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PHILANTHROPIC FOUNTAIN OF KORNAROU SQUARE: USING SFM TO CALCULATE THE FOUNTAIN'S GEOMETRIC CHARACTERISTICS IN ORDER TO DETERMINE ITS INELASTIC DYNAMIC RESPONSE

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Abstract: This paper proposes the use of Structure from Motion (SfM) techniques to survey inaccessible monument structures and presents its application on capturing Kornarou Square's philanthropic fountain in Heraklion, Crete. A series of aerial and terrestrial photos of the fountain were combined in order to build the 3D geometry of the monument using Agistoft's Photoscan. This 3D model was used to study the dynamic behavior of the fountain. Its response was determined through multiple inelastic dynamic analyses. The analysis results were summarized in the average dynamic curve.

Key words: **3D photoscan, multi step dynamic analysis, virtual archaeology, digital archaeology, structure from motion**

1. Introduction

In recent years, the rapid development of the capacities of Personal Computers offered new "tools" to contemporary scholars / engineers. Methodologies which a decade ago required specialized, high cost equipment and time-consuming processing of the results, can now be implemented within a short period by using ordinary equipment. The 3D Photo Scanning constitutes such a methodology, according to which, through the use of a conventional camera and PC can be produced a detailed 3D model of any structure. The Photoscan applications are varied and as long as technological progress opens up new capabilities, the applications will be multiplied.

A field, in which the Photo Scanning is predominantly used, is the geometric documentation of monuments (De Reu et al 2013) (Koutsoudis et al 2014). The lack of architectural drawings in combination with the difficult approach of several monumental structures, led to the search for alternative surveying methods. Photoscan is an interesting alternative proposal to deal with these issues.

The aim of this paper is the utilization of the computational capabilities of contemporary computers, by applying demanding procedures such as Photoscan and multi-step dynamic analysis. The Photo Scanning is applied to the Philanthropic fountain of Kornarou square, a 18th century's Turkish sebil located in Heraclion, Crete. The fountain's approach closer than 7m is not possible due to surrounding space's rehabilitation. The purpose of the study is the construction of an accurate model in order to measure in accuracy the outer dimensions of the fountain. Subsequently, according to these dimensions, a simplified finite element model of the fountain was constructed. The estimation of the actual response of the building is made through multiple dynamic analyses.

2. Philanthropic fountain of Kornarou square

During the Turkish occupation, the ottomans' squirearchy felt very strongly the need for finding water for the needs of the citizens, the people''s of the suburbs and their religious demands. During this period, in several Heraklion's squares, philanthropic fountains were built, while other simpler ones were erected in various streets in the centre of the town. Quite a few of them are preserved in good condition.

Figure 1: Philanthropic fountain of Kornarou square.

Philanthropic fountain of Kornarou square is the last preserved of this kind which was built by Hadji Ibrahim aga in 1776. Kornarou square's Sebil is of a circular type building with a domes and around the walls there are

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windows, in front of each one of them there exist a tap with a stone basin for the water to be collected (Fig. 1). Up to 2013, the funtain was used as a traditional coffeehouse.

3. Data collection

The fieldwork is separated into two steps. The first involves the terrestrial and aerial photo shooting of the Sebil. The photo shooting was performed performed following the 3x3 rules. A terrestrial "ring" of photo shoots were taken, fully zoomed out, around the Sebil with a DSLR Sony SLT a58 at 20.4 MP with an 18–55 mm lens. The camera was placed on a tripod at a constant height 1.7m and an average distance of 7 meters from tha fountain. For the photo shooting of the roof, a low cost Parrot minidrone along with a Smartphone (Sumsumg Galaxy S5) were used. The total number of photographs that has been used for the generation of the 3D model of the monument was 54 (42 terrestrial photos and 12 aerial photos). The photo shooting was chosen to take place late in the afternoon when lighting conditions were optimal for the monument.

4. 3D model generation

A 3D model can be generated in an automated three-step process, using Agisoft Photoscan (AgiSoft LLC, 2011, Parthenios et. al, 2015). Primarily, a pre-processing of the implemented photographs is recommended, in order to improve the quality of the model. Therefore, the areas in the images with 'moving' objects or shadows were masked.

The first step of the 3D model's processing includes the images' aligning. During this step a 3D sparse point cloud (17551 points) was generated representing the geometry of the scene (Fig. 2). The alignment of the pictures carried out according to the following arrangements i) Accuracy: high ii) Pair preselection: Generic. Subsequently, a dense cloud (4.408.941 points) was built in order to increase the model's accurate.

Figure 2: Dense cloud.

Figure 3: Final Agisoft Model.

During the second step, the final mesh was created based on the model that resulted from the densification. The mesh was carried out according to the following options: i) Surface type: Arbitrary, ii) Source data: Dense cloud iii) Polygon count: High. For the closure of the gaps, the tool "close holes" (tools-> mesh-> close holes) was used at level: 100%. In the final step, the texture model was built (generic mapping mode and max indensity) (Fig. 3).

5. Finite element Model

The model was exported to .dxf file from Agisoft in order to be imported to Autocad as a mesh. Nevertheless, the mesh model could not be used for dynamic analyses with the finite element software Msc Marc. The most important reasons for this inability are: a) Due to being nonuniform and full of blanks, Agisoft's mesh can not be used as a finite element's mesh (model in not suitable form) and b) The model includes several non-structural items such as the wooden roof and the fountain's decorative elements (eg marble columns).

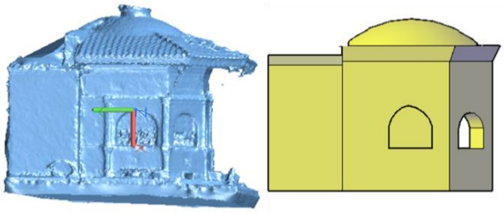

Figure 4: Left: Agisoft's mesh Right: Solid model.

Manual scaling was performed on the original model, based on the dimensions of the western gate of the fountain. The gate's actual width was measured equal to 1.4m and Photoscan model's gate's width is equal to 1.02m. According to these dimensions, a scale 1.4 / 1.02 was performed to the model to calculate all the fountain's dimensions. A simplified solid model was constructed, based on the original (Fig. 4). Overall 6396 3D solid elements were used for the finite element meshing of the model (Fig. 5).

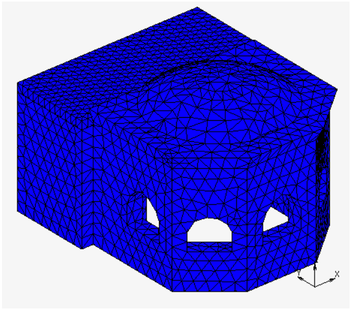

***Figure 5**: FE Model (MSC Marc).*

6. Mechanical properties of masonry

In this model, the compressive strength of the masonry which consists of dimensioned natural stone units and general purpose mortar was calculated according to Eurocode 6. The compression strength of stones (fb) and the mortar (fm) were assumed equal to 0.5MPa and 35MPa respectively (Greek type unreinforced masonry). Based on these values the compressive strength of the masonry is equal to 2.2MPa and the tensile strength alongside the joints and vertically to the joints is equal to ft⊥=0.25Mpa and ft//=0.125MPa respectively. The Young's modulus is calculated equals to E = 2.2GPa (EC6 (3.7.2.)). For the Poisson's ratio v = 0.25 is used. For the description of the inelastic behavior of the masonry the parabolic yield criterion Drucker-Prager is used.

7. Multi-step dynamic analysis

In order to study the response of the fountain, the method of the Multi-step dynamic analysis, was selected. Initially, an accelerogram is selected as reference and then in order to create milder and more powerful ground movements the record is modified by multiplying the amplitudes of accelerations with a single coefficient. So new accelerograms are created and the model is resolved with each of them.

Subsequently, a measure concerning the response of the structure, like the base shear, the node drifts, and the inter-storey displacements, is defined as Damage Measure. It is extracted from the inelastic dynamic analysis and is depicted in a graph in relation to the intensity of the seismic stimulation.

The response of the structure depends to a great extent on the selected recording (frequency, content and duration) for which the analysis was carried out; therefore more recordings are needed in order to estimate the response of the structure more accurately. The seismic input is defined through a poper set of acceleration time histories like recorded accelerograms.

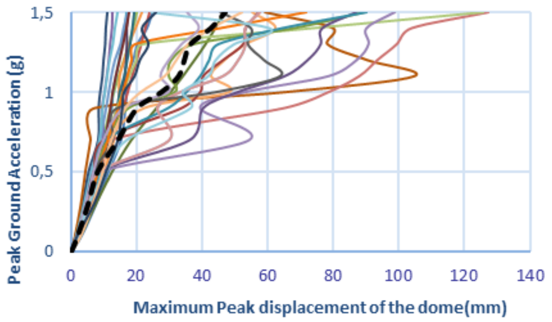

Figure 7: Multi-step dynamic analysis curves.

In this case, the selection of the earthquake records is based on the following criteria (Iervolino et al. 2008, Katsanos and Sextos 2013): i) earthquakes that occurred in Greece and Turkey; ii) compatibility with the type 1 spectrum shape of Eurocode 8 and iii) records from earthquakes with magnitude MS≥5. The acceleration time histories data were obtained from Peer Berkeley Strong-motion Database. Thirty seismic recordings with a gradual escalation of their intensity in 15 steps (0,1g-0,2g-…-1.5g), were used. The Peak Ground Acceleration as a measure of the accelerogram escalation and the maximum peak displacements of the dome as Damage Measure were used.

As confirmed in the results of dynamic analysis, the seismic response for the same level of intensity varies widely between the different seismic loadings. It is observed that the spectral acceleration is significantly altered in each examined accelerograms (Fg. 7).

8. Concluding remarks

The present study attempted to capture the inaccessible Philanthropic fountain of Kornarou square, exclusively through photographs. The study aimed to create an accurate 3D model by Photoscan, the dimensions of which will be able to be used to design a finite element model. Although the goal was achieved, there is considerable scope for improvement of the methodology.

The results of the analysis of terrestrial photographs were satisfactory in exporting an accurate model. On the other hand, the aerial photoshooting with minidrone, did not have the same results. The Agisoft did not recognise the drone's photos due to their poor quality. The use of a drone equiped with higher quality camera would solve these problems.

The geometric characteristics of the fountain were calculated with high accuracy, by making it possible to construct a representative finite element model, which was subjected to multi-step dynamic alalysis. The analysis results are summarized in Multi-step dynamic analysis curves. It is observed that the response of the structure varies among various earthquakes with the same intensity. Furthermore due to the large movements, the fountain might need retrofit.

It becomes clear that the application of Photoscan and FE software, contributes to cultural heritage buildings' study. In order to facilitate and combine this software, the creation of a middleware is required which will be able to automatically convert the Photoscan's nonuniform mesh to FE mesh.

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