http://dx.doi.org/10.15576/GLL/2019.4.155

GLL

Geomatics, Landmanagement and Landscape No. 4 • 2019, 155–169

MODELLING OF A HERITAGE PROPERTY USING A VARIETY OF PHOTOGRAMMETRIC METHODS

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Summary

In recent years, 3D modelling of historic heritage properties is most often based on photogrammetric measurements. Data on such properties can be obtained, however, by a variety of entirely different methods.

This publication presents an example of developing a 3D model of a historic heritage building using two photogrammetric methods. The first one was based on photographs taken with a non-metric camera, and the second one was based on data from terrestrial laser scanning.

The object of the study was the Museum of the Estreicher Family in Krakow. The photos were obtained with a Canon EOS 400D DSLR camera and a cloud of points from terrestrial laser scanning with a Leica ScanStation P40 scanner. The development of the 3D model based on photographs was carried out using the Bentley ContextCapture software application, and the Agisoft PhotoScan Professional. In contrast, TLS (Terrestrial Laser Scanning) data was processed in the Leica Cyclone software application and modelled in the 3DReshaper. Both methods were analysed and compared in a tabular presentation.

Keywords

3D model • terrestrial laser scanning • non-metric imaging

1. Introduction

The application of three-dimensional technique in the visualization of architectural objects has for many years become the foundation of various types of architectural and planning studies. The 3D model of the object makes it possible to reproduce the properties as well as features of the examined object. Presenting the object in the third dimension allows architects to draw up a full inventory of complex architectural objects, including those with limited accessibility. Acquiring information about such objects can be done in various ways, using various methods. The application of photogrammetric techniques facilitates the use of metric or non-metric measuring cameras, and in recent years terrestrial laser scanners have been successfully employed for this purpose [Kwoczyńska and Rzepka 2013]. These issues were raised by, among others: Kędzierski and Walczykowski [2008], Zawieska [2008], Mikrut et al. [2014], Głowienka et al. [2015] or Kwoczyńska et al. [2016].

3D modelling of historic properties, based on photogrammetric data and laser scanning, has recently become a rapidly developing field due to the increasing capabilities of measurement and graphic presentations. The speed and accuracy of data acquisition goes hand in hand with the possibilities associated with modelling and visualization of this type of data. Since the emergence of the laser scanning technique, it is becoming increasingly common to use it for cataloguing and describing heritage properties [Bęcek et al. 2015]. Also frequently used is the integration of photogrammetric and laser data, which has been discussed in studies by Mikrut et al. [2014], Buckley et al. [2006], Guarnieri et al. [2006] and Mitka and Rzonca [2012].

Research on the use of laser scanning for registering and cataloguing architectural objects has been conducted for many years around the world, as evidenced in the works by Bernat et al. [2014], Boehler and Marbs [2004], Cantoni et al. [2002], Głowienka et al. [2015], Pyka and Rzonca [2006].

Continuous technological advancement means that the already outdated, inconvenient methods of collecting geospatial information have been replaced by modern technologies, which have completely revolutionized the work of engineers. Such technologies include, among others, laser scanning and studies based on digital imaging.

The following publication presents and compares two methods, leading to the creation of a 3D model of a historic property. The first uses a non-metric Canon EOS 400D DSRL camera for this purpose, and the second employs a Leica ScanStation P40 terrestrial laser scanner. The comparison of the obtained models allowed us to demonstrate the advantages and disadvantages of the development methods used, and the accuracy of 3D models achieved through their application.

2. Research methodology

Classical data acquisition techniques, despite the fact that for many years they were the only source of data on the location, shape or size of objects, gradually began to be supplanted by methods that require less work and are less time consuming. The advancement of geoinformation technology, associated with both the development of equipment and software applications for data treatment and processing, causes the continuous progress of contemporary methods of data acquisition, such as photogrammetry and laser scanning, examples of which are found in the work by Buckley et al. [2006], Figiel [2015], Gawronek and Mitka [2015], Kędzierski et al. [2008].

Currently, terrestrial laser scanning is one of the most up-to-date, convenient forms of data collection, and its popularity is mainly due to the efficiency and high accuracy of the development, compared to previously used measurement methods [Kwoczyńska et al. 2018].

The subject matter of measuring architectural objects encompasses a broad spectrum of tasks, methods and solutions. Classic measuring methods, despite ensuring a high level of accuracy, are time and work consuming. Hence the clear increase in the demand for and use of terrestrial, as well as airborne laser scanning, wherever a compromise between quality and speed of obtaining information is required and achievable. The automation of desk studies allows reducing the role of the operator of systems that support laser data, however, the complete elimination of the operator's presence in the production process of studies still seems inconceivable. This results from the necessity of interpreting the displayed image and of having specialized knowledge in a given field, as well as the ability to use other additional or supplementary materials regarding the object at hand [Kwoczyńska et al. 2016a].

Terrestrial photographs currently used for photogrammetric measurements are taken with various types of digital SLRs. However, they require prior calibration [Boroń and Tokarczyk 2000]. The documentation created on their basis is characterized by a high degree of detail and high accuracy of representation.

The photogrammetric method is a highly complicated process that involves carrying out many technically and computationally demanding procedures. This constitutes its main disadvantage. However, if the goal of modelling is to achieve the best geometric accuracy, metricity, and detail, this method is irreplaceable. Contemporary architectural inventory and description of buildings, as well as cataloguing historic buildings are based on this method. [Kwoczyńska and Rzepka 2013]

In today's practice, the use of contemporary software applications, such as ContextCapture, Agisoft Photoscan, 3DReshaper or Leica Cyclone, which are largely based on automatic modules, significantly simplifies and speeds up the work.

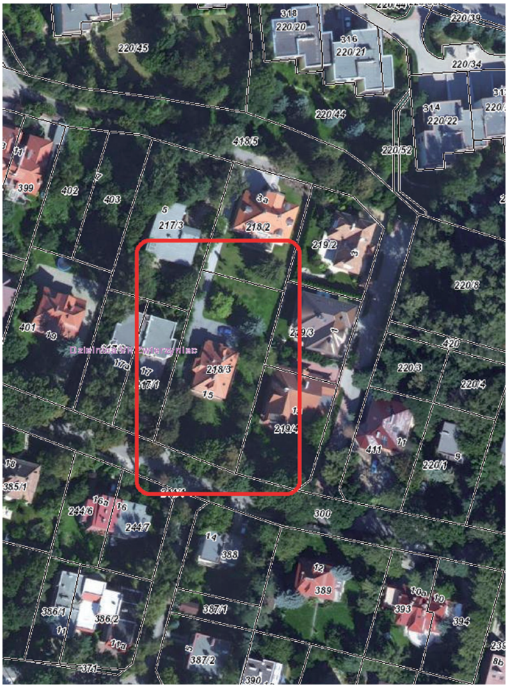
The present publication compares two different methods to obtain a 3D model of a historic property, as illustrated with the example of the Estreicher Family Museum in Kraków.

The first method was based on photographs taken with a Canon EOS 400D DSLR camera, with a image sensor resolution of 0.0057 mm, a Sigma fixed focal length lens of f = 20 mm, and calibrated in the PI 3000 Calib software application. The second method was obtaining a point cloud with a ground laser scanner Leica ScanStation P40, pulse mode with WFD, and the scanning range capacity from 0.4–270 m, the scanning resolution set at 2 mm, and photos taken with the built-in camera (Canon EOS 600/700 option).

The focus was on the disadvantages and advantages of 3D models of the examined object obtained by the application of each method, without comparing the accuracy of the 3D models themselves. When comparing the modelling methods used, we have taken into account both the time and degree of difficulty of individual stages of preparatory work and the development of the 3D model itself, as well as the latter's correctness and facility i.e. the ease of implementation.

2.1. Description of the studied object

The object of the study was the Museum of the Estreicher Family, Centre for the Loss and Recovery of Cultural Heritage in Krakow, located at number 15 in Sarnie Uroczysko street. The museum is located in the vicinity of a single-family housing estate (Fig. 1), in a wooden single-family house on a stone foundation (Fig. 2).



Source: geoportal.gov.pl

Fig. 1. Location of the studied object

Photo: B. Kwoczyńska

Fig. 2. Estreicher Family Museum in Kraków

The museum is located in the villa of professor Karol Estreicher Junior, the so-called "Nowa Estreicherówka". The villa, designed by Józef Gałęzowski, is a listed building (entered in the register of heritage monuments). In 1946–1948, Karol Estreicher Junior moved it from Ojców and reconstructed it in Kraków, in Sarnie Uroczysko (in Wola Justowska district). Professor Estreicher lived there with his wife until his death, on April 29, 1984. He transferred the ownership of the villa to the Society of Friends of Fine Arts in Kraków.

2.2. Developing a 3D model based on photographs

A series of 173 non-metric images taken in three sequences, with 65% langitudinal overlap and 30% side overlap were used to develop the 3D model. The first sequence of photos was taken perpendicularly to the object – as regular photos. The remaining two sequences, due to the location of the object surrounded by large and old trees, had to be made at oblique angle. The photos were taken with a Canon EOS 400D DSLR camera with 20 mm prime lens.

The images were processed using the Bentley ContextCapture and Agisoft PhotoScan Professional software applications. Based on that, TIN models were developed from point clouds, and, as a result, solid models were created.

ContextCapture software application makes it possible to automatically generate a high-resolution 3D model, using photographs or a cloud of points. The photographs can be taken with a digital camera, or even a regular smartphone with a built-in camera.

The quality of photos, which constitute the input data in the process of creating a 3D model, has a significant impact on the quality of the final model. Hence, they are required to be taken: with a fixed focal length camera, with homogeneous lighting (with no shadows on the subject), with no blur in the photo and digital zoom, with a minimum coverage of 50%, but preferably 70%, and at an equal distance from the object.

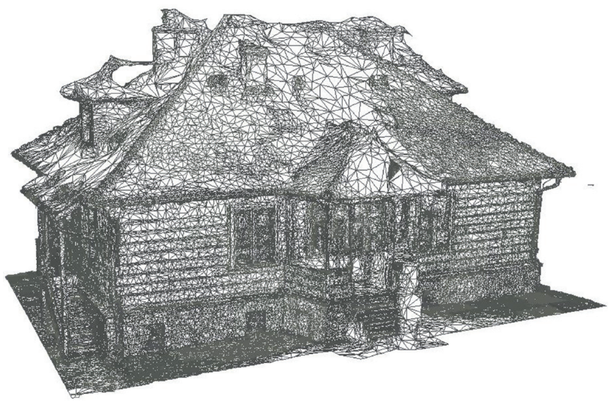
In order to create a point cloud based on the photographs, the ContextCapture software application performs aerotriangulation. The cloud execution time in the program depends on the parameters used, the number of images, and the computing power of the computer. The resulting cloud of 38 436 519 points was filtered in the Bentley Descartes software application (Fig. 3).

However, the cloud was not complete, namely, it was missing in places covering the roof through the branches of trees. The incompleteness of the cloud was caused by the restriction to terrestrial images only (the inability to use UAVs was due to the trees surrounding the object). This resulted in failure to capture all the details, and remaining "holes" on the roof of the object. Other disadvantages of the cloud were caused by the presence of windows and other glass elements, as well as other reflective objects. The cloud of points obtained in this manner influenced subsequent products (TIN model) obtained during further stages (Fig. 4), and affected the final solid model (Fig. 5).

On the resultant solid model, the abovementioned deficiencies on the roof windows and on the porch of the building are found in places where reflective elements are visible. This is due to the fact that a large part of the roof is obscured by trees, and by the presence of glass elements on the porch.

Source: Spytkowska [2017]

Fig. 3. Model from point cloud with marked faults



Source: Spytkowska [2017]

Fig. 4. TIN model in ContextCapture software app.

In order to verify how the Agisoft PhotoScan program can handle the 3D model based on the same photographs, we developed another model using this software application. However, the result achieved was not satisfactory (Fig. 6). Using this particular software application would only be justified if we could use data integration with UAVs or airborne scanning. However, the proximity and size of the trees around the object limits the options. Both models were compared, but only in terms of walls, creating a differential model in CloudCompare software application (Fig. 7). Having analysed the obtained results, we concluded that 94% of the compared points remained within the error range between points from 0 to 25 cm. 5% of the points were burdened with an error in the range of 25 to 50 cm.

a.

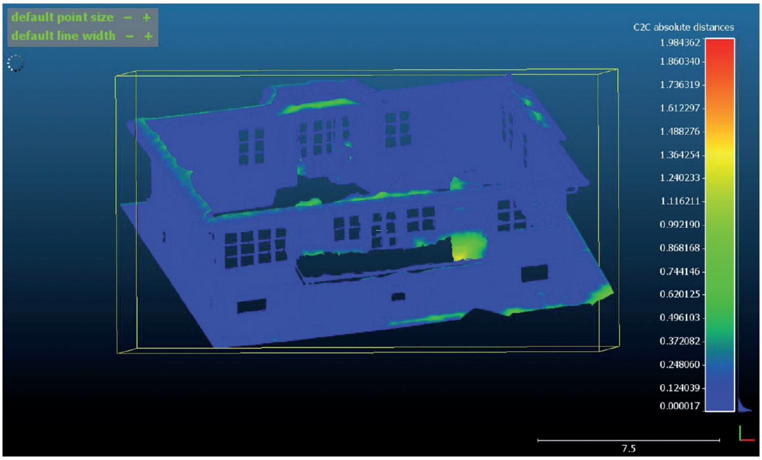
b.

Source: Spytkowska [2017]

Fig. 5. Solid model of the Estreicher Villa in Kraków developed using ContextCapture software application: a. front view, b. back view

Source: Spytkowska [2017]

Fig. 6. Solid model developed using Agisoft software app.



Source: Spytkowska [2017]

Fig. 7. Differential model

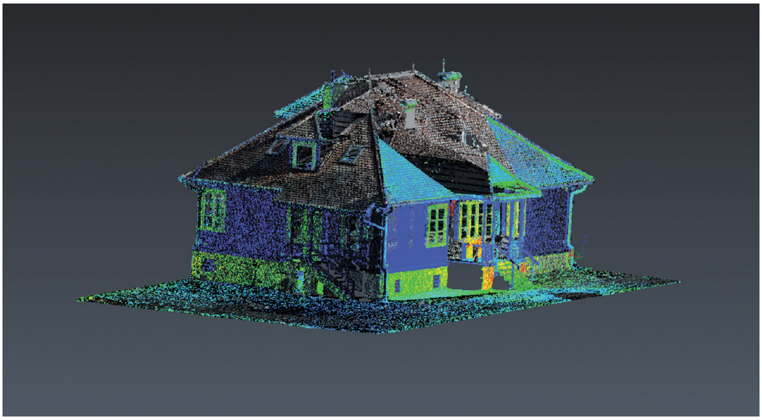
When comparing the two models, significant differences are noticeable. The model obtained from the ContextCapture software application had much better modelled window geometry (the correct shape of window frames and divisions), and more expressive details. As for the Agisoft PhotoScan Professional model, some details are not modelled at all, or they are distorted. Compared to the model from ContextCapture software application, the porch has a lot of shortcomings, for instance, stairs are not modelled in their entirety. The walls of the buildings have been reproduced well in both models.

2.3. Developing a 3D model based on TLS data

The scanner's operation is based on measuring the distance and the angle between the device and the selected object, thus enabling the determination of the *X*, *Y*, and *Z* coordinates. As a result of these measurements, a point cloud is obtained [Wężyk 2010].

Terrestrial laser scanning (TLS) is one of the most recent, state-of-the-art solutions, used in increasingly new fields of science and technology. It allows very accurate determination of spatial coordinates, visualization of any area, any complex object, building structure, as well as interiors, with extraordinary speed and precision. Contemporary devices take measurements in mere minutes, thanks to which it is possible to perform measurements of as many as several dozen stands in one day, which in the case of large and complex objects means a relatively short time needed to complete work in the field, compared to, for instance, working with a total station. Subsequent combination of all scans from each measuring stand produces one point cloud, showing the entire object in a virtual environment [Kwoczyńska et al. 2016b].

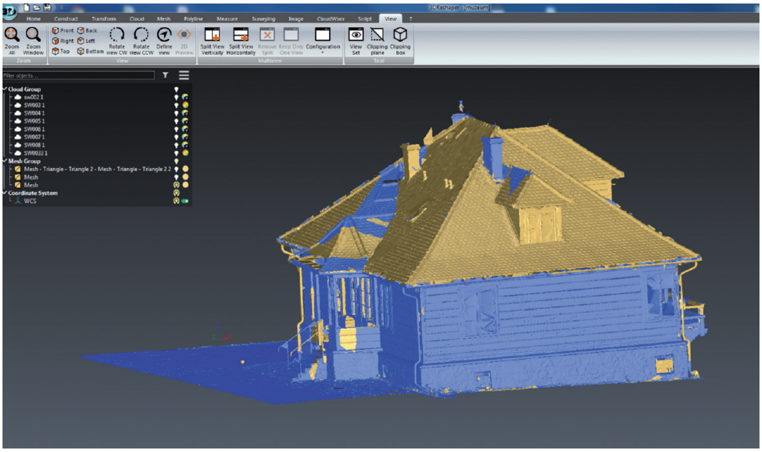
The TLS (Terrestrial Laser Scanning) point cloud for the examined object was obtained during the measurement with the Leica P40 scanner. The object was scanned from 8 stands (positions) and oriented using reference spheres and target plates. The average error of orientation was 0.002 m. Filtering and processing of the point cloud was performed using the Leica Cyclone REGISTER 360 software application, and the result of the work is shown in Figure 8.



Source: Stachura [2019]

Fig. 8. Point cloud in the Leica Cyclone software app after filtering

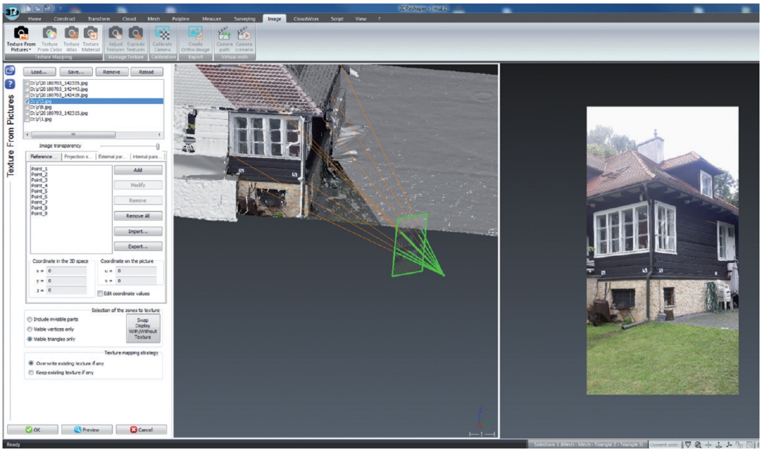
3D model of the studied object (Fig. 9) was developed using the 3DReshaper software application, produced by a French company called Technodigit.



Source: Stachura [2019]

Fig. 9. 3D model developed using 3DReshaper software app

The resulting model had many gaps in places where the density of points was lower than the set parameters required for creating the model. The largest defects arose on the roof and on the balcony, where the barrier made it difficult to scan beyond it. Filling the gaps was done automatically by joining the edges. The texturing of the model was based on the photographs taken (Fig. 10).



Source: Stachura [2019]

Fig. 10. The texturing of the 3D model using the 3DReshaper software app

The accuracy of the 3D model depends on many factors. Undoubtedly, the most important of those include the placement of measuring stations, and the presence of obstacles between the scanner and the object. The Museum of the Estreicher Family, Centre for the Loss and Recovery of Cultural Heritage in Krakow is housed in an old building with a lot of timber columns and railings. The railings on the balcony and the porch caused a low accuracy of the scan in those areas, which produced empty spaces – gaps in the developed model. Railings and columns also caused difficulties when applying textures to the object. They led to the creation of "shadows" and even slight inaccuracies in superimposing the photograph on the railings caused the column texture to be displayed on the building wall (Fig. 11a and b).

The trees growing in the immediate vicinity of the building obscured the view of the object, which made it impossible to scan the roof accurately, contributing to the imprecise rendition of this element on the 3D model. Textures applied to the roof are inaccurate, because the leaves within range of the camera were projected onto the roof (Fig. 11a). Unfortunately, with such a high density of trees, it is very difficult to get clear shots for applying textures. This is the case when applying original textures to the 3D model of the studied object. Otherwise, with the application of artificial textures, the model would not raise major objections.

a.

b.

Source: Stachura [2019]

Fig. 11. 3D model of the building: a. SE elevation, b. N elevation

3. Conclusions

The variety of methods used both for obtaining image data and later during the implementation of the 3D model of the studied object, creates the opportunity to choose as well as the need to optimize the adopted technique and development methodology. It is not always necessary to use expensive solutions [Głowienka et al. 2015].

Today, 3D models of objects remain among the most popular ways of representing the world around us – it is only the tools that change: tools, which allow us to obtain information about the objects and create 3D models of these objects. The purpose for which the 3D model of the given building is developed largely decides which method should be adopted to obtain the data, and then which software application should be used for this purpose.

According to research conducted by Iavarone [2002], the accuracy of the 3D model is a derivative of the original object model generated using points measured on the surface of the object. The accuracy he obtained for a single measurement was down to 10 mm, however, if we use an algorithm based on the least squares method, we can obtain a resulting accuracy down to 1–2 mm. The capacity to accumulate a dense grid of points for large areas over a very short period of time is the advantage of terrestrial laser scanning. However, if a compact model is not created or if the number of points on the surface of the object is too small, then the obtained accuracy of the model will deviate from reality.

In the case of the Estreicher Family Museum, the focus was on demonstrating the shortcomings and advantages of a 3D model obtained from digital photographs and from terrestrial laser scanning. It should be noted, however, that the accuracy of the 3D models obtained by these methods has not been compared.

The model based on close range photogrammetry is geometrically correct, fully metric and detailed, and it should be used in architectural inventorying, as well as for engineering and industrial purposes. However, sometimes using just one measurement method is not enough. Therefore, the combination of photogrammetric data, laser scanning and UAVs is increasingly used.

Comparing both methods adopted in order to create the 3D model of the Estreicher Family Museum has led us to draw the following conclusions. If the criterion for choosing the modelling method is the facility and ease of making the model, then the method based on the use of images and ContextCapture software application wins beyond any doubt. Having said that, the model made under this method is not always suitable for the inventorying purposes of the given object. It can, however, be successfully posted online as a visualization of the given object, with an aim of providing information about its appearance and basic geometry. Such a model can also be used by architects to illustrate the completed project, when aiming to elucidate the designer's intention to the recipient.

Definitely higher 3D model accuracy will be obtained by using terrestrial laser scanning. This method, however, entails much more work, both in terms of measuring and processing the measurement data. However, if the goal of modelling is to achieve the best geometric accuracy, metricity and detail, this method remains unmatched.

Each of the methods presented above has both pros and cons. Their detailed comparison, taking into account the creation of the 3D model of the heritage building, is presented in tabular format below (Table 1). However, as mentioned above, the accuracy of the 3D models obtained through the application of these methods has not been compared.

Table 1. Comparison of the applied methods of 3D modelling

No.	Criterion	Method based on laser scanning	Modelling using the ContextCapture and Agisoft Software applications
1	Stages preceding the modelling process	1) location of reference spheres, 2) performing the scanning of the object, 3) measurement of photogrammetric measurement matrix, 4) taking the photographs, 5) orientation the point cloud, 6) filtering the point cloud	1) taking the photographs of the object, 2) measurement of distances on the elevation in order to perform scaling of the model at a later stage

2	Stages of the modelling process	1) building the TIN model, 2) building the vector or solid model, 3) 3D model covered in textures	1) creating the point cloud from the photographs taken, 2) building the TIN model, 3) building the plane model, 4) covering the plane model with textures
3	Model's metricity	Full metricity	Has metricity, but requires additional measurements of the object in the field (either photo-points or specified distances on the elevation)
4	Geometrical correctness of the model	Object's geometry is true to reality	Model depends on the quality of the lens, and its possible distortion
5	Time-consuming	Long-lasting process	Fast development
6	Workload	High workload	Low workload
7	Required number of software applications	2	2
8	Facility (ease) of development	Necessary to have basic knowledge of photogrammetry and navigation of specialised software applications	Very simple, intuitive navigation of an uncomplicated software application

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