Photogrammetric evaluation options of an ancient monument for different survey levels

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ABSTRACT

Recently, for the purpose of data management, more advanced digital data are required for different survey levels of irregular ancient monuments. For irregularly formed monuments and amorphous surfaces, 2D photographs and 2D measured surveys are inadequate to illustrate the condition of the building for condition reports or relationships between components and materials for structural surveys and conservation decisions, especially in archeological remains. However, image-based documentation techniques can be used as simple tools for different types of surveys due to their ease of use and fast and economical properties. Therefore, the aim of the study is to test multi-image photogrammetric documentation techniques to improve and standardize visual data appending condition reports and further detailed reports regarding conservation of irregular ancient monuments.

In the literature, there are many studies about image-based documentation techniques. However, the innovation of the study is to provide an improvement of the pipeline of condition and structural surveys of irregular ancient monuments by making use of photogrammetric techniques.

In order to measure the effects of the relationship between the type of documentation technique and survey level on the photogrammetric documentation process of an ancient monument, a series of experiments were designed and the results compared. For this purpose, automated image orientation packages Autodesk 123D and Photosynth and manual image orientation package Tgi3D were evaluated in terms of process time, reliability and level of detail to identify appropriate techniques for different survey levels.

This study proved that documentation of the structural characteristics of ancient monuments can be achieved successfully with the Tgi3D package, which has manual workflows. The documentation results might support structural intervention decisions. The 3D models based on automatic workflows might support a preliminary condition survey, since their production takes a relatively short time and scaled models are acceptable for identifying mass characteristics.

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1. Introduction

According to the standards of the European Committee for Standardization, the first step in the conservation of cultural property is the preparation of a condition survey. Then, the data gathered from the condition survey are used for the identification of the next steps such as preventive conservation, maintenance, immediate repairs, and planning for further studies when causes of damage are not evident (UNI EN 16096, 2012).

The condition report includes assessment, documentation and recording of the condition of cultural heritage buildings to keep them in a well-maintained condition. For the purpose of data management, it is advisable to establish a digital system in the condition survey and the related visual sources such as old and current photographs, old drawings, earlier inventories, earlier conservation plans, etc. Although information on the height and ground area of the building is necessary for the condition survey, the present reporting form does not include a measured survey of the current state, which is a time-consuming process. This study suggests that automatic image-based modeling techniques are user friendly and fast tools for measured surveys of the mass of irregular formed ancient monuments in 1/200 and 1/500 scale. However, if further studies such as a structural diagnosis are necessary, then manual image based modeling techniques are economical tools for detailed and reliable measured data.

The innovation of the study is to provide an improvement of the pipeline of the condition and structural survey of ancient monuments by making use of image based photogrammetric techniques. The aim of the study is to test multi-image photogrammetric documentation

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Fig. 1. Southeastern facade of Hypokremnos Viaduct.

techniques to improve and standardize visual data appending condition reports and further detailed reports regarding conservation of irregular ancient monuments. Advantages and disadvantages of automatic and manual image-based modeling techniques are identified to provide adequate data for different survey levels.

Parameters affecting the quality of architectural surveys such as the type of software (Böhler and Heinz, 1999; El-Hakim et al., 2004; Remondino and El-Hakim, 2006; Guidi et al., 2008; Barazzetti et al., 2010; Annibale, 2011; Rosnell and Honkavaara, 2012; Salonia et al., 2009, etc.) and the reason for the documentation and the related presentation scale (Arias et al., 2005) are evaluated together. Image based photogrammetric software with manual and automatic workflows is tested in terms of visual and metric evaluation of accuracy and level of detail to identify appropriate techniques for condition and structural surveys. The Hypokremnos Viaduct, a monument that has irregular formed and amorphous surfaces is documented with automatic photogrammetric software (Autodesk 123D and Photosynth + Meshlab) and manual photogrammetric software (Tgi3D). The results are compared.

2. Characteristics of the ancient monument

The ancient monument, the Hypokremnos Viaduct (Uygun, 2013), is part of a series of remains of viaducts crossing the brooks on the Hypokremnos Plateau, İçmeler, Urla, İzmir. The viaduct is a masonry structure with linear form (W: 3.49, L: 16.37, h_{max}: 1.93 m) (Fig. 1).

An ancient road connecting the cities of Eryhtrai, Clazomenai and Teos passed through Hypokremnos in the Roman period (Bakır and Anlağan, 1980). The viaduct is thought to have been first constructed

in the Roman Period and probably reconstructed with spolia after being demolished during the Turkish period, which started in the region in the 11th century.

The structural integrity of the monument is under risk as a result of the continuous action of waves, salt and sand. Urgent and immediate measures are necessary to prevent further damage. This should be followed by further detailed surveys of structural elements and materials.

3. Experimentation process

The experimentation process was composed of two steps, data gathering and data processing in both manual and automatic workflows.

3.1. Data gathering

For data gathering, a Nikon D70 digital SLR camera equipped with a 28 mm lens, a ladder and a steel tape (20 m) were used. Photos describing the object in general and photos parallel to the surfaces of the object, all overlapping each other, were taken for both automatic and manual evaluation.

3.2. Data processing

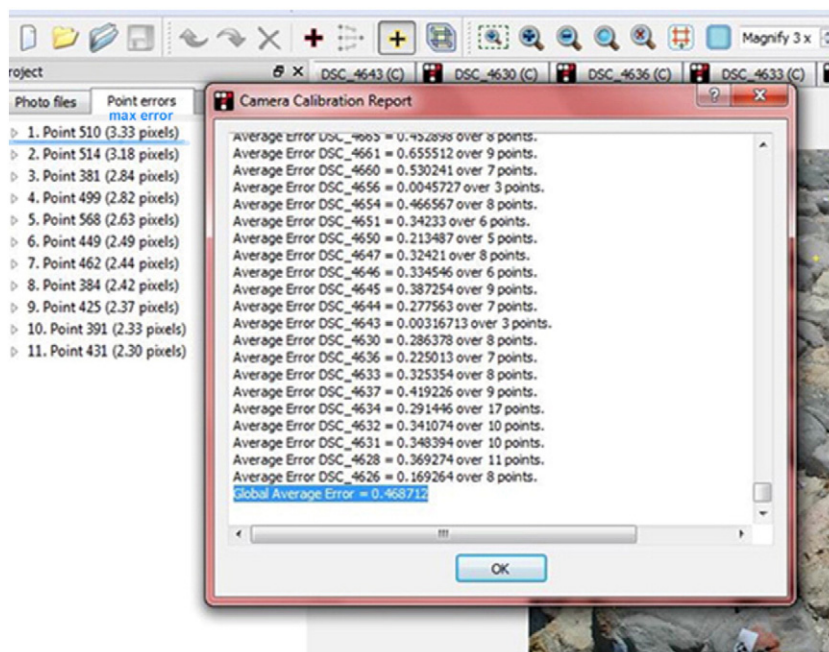The data processing phase is composed of two steps; point cloud generation and modeling.

Fig. 2. Global and maximum error values.

Table 1
Error-scale relationship.

Maximum tolerances for scales (Andrews et al., 2015 and RICS, 2014)	
Scale	Tolerances
1:5	±4 mm
1:10	±5 mm
1:20	±6 mm
1:50	±15 mm
1:100	±30 mm
1:200	±60 mm
1:500	±150 mm

Table 2
Average error computed between meshes.

Haussdorf distance calculation	Average error
Photosynth on Tgi3D	5.3 cm
Autodesk 123D on Tgi3D	14.3 cm

3.2.1. Point cloud generation

Calibration and orientation of images were carried out automatically by the automatic software. Images were uploaded to this software and no more interaction was required. In Photosynth, point clouds are automatically placed at the disposal of the web community. Autodesk 123D is fully automatic open source software containing both orientation and modeling tools. In addition, it has manual orientation facilities for photos that cannot be oriented automatically. The model produced can be viewed in wireframe and texture and texture only formats.

Tgi3d allows the orientation of images without any preliminary information about the sensors and does not require calibration. Orientation of image pairs was carried out manually. Image sets were loaded to the software individually and each image pair was oriented, respectively. Three control points were usually sufficient, while for long facades, four or five control points were used to strengthen the bonding system for the corners and damaged short facades. With the automatic addition of control points by the software, the number of control points reached six for the long facades and eight for the short facades.
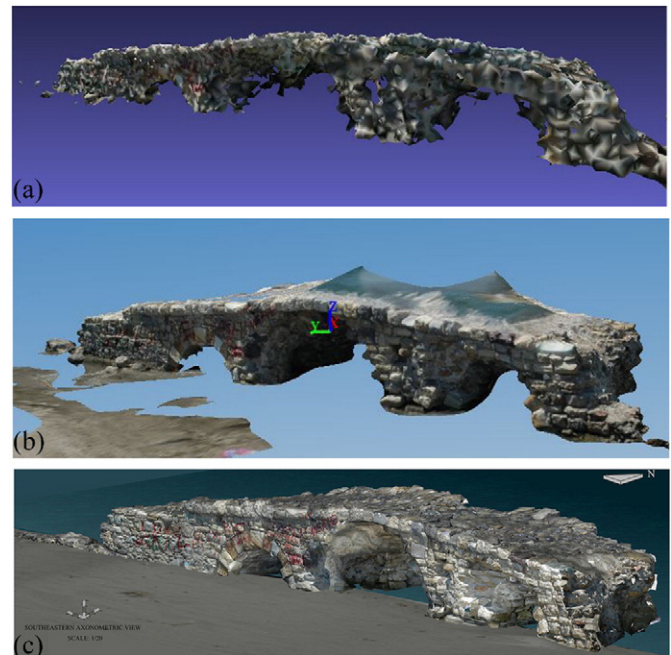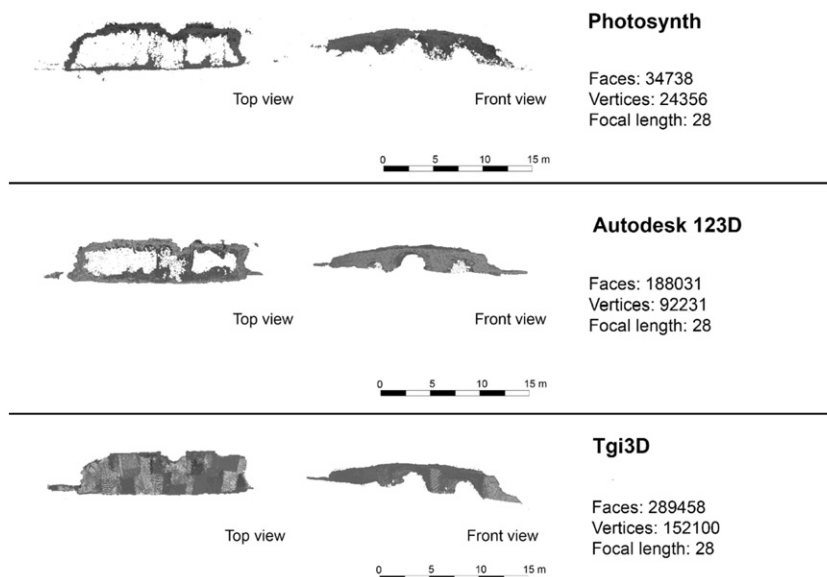

Fig. 4. Textured models of Hypokremnos Viaduct with a) Autodesk 123D b) Tgi3D.

3.2.2. Reality-based modeling

In Autodesk 123D, which is fully automatic software, surface construction was carried out automatically. Photosynth does not provide reconstruction of surfaces. Surface construction of point clouds was carried out in Meshlab. The ball pivoting surface reconstruction filter was preferred for the meshing process due to the irregular surfaces of the monuments.

After exporting the point cloud from Tgi3D to SketchUp 8, both the toolbars of SketchUp 8 and the toolbar added to SketchUp 8 automatically by Tgi3D were used for modeling.

A 3D surface was drawn by connecting three control points on the images that were not tilted. This surface was converted to real surface with the Image-Based Surface Modeler toolbar.

Photosynth

Faces: 34738
Vertices: 24356
Focal length: 28

Autodesk 123D

Faces: 188031
Vertices: 92231
Focal length: 28

Tgi3D

Faces: 289458
Vertices: 152100
Focal length: 28

Fig. 3. Visual evaluation of point clouds in 1/500 scale.

4. Discussion

The 3D models are evaluated in terms of precision, level of detail and process time to identify advantages and disadvantages of the selected image-based techniques.

4.1. Precision

The precision of the 3D model produced with Tgi3D is calculated considering maximum error value calculated by the software automatically (Fig. 2), the shot length of the object at the site and in the image.

The maximum error amount for 1/5 scale is around 4 mm, therefore, the end product model's precision is more than enough for the acceptable limits of 1/5 scale (Table 1).

Also, to test the error values given by the software, dimensions between the targets in the 3D model are checked with traditional measurements.

Maximum error: 3.33 pixels.

Error (max) ~L/N × pixel error (max).

Error (max) ~3450/3000 × 3.33–3.8 mm.

Since the results of Tgi3D have high precision, the models obtained by automatic packages are compared with this model using Haussdorff distance in Meshlab. Hausdorff distance is the *maximum distance of a set to the nearest point in the other set* (Rote, 1991). First, the problematic vertices created by tilted photos in automatic point clouds were cleaned. Mean distance error values of the vertices gained by automatic techniques were computed using the Tgi3D model as the target mesh. The results demonstrate that the Photosynth package produces more precise 3D models in comparison to Autodesk (Table 2). Nevertheless, the Photosynth model is acceptable for 1/200 scale, while the Autodesk model is for 1/500 scale (Table 2, Table 1).

4.2. Level of detail

The images of the roadway were not oriented by automatic techniques since automatic software discarded the images. Thus, point clouds obtained by Autodesk and Photosynth have incomplete parts. However, Autodesk results are more satisfactory than Photosynth. The point clouds of Tgi3D do not have incomplete parts in comparison to automatic evaluations due to the advantages of a human operator.
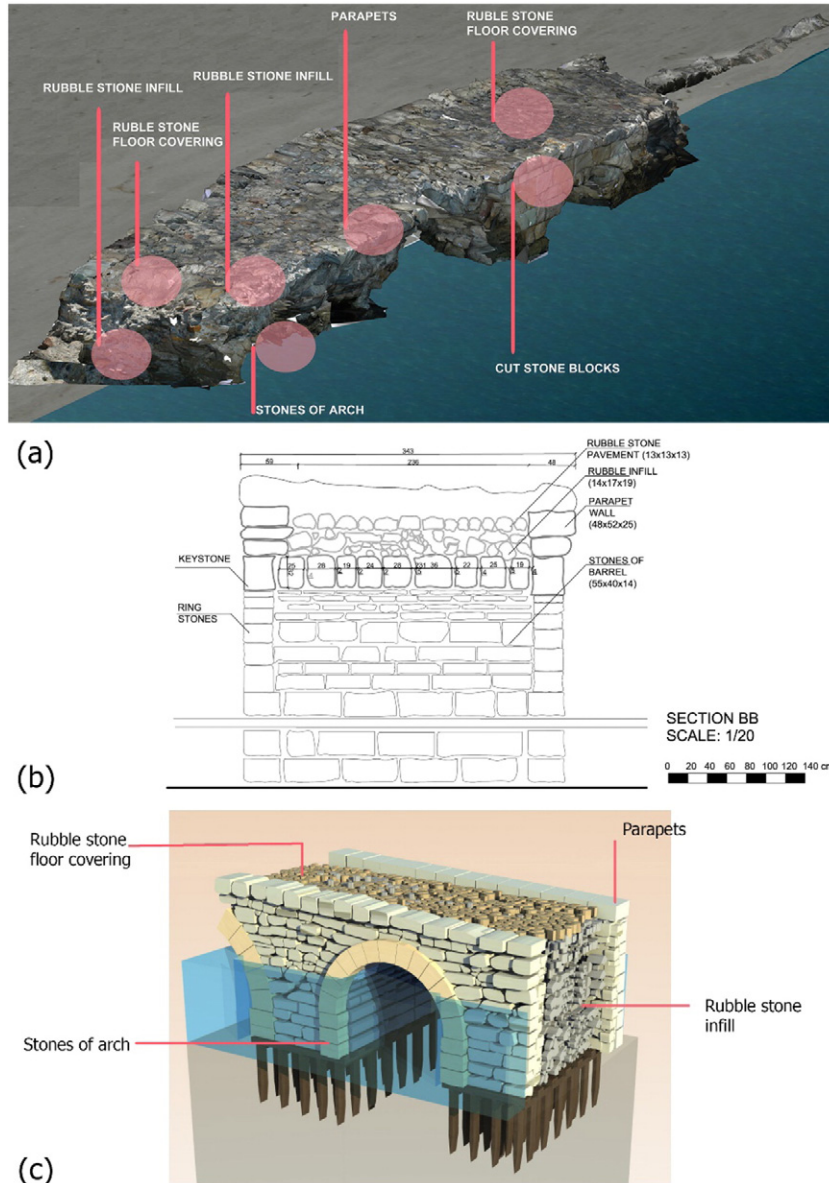

Fig. 5. a. Positions providing structural information, b. System detail, c. Virtual reality model.

Autodesk 123D	Orientation+ Modeling Period	30 minutes + 15 min (manual stitching time)
Photosynth+ Meshlab	Orientation Period	20 minutes
	Modeling Period	20 minutes
Tgi3D	Orientation Period	420 hours
	Modeling Period	600 hours

Photo number	Orientation Period
10. photo	2 seconds
15. photo	4 seconds
40. photo	24 seconds
65. photo	1 minutes 4 seconds
100. photo	7 minutes 30 seconds
140.photo	45 minutes 20 seconds
180. photo	1 hour 30 minutes
210. photo	1 hour 34 minutes

Fig. 6. Duration of orientation and modeling.

Discarded images of the roadway also affected the integrity of the mesh and texture in automatic software. Since the points are tied automatically by the automatic software, meshes and surfaces that do not illustrate components of monuments in detail are created automatically for missing parts (Fig. 3). Thus, the level of detail of 3D models produced with automatic techniques is lower than the Tgi3D model (Fig. 4). Comparison of numbers of vertices and faces of the models also supported visual evaluation of the level of detail quantitatively. The Tgi3D model has many more vertices and faces in comparison to automatic models. The number of faces and vertices of the Autodesk 123D have more than the Photosynth model (Fig. 3, Fig. 4).

The Tgi3D model has a high level of detail to provide data about relationships between structural components (Fig. 4.c). The system detail was drawn by collecting data of structural components from different parts of the bridge. This system detail was used to develop the virtual reality model regarded as important for structural intervention decisions.

The mixed structural system detail to be used in intervention decisions of the monument is produced in Autocad 2013 with the help of the reality based 3D model of Hypokremnos Viaduct produced with manual photogrammetric evaluation. In the development of this mixed system detail, not just a specific part of the viaduct is studied but data are collected from different parts of the object that have some deformations (Fig. 5). Construction phases of the historical structure have been interpreted and presented in the virtual reality 3D model with reference to the mixed detail drawing based on the reality based 3D model via Archicad 13.

4.3. Process time

The major advantage of automatic techniques is the reduction they provide in the data gathering and processing periods. Taking photos parallel to the surface and illustrating object-surrounding relationship

is the only requirement. In the office, calibration, orientation and surface construction phases were carried out by the software automatically. However, the detailed Tgi3D model takes a relatively long time (with Intel (R) Core (TM) 2 Duo CPU E8400 @ 3000 GHZ) (Fig. 6).

Processing periods of the automatic software are reasonable for a condition survey if the operator is experienced. Manual software is appropriate for further studies and measures.

5. Conclusion

In this study, our experience of some of the capabilities of the photogrammetric evaluation software Photosynth-Meshlab, Autodesk 123D and Tgi3D; was presented and their suitability for various documentation purposes of irregular ancient monuments was discussed (Table 3). Photosynth and Autodesk are user-friendly software programs that provide acceptable scaled presentations of mass characteristics so they are appropriate for supporting condition surveys. They can be useful for inventory, making preliminary evaluations and guiding limited emergency interventions. The manual orientation package, Tgi3D, provides a detailed 3D model illustrating the relationship between all components and materials and can be used for investigation of the structural behavior of the monument and guide the related intervention decisions.

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Table 3
Pros and cons of Autodesk 123D, Tgi3D and Photosynth + Meshlab for surveys.

	Autodesk 123D	Tgi3D	Photosynth + Meshlab
Process time	+++	+	+++
Reliability	+	+++	++
Level of detail	+	+++	−
Necessity of experienced operator	++	+++	++

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