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STRUCTURE FROM MOTION TECHNOLOGY FOR HISTORIC BUILDING INFORMATION MODELING OF TORON FORTRESS (LEBANON)

ABSTRACT

Structure from motion (SFM) algorithms greatly facilitates the production of detailed 3D models from photographs we applied this technology for the purposes of Building Information Modeling (BIM) of a historic fortress in Lebanon. Aerial and terrestrial imagery processed in SFM-based software for exterior and interior 3D modeling of the fortress.

In this paper, we applied new geospatial technologies, aerial and terrestrial photogrammetry for Historic Building Information Modeling HBIM database construction. The UAV used for aerial photogrammetry, a DJI Phantom 4 pro with a camera of 20 megapixels for building facades capturing and a DSLR camera for the terrestrial photogrammetry inside the fortress.

Aerial and terrestrial images processed in Agisoft Photoscan for the construction of Toron fortress HBIM of a block Geographical Information System constituted from points cloud, Digital Surface Models (DSM) and Digital Ortho Models (DOM).

HBIM is a novel prototype library of parametric objects, based on historic architectural and archeological data and a system for mapping parametric objects on to point clouds database.

As a result, the production of Toron fortress HBIM database containing Geographical Information Systems (GIS) and Computer Aided Design (CAD) features and entities in the form of sections plans and 3D models for both the analysis and conservation of historic objects, structures, and environments.

KEYWORDS: HBIM, SFM, Photogrammetry, 3D modeling, parametric objects

INTRODUCTION

The terms heritage BIM, Historic Building Information Modelling, HBIM will be used throughout this publication when referring to any use of BIM for heritage and archaeology.

Nowadays, information about historic buildings and archaeological sites is not only represented as, reports, drawings, computer-aided design in CAD; 2D or 3D, but with new geospatial technologies datasets as point clouds, 3D triangulated irregular networks (TIN), Digital Surface Models (DSM) and Digital Ortho Models (DOM).

Unfortunately, geospatial technologies still unknown and inapplicable from a huge number of architects and archeologists and till now it is not added to academicals educational courses. Only organizations dealing with a large portfolio of historic assets are using different types of geospatial systems such as asset management system, facilities management system and geographical information system (GIS). As HBIM is capable of incorporating both qualitative and quantitative information about a built asset to represent physical and functional characteristics, which could be integrated into a 3D model allowing information extraction.

By incorporating high-quality digital survey datasets, HBIM represents the appearance of the existing historic fabric and allows the exploration and complex analysis of several applications such as conservation planning, maintenance, heritage management, and interpretation.

The advantages of 3D geospatial dataset like point clouds for HBIM are significant because of their large volumes and high-resolution gives the possibility to generate realistic 3D models.

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Knowledge of the shape dimensions of a historic building is a fundamental part of a cultural heritage conservation project. The choice of surveying technologies methods is related to the size, complexity, and accessibility of the project. Usually, architects and archeologists use hand measurements, this method is applied to small projects. Total stations and global navigation satellite system (GNSS) is generally used for geographic information system (GIS) data collection and typographic works.

With the fast evolution of Unmanned Aerial Vehicles (UAV) now they can be used to map at scales up to 1:200 at a very high level of details.

Small topographic survey using Total Stations and kinematic GNSS may produce a lower cost site plan but over a large area, UAV survey becomes the efficient method.

With traditional surveying methods operator should choose what to survey and, possibly, missing detail that may not have been required at the time but could prove useful in a later analysis, in photogrammetry all details are captured.

UAVs are far more efficient from GNSS receivers and total station at capturing geographic data, in our project beside total stations and GNSS receivers we used terrestrial and aerial photogrammetry.

Photogrammetry and laser scanning are examples of big projects data collection techniques with millions of points. The generated 3D points constitute the bases foundation of 3D modeling for an HBIM database, in another way they form a complicated issue for CAD users. In this paper we discuss the generation of 3D points based on SfM technology inside and outside Toron fortress for parametric modeling allowing the simulation of different types of intervention, helping architects, archeologists to choose the most efficient solution based on orthographic drawings, sections and 3D models produced automatically from the Historic Building Information Model.

MATERIALS AND METHODS OF THE RESEARCH

Among the historical monument in South Lebanon, Toron the fortress above the village of Tibnin is one of the most important sites for understanding the medieval history of the region [Piana, Curvers, 2004].

The peculiarity and complexity of the architectural elements of the fortress required specific instruments and a variety of techniques for simulations and analysis. The survey started with a GNSS receiver and a total station, it was principally based on four main GPS stations outside the fortress for achieving the external survey and eight total station inside the fortress for an internal survey.

In aerial photogrammetry, we took the whole area of the fortress but for HBIM we surveyed only the big undestroyed part (fig. 1).

The SfM approach, used, in several software like Bundler, Agisoft Photoscan, Photomodeler, and Pix 4D mapper, defines the camera's interior orientation and simultaneously calculates the exterior orientations using tie points (similar pixels) between images in a process called bundle adjustment.

The results of bundle adjustment are a model in arbitrary coordinates, for the geo-referencing of the model in Deir Ez Zor coordinate system we used GNSS receivers for outdoor survey and a Total Station for the indoor one.

As our project is divided into two SfM parts aerial and terrestrial, the workflow methodologies for both parts are the same as listed in fig. 2.

The workflow of Toron HBIM constituted from two-part, aerial and terrestrial photogrammetry.

The aerial photogrammetry outdoor field work part begins by ground control points placement; accurate ground control is essential for project geo-referencing. A total of 8 ground control points (GCPs) were used fig. 3. Removable markers were specified so that no trace would be left once the survey was completed. The position of each GCP was surveyed using a global navigation satellite system (GNSS) receiver to an accuracy of approximately 10mm in x, y and z.

Fig.1. Digital Ortho Model (DOM) of Toron Fortress,
the red ellipse englobing the main building in the fortress

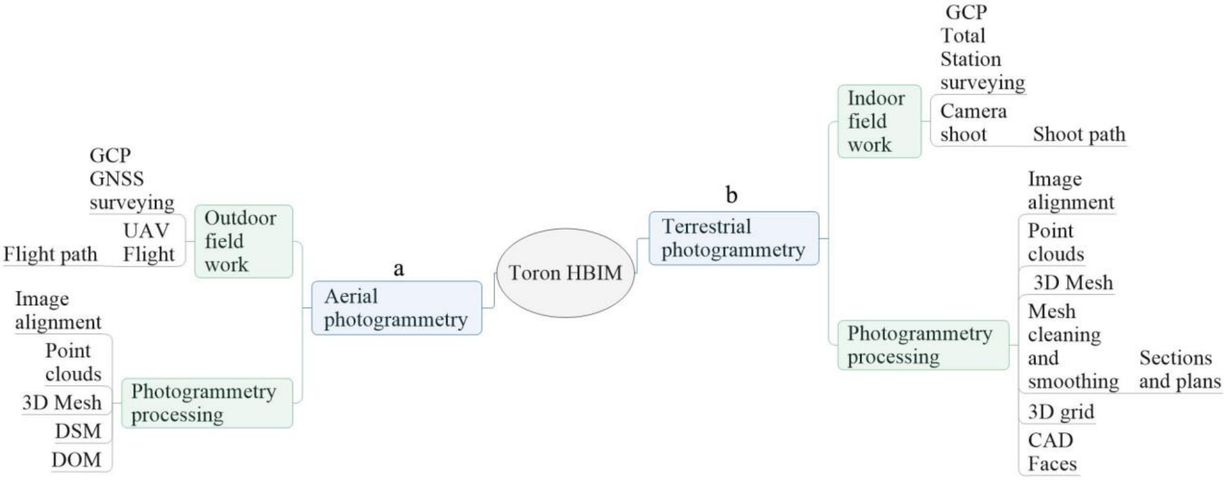

Fig. 2. Toron HBIM workflow:
a) aerial photogrammetry part; b) terrestrial photogrammetry part

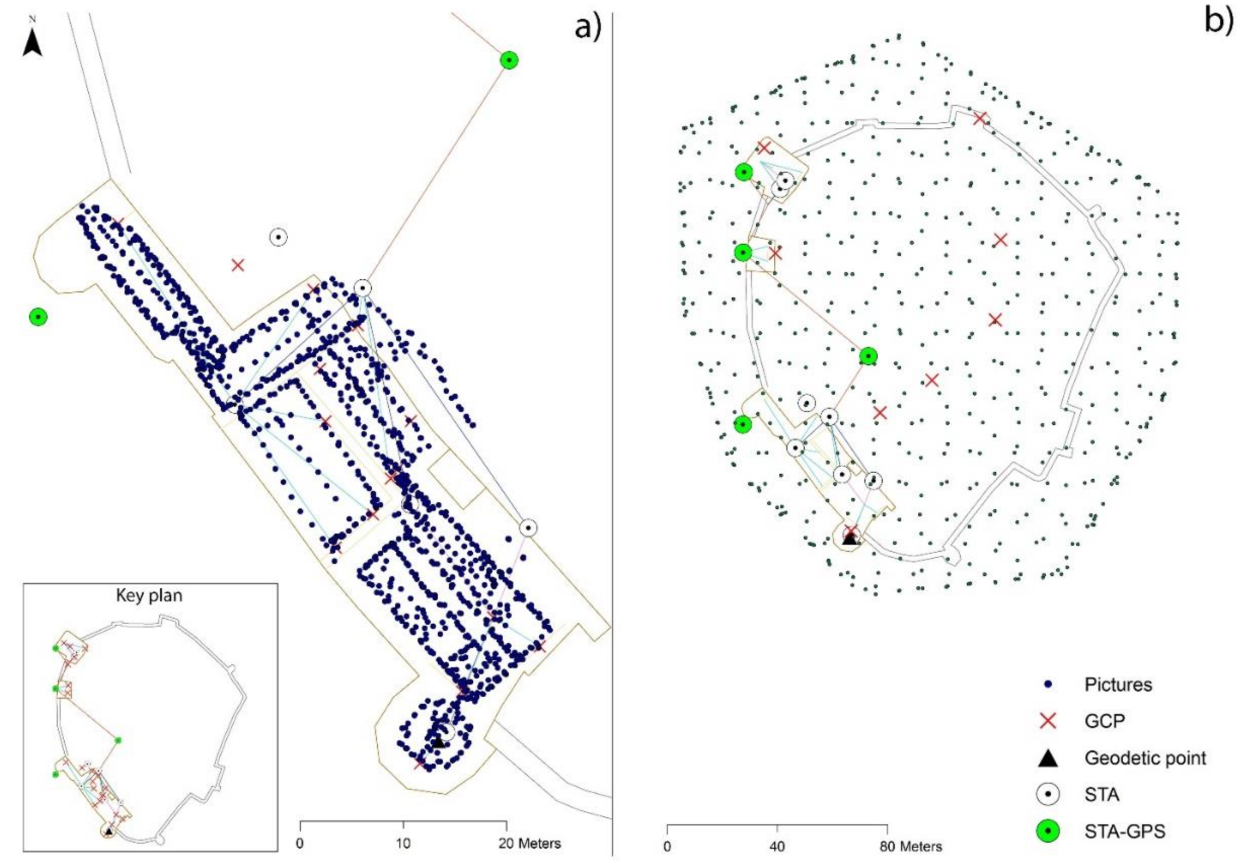

Fig. 3. Toron fortress plans:
a) terrestrial photogrammetry inside the fortress; b) aerial photogrammetry of the fortress

In terrestrial photogrammetry inside the fortress field work, Control Points CP was placed at the walls of the fortress, a total of 15 CPs has surveyed with a reflectorless Total Station of 2 mm accuracy in x, y, and z.

The outdoor GCPs and indoor CPs provide a network of accurate points unified into the stereographic coordinate system of Deir Ez Zor for geo-referencing of the exterior and the interior models of the fortress. A very accurate geo-referencing can provide the basis for long-term monitoring or structural analysis.

Fig. 3 shows the general plan of the fortress with the images taken inside and outside the fortress as a result of terrestrial and aerial photogrammetry, GCPs are symbolized by X, total station and GNSS base points and the geodetic initial point of our project.

Terrestrial images taken inside the fortress manually with a DSLR camera symbolized in fig. 3 a, points were captured following a walking path in a way to get the maximum coverage between simultaneous frames.

Aerial images were taken by a DJI Phantom 4 pro quadcopter with a camera of 20 megapixels with an oblique camera gimbal of 30 degrees from Nadir to capture the facades of the building.

UAV flights made in four different gimbal orientations: North, East, South, and West to cover all the fortress territory, the four flight paths designed in the same way in precision flight mobile application with an overlap of 80 % and a sidelap of 70 %.

The aerial captured overlapping oblique image from an altitude of 60 m above the roof of the fortress more precisely from the taking off point of the drone. 590 aerial oblique images were captured (fig. 3 b); 2314 images were captured inside the fortress (fig. 3 a); each image was manually quality checked to ensure only clear images were processed; 339 images were removed from the data set because of their poor quality.

All aerial and terrestrial captured images were processed using Agisoft Photoscan Professional based on SfM algorithms which are able to reconstruct large-scale environments from a huge number of unordered photo collections in a reasonable time [Frahm et al., 2010; Doumit, Kiselev, 2016]. The SfM approach created a dense point clouds can provide useful information such as static scenes and cross-sections. The generated dataset can be delivered as raw to architects and archeologists for them to extract information in a CAD or GIS system.

The extraction of CAD or GIS data is the foundation of HBIM, surveyors and GIS analysts could provide only colored point clouds, meshes, and textures to a 3D modeler for final correction and renders.

Aerial and terrestrial data generation follow the same photogrammetric processing workflow (fig. 2), beginning from image alignment by SfM technology and ending with the generation of dense colored point clouds.

After the generation of point clouds, subsequent processing steps to provide an HBIM dataset includes:

1. Cleaning and removing the artifact from point clouds;
2. Filtering to reducing the noises;
3. Classification of the point clouds;
4. Meshing and smoothing a TIN;
5. Generating a CAD grid draped on the TIN;
6. CAD Grid 3D faces;
7. Sectioning;
8. Tracing in CAD or GIS for a detailed HBIM (vectorization).

HBIM structures (plans, profiles, and sections) can be generated by using point clouds as a base for the vectorization of features. This operation is carried out by a GIS analyst or a CAD operator it will be a basic data interpretation and will not include the subtleties that can be provided by archaeologist or conservation specialist. GIS analyst and CAD operator can extract only metric data while archaeologists will provide a fuller data interpretation and the data becomes an intelligent attributed dataset that can be queried, analyzed and accessed easily by most end users. The process of mapping vectors onto a 3D point cloud can be improved by automatically placing a 3D grid onto the Triangulated Irregular Model (TIN) mesh interpolated from point cloud (fig. 4).

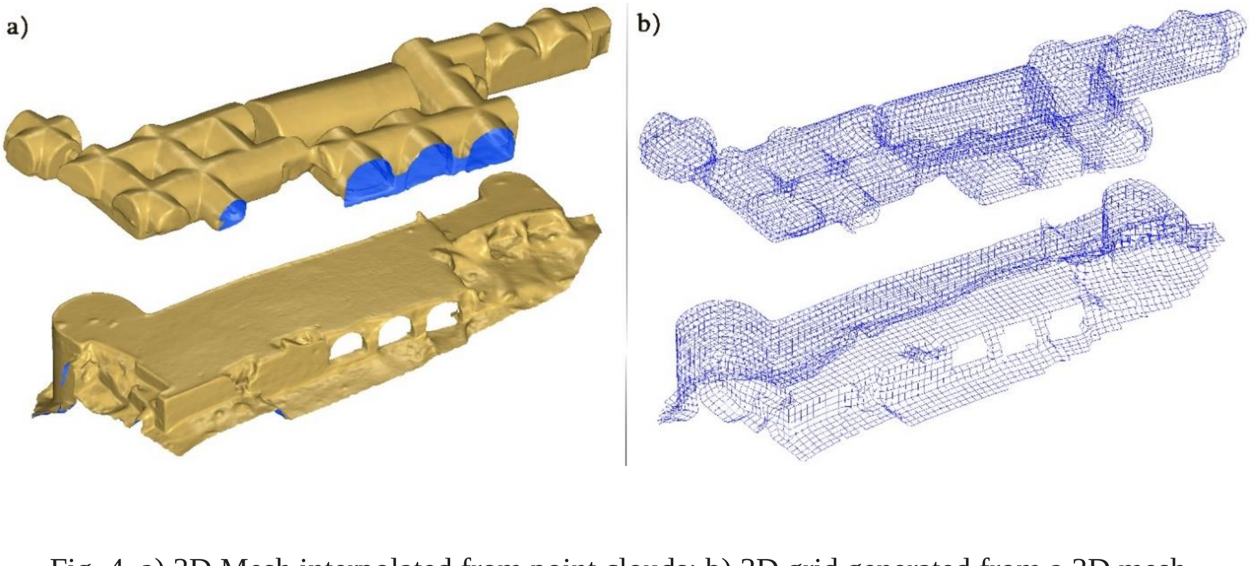

Fig. 4. a) 3D Mesh interpolated from point clouds; b) 3D grid generated from a 3D mesh

The shaded mesh of the fortress of fig. 4 a could be seen in different modes as wireframe, shaded and textured models, the 3D mesh of the fortress showing its internal and external cover without saving architectural details it means smoothing the level of details and removing stone textures. The architectural elements can be represented by a grid fitting the surface as a parametric object and mapped onto 3D mesh or image-based surveys [De Luca et al., 2007]. The 3D wireframe grid fitting the mesh of fig. 4 a, then transferred to a solid 3D faces grid (fig. 5), this 3D faces grid of as a parametric model can be edited to revise any or all of its parameters of construction, texture, and orientation. Parametric CAD differs from generic 3D CAD, generic CAD used to create lines, arcs, and dimensions that in turn create nonparametric architectural elements. These elements exist as graphic entities but they do not have intelligence [Ibrahim, Krawczyk, 2004; Ibrahim et al., 2003]. Mapping vectors onto the point cloud. is a very complex process for architects and engineers as the point cloud data huge size and the difficulty of mapping in 3D space onto a point cloud. Vectors can be digitized onto both the point cloud and the Digital Ortho Model (DOM).

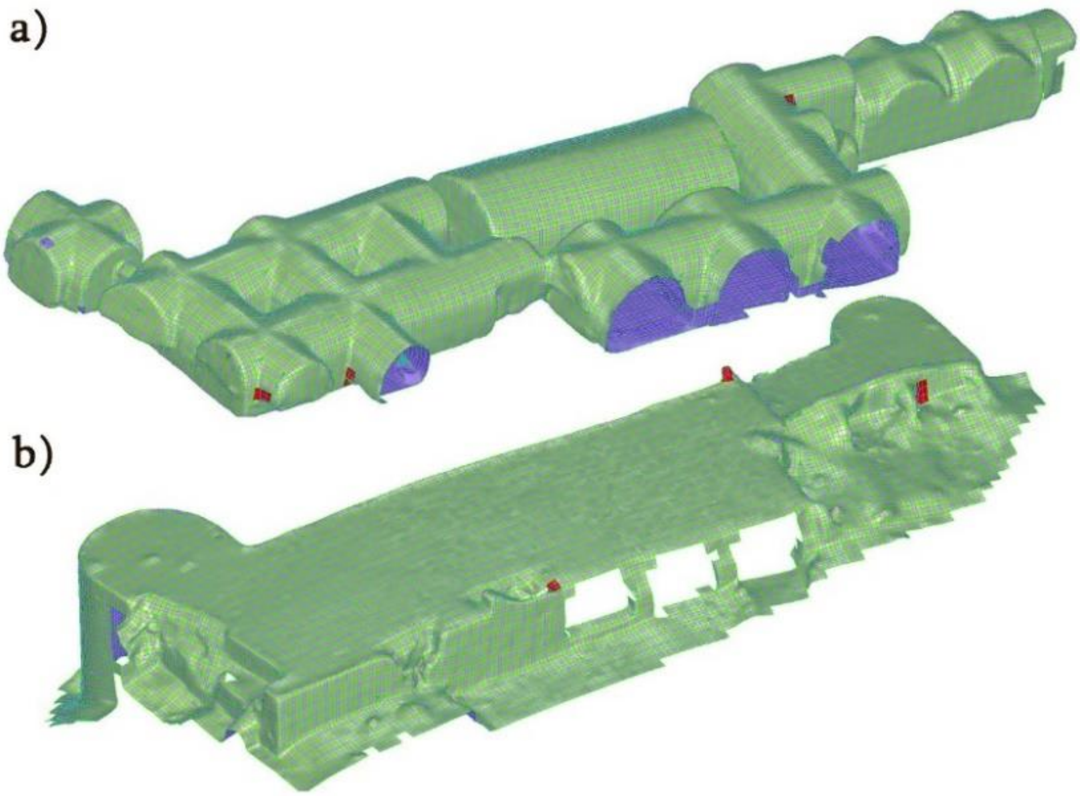

Fig. 5. Parametric models: a) inside the fortress; b) outside the fortress

RESULTS OF THE RESEARCH AND DISCUSSION

An HBIM for Toron fortress was built with a commonly used SfM technology based on Photoscan software. The HBIM intends to create a digital model that provides the greatest amount of fundamental information for any maintenance work or renovation project.

The HBIM of Toron fortress constituted from GIS and CAD databases, the GIS database figure 6a containing a Digital Ortho Model (DOM) for the whole fortress (inside and outside) it helps architects and archeologists digitizing detailed accurate plans, besides the DOM a Digital Surface Model (DSM) generated form photogrammetric software expressing the terrain elevations and structures.

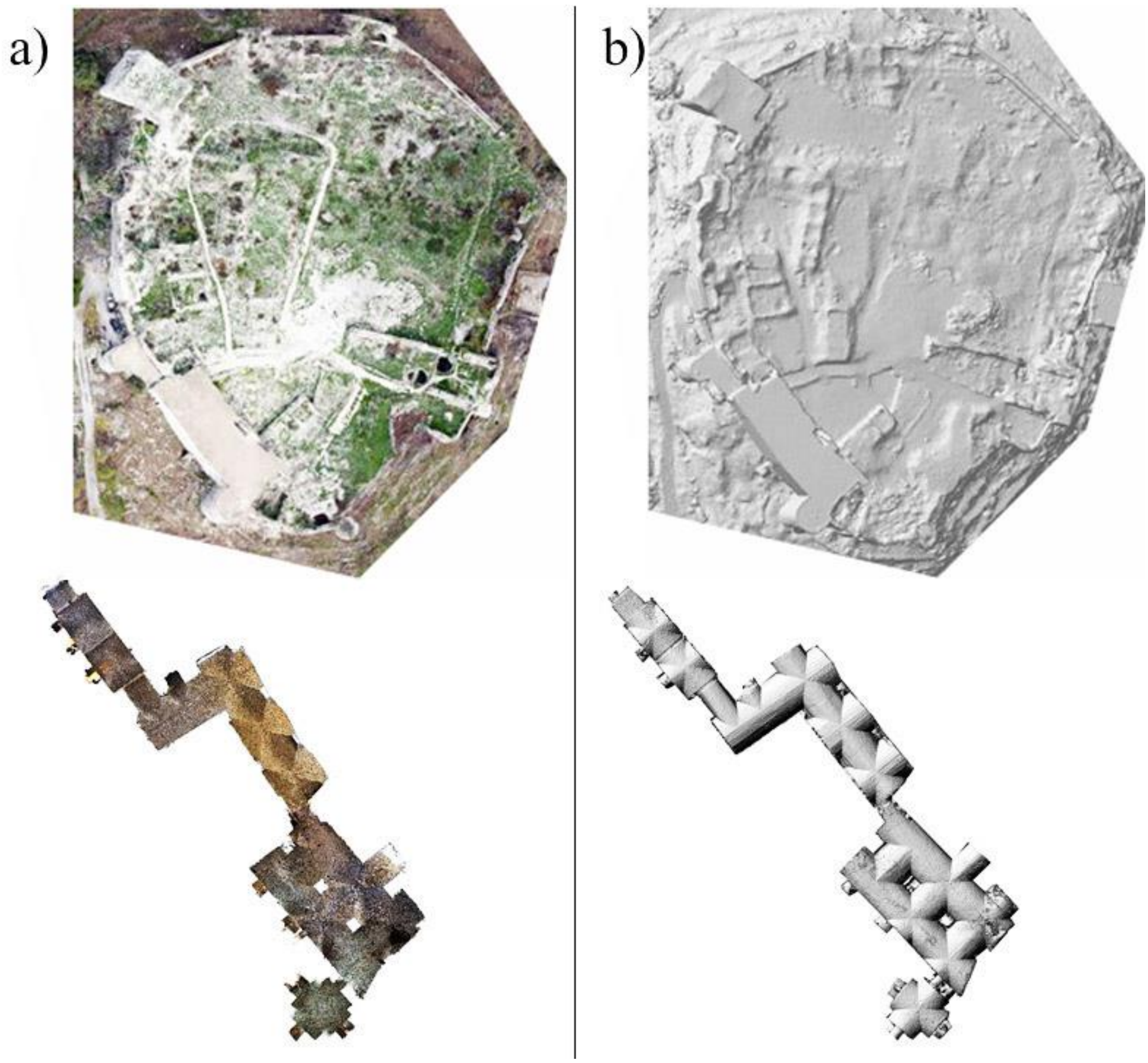

Fig.6. GIS database:
a) DOM; b) Hillshade model

Fig. 6 b of Toron hillshade model generated from the DSM in GIS module showed the unclear archeological structures in DOM figure 6a, these structures could only be detected from DSM and constitute an important research material for archeologists and a new renovation object for architects.

The internal DOM of the fortress showed in details the stone structures of the fortress roof and could form a good dismantling map for restoration purposes.

Fig. 7 of the parametric model showed the internal model with high level of details covered by the external shape of the fortress, this high accuracy model is a huge source of technical information about the fortress dimensions and volumes.

The final result of the HBIM was 2D plans, elevations, and sections of the fortress carried out to a high detail level both internally and externally. Within the issued data, drawing sheets were set up, along with elevations and typical sections in DWG file format. These were then exported as shapefiles to be viewed and analyzed on GIS platforms. In addition to the 2D outputs, a 3D textured model was produced in OBJ format.

The final work includes project drawings and a database, which is suitable for the analysis and design of the fortress.

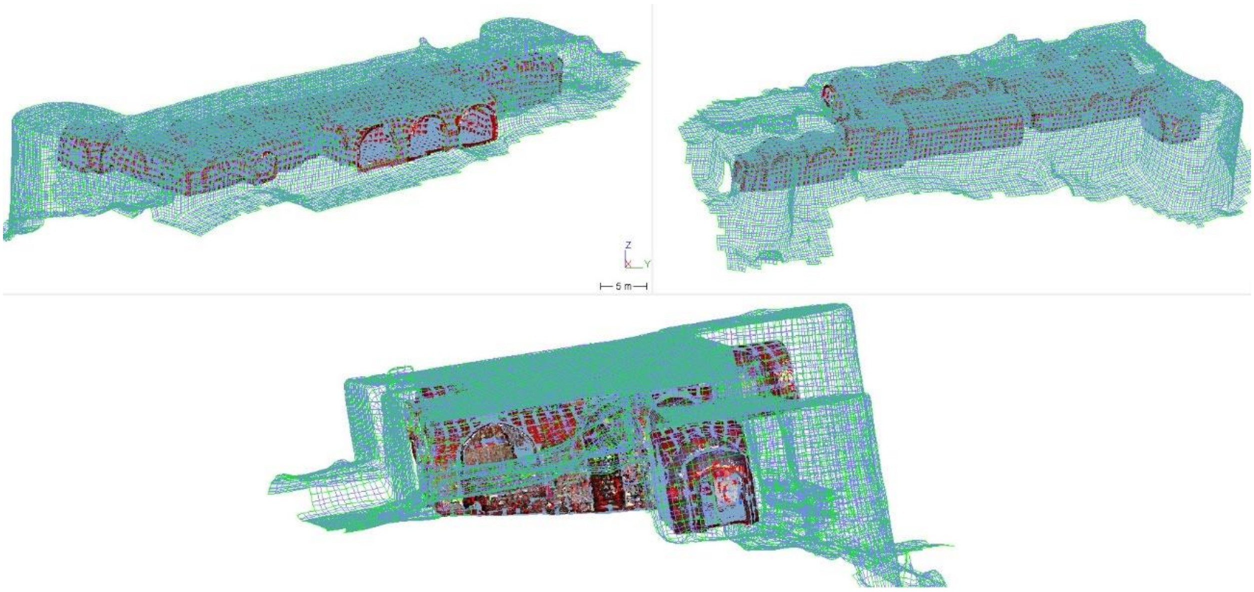

Fig.7. Different perspectives of the parametric models in the CAD database

CONCLUSIONS

This study focused on the work phases and methodologies of a photogrammetry HBIM project, time and their cost, for a global view of various solutions.

Through the example of the case study, it is possible to observe how historical building heritage can be analyzed in different aspects. After a photogrammetry aerial and terrestrial surveys obtained dimensional information allows the realization of the HBIM, including architectural and archeological descriptions in a two and three-dimensions.

This paper proposes a real case example which could form a template to understand the best way to apply HBIM technology before starting a restoration project.

HBIM technology may present a real help in Historical building heritage by contributing to the maintenance of the historical memory of buildings and developing appropriate databases which can be consulted and divided into multiple levels of description.

This paper shows the potential for HBIM for use in the conservation of historic structures and environments by producing engineering survey drawings for architectural heritage conservation.

A new methodology for the HBIM structures and environments is proposed, this process involves the following stages: photogrammetric collection and processing of the acquired images; identification of archeological details from the architectural pattern; mapping of parametric objects, production of drawings and documentation, the creation of detailed 3D.

The HBIM provides full architectural drawings for the conservation of historical buildings and environments including 3D documentation, orthographic projections, plans and sections for future animation and visualization projects.

The development of national Lebanese HBIM libraries would help the greater heritage conservation. The HBIM object would be complete in information relating to archeology, history, and geography.

REFERENCES

1. *De Luca L., Véron P., Florenzano M. A* generic formalism for the semantic modeling and representation of architectural elements. The Visual Computer Journal, 2007. No 23 (3). P.181–205.

2. *Doumit J.A., Kiselev E.N.* Structure from motion technology for macro-scale objects cartography. Breakthrough scientific research as the modern engine of sciences. St. Petersburg: “Cult Inform Press” Publishers, 2016. P. 42–47.
3. *Frahm J.-M., George P.F., Gallup D., Johnson T., Raguram R., Wu C., Jen Y.H., Dunn E., Clipp B., Lazebnik S.* Building Rome on a cloudless day. ECCV, Springer, 2010. V. 6314. P. 368–381.
4. *Ibrahim M., Krawczyk R.* The level of knowledge of cad objects within the building information model. CAADRIA Conference, Seoul, South Korea, 2004. P.173–177.
5. *Ibrahim M., Krawczyk R., Schipporeit G.* CAD smart objects: potentials and limitations. eCAADe 2003. Education in computer-aided architectural design in Europe Conference, Graz, Austria, September, 2003. P. 547–552.
6. *Piana M., Curvers H.* The Castle of Toron (Qal’at Tibnin) in South Lebanon preliminary results of the 2000/2003 Campains. BAAL 8, 2004. P. 333–356.