that it is not possible to calculate the area of the castle ruins accurately and reliably on the basis of the obtained model, as the model was not mapped on a scale of 1:1 in relation to the actual dimensions of the castle.

Therefore, it was decided to compare the acquired dense point cloud with the orthophotomap made available by the Central Office of Geodesy and Cartography. In order to do so, the model was transformed from the local system to the 1992 coordinate system. Next, an attempt was made to find a scale factor for the model, so that the obtained point cloud could be superimposed on the orthophotomap as accurately as possible (Fig. 22). In order to do that, the respective lengths of sections obtained from field measurements and on the model in the local layout of the mock-up were compared. The mock-up model was enlarged approximately 110 times.

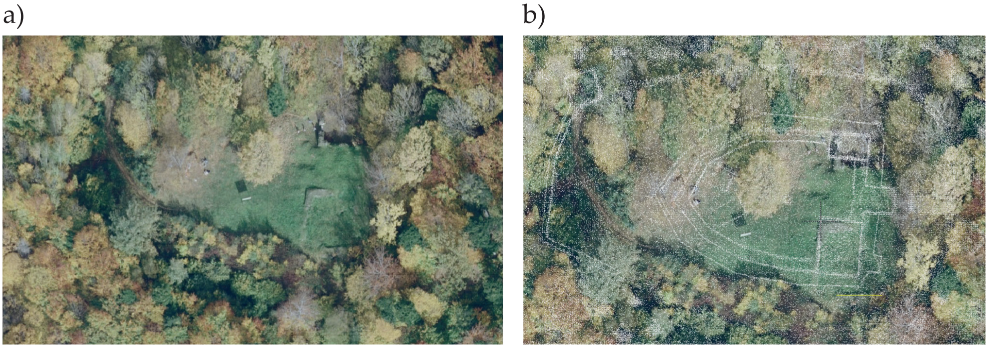

Fig. 22. Orthophotomap: a) of the area; b) with an overlay of a point of cloud, where every 100 points are displayed

On the basis of a scaled 3D mock-up model, an estimate was made of the area occupied by all the masonry elements of the castle, i.e. the fragments which were likely to have survived to the present day. The calculation of surface area took into account the double walls surrounding the castle, the residential building and the tower in the former courtyard, the main gate in the east, and the western gate tower with its incomplete ring of walls. The total surface area of all the elements listed above was about 417 m^2. It should be noted here that this is not the actual area of the walls of the fortress that existed in the 15th century, but only an approximation. Next, the area of the ruins was calculated on the basis of data obtained from field measurements, i.e. planimetry of points measured along the axis of individual elements of the currently existing walls and their width. The calculated surface amounted to a total of 150 m^2. After verifying the calculated surface on the basis of the model of Wołek Castle with its actual state, it can be stated that about 36% of the castle has survived to the present day. Unfortunately, the ruins are not protected against destruction in any way, so their condition will only worsen with time.

6. Conclusions

The article presents the results of research whose aim was to verify a model generated on the basis of photogrammetric measurements of the model of the Wołek Castle with the actual ruins of this object obtained from tacheometric measurements and GNSS RTN.

On the basis of the obtained results, it can be concluded that the SfM method proved to be excellent for rapid acquisition of the spatial model of the mock-up. The study attempted to determine the scale of the existing mock-up in relation to the actual castle model. However, the research found that the mock-up had not been reproduced at a scale of 1:1 in relation to reality. The model shows the general character and construction of the castle, but the actual proportions have not been preserved.

However, in spite of these difficulties, the surface of the masonry elements of the castle was estimated by scaling the cloud. The estimated area of the castle was approximately 417 m^2. This area was calculated on the basis of a model which had been constructed according to historical plans, containing all the elements of the castle. On the basis of field measurements, it was calculated that the remains of the castle currently occupy an area of 150 m^2. Thus, the estimated area that the ruins of the castle currently occupy is 36% of the former castle area.

The research proves that the use of modern surveying technologies makes it possible to quickly acquire spatial data on objects, which in turn enables analysis and the collection of information on historical objects.

Author Contributions

Author 1: methodology, formal analysis, software, writing – original draft preparation.

Author 2: methodology, formal analysis, software, writing – original draft preparation.

Author 3: conceptualization, methodology, writing – review and editing, supervision.

Acknowledgements

The authors would like to thank the Director of the Museum in Kęty for allowing access to the model for the needs of our project as well as the Geodezja Łukasz Kacorzyk company for lending us the necessary equipment and assistance during the measurements.

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