Establishing a Three-dimensional Model and Digital Documentation of Beaufort castle by using GPS, 3D Laser Scanning and Digital Photogrammetry

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ABSTRACT

Archaeology aims to document and explain the origins and development of human culture, its history, cultural evolution, behavior, and ecology. The increase in threats facing archaeological sites such as terrorist attacks, archaeological thefts and natural disasters requires increasing the efforts to preserve archaeology worldwide. Advances in the three-dimensional (3D) laser scanners and modeling techniques provide a reliable accurate tool for preserving archaeological sites. Terrestrial laser scanners and unmanned aircraft vehicles (UAV) are two major approaches used in 3d modelling particularly for archaeological purposes. To test the performance of each of those methods, a 3D model was generated for Beaufort castle in Arnoun, South Lebanon using both procedures. The terrestrial laser provided higher positional accuracy compared to photogrammetry. Data collected by both the terrestrial laser scanner and UAV photogrammetry was aligned and merged resulting in 3D model, with planar and perpendicular geometries. This study demonstrates the potential of using the integration of terrestrial laser scanning and photogrammetry in 3D digital documentation and spatial analysis for Lebanese archeological sites alongside GPS technology.

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1. INTRODUCTION

Laser scanning is a valuable survey method that reduces costs and increases efficiency. Laser scanning of archaeological sites provides a visualization approach for said sites and thus promotes the rich value of archaeological sites to the general public. In addition, laser scanning allows archaeologists to further their studies and research.

While laser scanning is shaping the future of high-resolution 3D documentation of archaeological sites and features, it is still underestimated by professional archaeologists. Thus, this paper demonstrates an example of the potentials of laser scanning by monitoring and developing a 3D model of Beaufort Castle in Lebanon which is a historical and touristic attraction of great cultural and historic value. The 3D model obtained relied mainly on the use of laser scanning and UAV (Unmanned Aircraft Vehicle) techniques.

Archaeology aims to document and explain the origins and development of human culture, its history, cultural evolution, behavior, and ecology. Therefore, preserving it is a needed responsibility for human civilization. The use of technology to preserve and protect archeological sites from damage has become a must thing to do for the future. the widespread of terrorism mainly represented by ISIS (Islamic State of Iraq and Syria) in Syria, the home of some of the oldest and culturally rich cities and archaeological sites in the world, has led to complete devastation of the UNESCO (United Nations Educational, Scientific and Cultural Organization)World Heritage Sites in Syria, and this is only the tip of the iceberg. The situation has worsened since ISIS jihadists, whose strict Salafi interpretation of Islam deems the veneration of tombs and non-Islamic vestiges to be idolatrous, seized swathes of Syria and Iraq in recent months, destroying sites and burning precious manuscripts and archives (Mulder. 2014).

Natural disasters can also strike and threaten a country's art, artifacts, and cultural heritage. Earthquakes, wildfires, volcanos, landslides, hurricanes, and floods are just some examples of natural disasters. A country's geographical location and geological make-up are just some of the factors that contribute to whether a natural disaster will strike or not. They occur without warning and can cause irreplaceable damage and destruction. Lebanon has a history of earthquakes, most notably the earthquake that struck the Lebanese coast and destroyed Beirut in 551 A.D. Another earthquake of magnitude of 7.6 at the Yamuna fault caused the fall of 31 columns from Baalbek temple and serious damage in Tripoli and Baalbek cities. In recent history, many tremors occurred of magnitude 6 most notably in 1956 at the Roum fault which caused damages in the region of Iqlim Tuffah, Iqlim al-Kharroub and the Bekaa (Akiki, V. 2014).

One of the major examples demonstrating the potential of 3D laser scanning in preserving historical and architectural sites is the work of engineer Andrew Tallon on the Notre Dame cathedral in Paris. After the 2019 fire broke in the cathedral, Tallon used the previously scanned data to construct a precise 3D model of Notre Dame based on the highly dense point cloud. His model will be the solid foundation towards restoring and rebuilding the historic landmark.

Laser scanners used LiDAR (Light Detection and Ranging) technology to capture data. It is an optical remote sensing device that can determine a target's range or other properties by lighting the target, often using laser pulses. LiDAR uses ultraviolet, visible and near-infrared light to view objects and can be used with a wide variety of targets, including non-metallic objects, stones, rain chemical compounds, aerosols, clouds and even single molecules (Cracknell, et al, 2007). A small laser beam can be used to map very high-resolution physical characteristics of objects of interest.

Compared to conventional surveys where angles and distances are measured, the main advantage of photogrammetry is its ability to depict even the smallest details of the structure studied. In any restoration work, the photogrammetric survey can be considered essential as it offers a complete geometric overview of the elements involved in the structure to be analyzed with high precision. The aim of a terrestrial photogrammetric survey is to provide accurate data on the form, size, and location of a structure or monument at a given time to assess its actual conditions and architectural aspects.

Aerial photography is a very valuable tool to be paired with other archeological techniques because of the full sight of the study area it offers. With any supported drone, topographical surveys can be quickly performed using the fully independent flight modes and then create high-resolution orthomosaics and 3D models using various image processing software. For accurate mapping of drones, ground control points are necessary.

2. METHODOLOGY

2.1 Study Area

Beaufort or Qala'at al-Shaqif is in Lebanon, about one kilometer from Arnon. It was built by the Romans on a high rock «Cher » overlooking the Litani River, Marjayoun plain and the Nabatieh area. Its geometry twists with the mountain, and its walls are built with local rocks. These make it seem "hidden" amid the rock. The historic castle is known as Beaufort, a beautiful fortress. The castle is built on a rocky section in a north-south direction rising about 710 meters above mean sea level. The castle spans on two levels: to the west is the upper castle that commits the junction of the extrusion, to the east is the lower castle which overlooks a steep slope above the Litani River.

Figure 1. Beaufort al-Shaqif Castle

Qala'at shaqif castle (Figure 1) was very important due to its strategic location on the mountain which stands atop a 300 meters' cliff that declines steeply to the river.

The entrance to the castle is reached from a plateau to the south. Entrance A (Figure 2) is surrounded by two circular towers and leads to a lower courtyard through a covered passage to reach the upper castle. It required the rise of a steep walkway and traversed two consecutive entrances B and C.

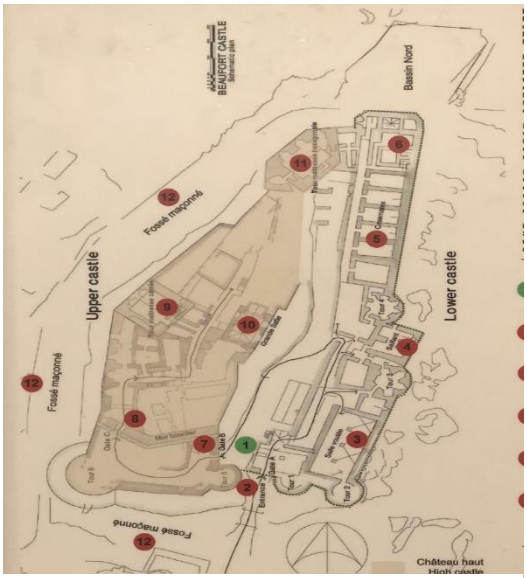

Figure 2. sketch of Beaufort Al-shaqif (Beaufort administration)

1. You Are Here
2. Gate A
3. Stables
4. Firing Chambers
5. Barracks
6. Tower Residence
7. Gate B
8. Gate C
9. Main square tower
10. Gothic Hall
11. Main hexagonal tower
12. Castle Ditch

The overall area of the study area is 7190 m^2 (Figure 3) as shown in the AutoCAD generated map below.

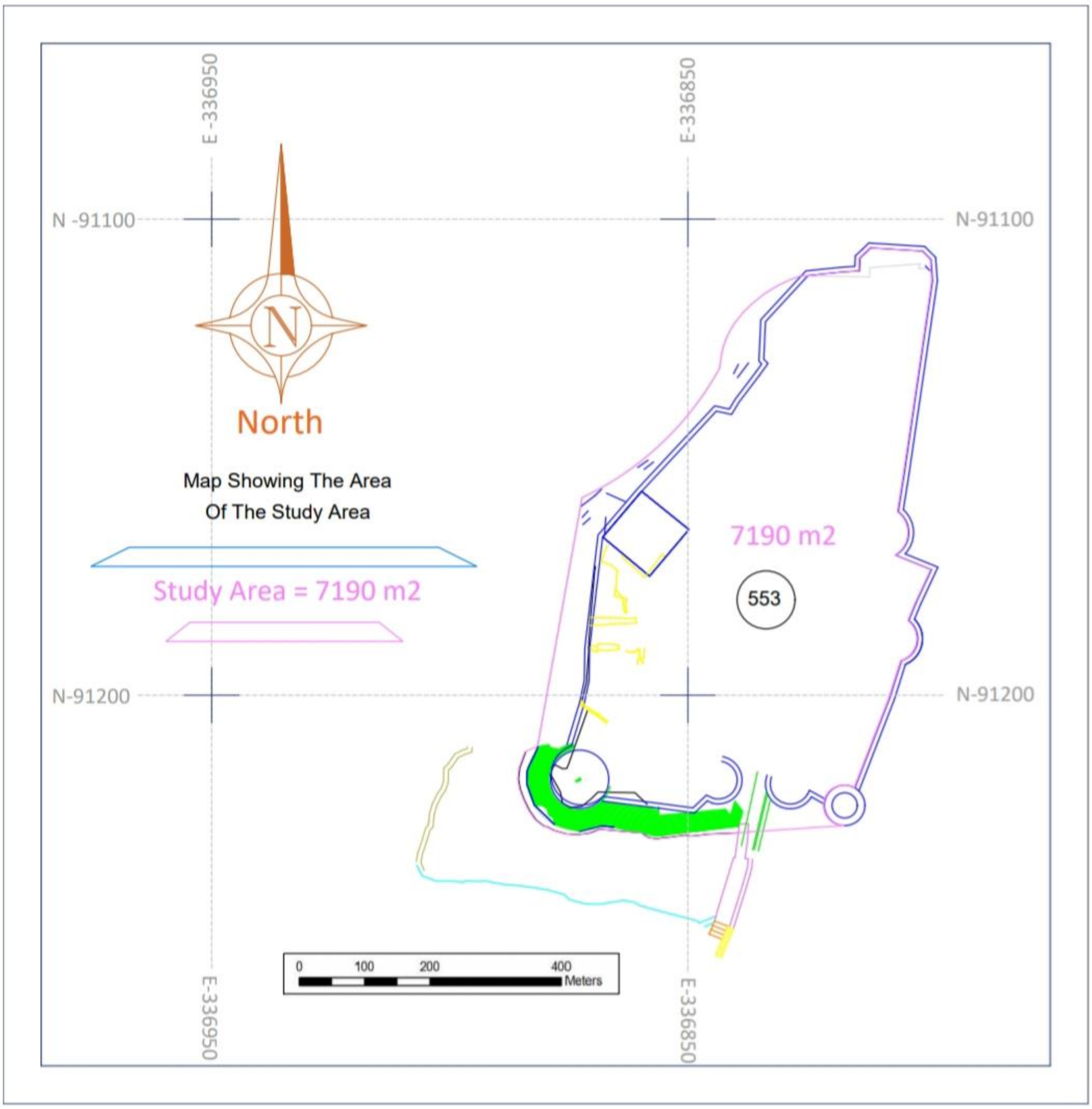

Figure 3. Study Area Map

The castle was vandalized by the Israeli army and bombed several times before the 1982 invasion. The occupation army then used it as a military post. The occupation forces attempted to destroy the features of this castle, where the walls were collapsed and cracked because of the movement of military vehicles inside the campus of the castle. Add to this, the change in the shape of the castle's geometry. The raids and artillery bombardment destroyed the main tower and the outer walls of the castle during the years of occupation. But the filling of the tunnels surrounding the hill of Shaqif Arnon remains one of the most disastrous actions ever known. Dug by the Crusaders to secure a defense center for the castle, the trench was first filled by the Israelis with cement, and then they built fortifications inside it. Before the withdrawal, the

Israeli army had intended to blow up the structures inside the trench, which would inevitably lead to the destruction of the site (Solyman Daher Ameli).

After wars that damaged the castle, the Lebanese government has taken numerous plans for restoring and repairing the castle with the latest ongoing construction started in 2018.

2.2 Workflow

The initial and most crucial step was obtaining the approval from the Lebanese Ministry of Tourism in order to access the castle and perform the study. An overall workflow of field and office work is depicted below (Figure 4).

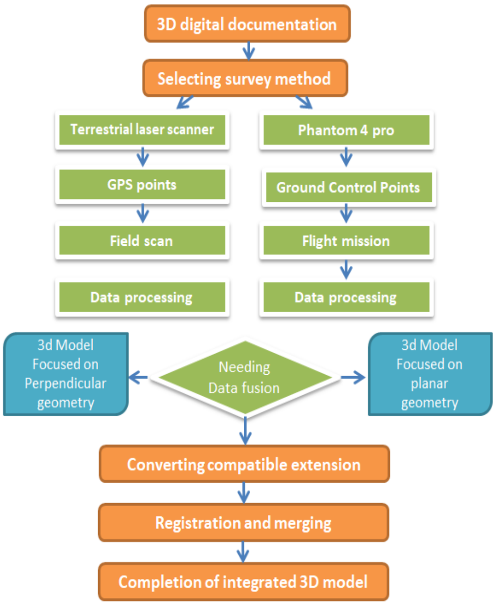

Figure 4. Workflow of integrated 3D modeling using TLS & Phantom 4 pro

2.2.1 Global Positioning System (GPS)

In order to determine the ground location of an object, Global Positioning System (GPS), satellite navigation system, was used. To start location points using GPS, an accurate point (base) was needed. GPS station points were recorded Real Time Kinematic (RTK) method using Sokkya and Topcon GPS system.

2.2.2 3D Laser Scanning

The P30 model is a mix of range, speed and accuracy that is adaptable for a range of scanning clarifications. In this work, resolution of 1.6mm @10m was used. Every scan took around 13min. With respect to the Image resolution, HDR with resolution of 1920x1920 was taken for an estimated time of 7 minutes.

2.2.3 Ground Field Work

The starting point was establishing a survey network using Sokkia GPS (base and rover) and setting up base on known station points near the castle (accurate point) to achieve a great accuracy network. These points were chosen to facilitate scanning the entire site. Upon ensuring the visibility of at least four satellites within range, fixed accurate measurements were taken with precision. Then, the laser scanner is set up on a tripod over a known point, entering the coordinates of the occupation point and the height of the instrument. Setting up the target over a visible back sight point (over a tripod or directly on ground) and entering the coordinates of this station on the 3D laser scanner, the target is chosen. At this level, the camera will automatically open zoom in and focus on the target to precisely focus on the center of the target. The needed settings by are edited by adjusting the laser scanner height and back sight height and prior to scanning.

2.2.4 Drone Field Work

Phantom 4 Pro is the drone used for the flying portion of this work. In order to identify the detailed path of the drone, Geo Flight was used for mission planning. The mission included 245 way points distributed in 11 lines with a speed of 15 m/s and flying height of 40.7 m. The camera used is the FC6310 model having a focal length of 8.8 mm and pixel size 2.41×2.41 μm mounted on the Phantom 4 Pro. The mission had an 80% side and front overlapping. The total flying time was about two hours with the drone's maximum flight time being 30 minutes.

2.2.5 Software Processing

Agisoft Metashape is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications, archeological documentation, and visual effects production as well as in indirect measurements of objects of various scales. The data collected by the Phantom 4 Pro and by the laser scanner was projected into the same coordinate for processing. Agisoft processed around 560 digital images alongside the Ground Control Points (GCP) for an accurate final model. At the end of the process, the Root Mean Square Error (RMSE) from the forming 3d model through the report taken from Agisoft was checked (Table 1).

Table 1. Control points RMSE

Count	X error (cm)	Y error (cm)	Z error (cm)	XY error (cm)	Total (cm)
5	2.24599	2.12691	3.4843	3.09325	4.65925

3. Results

Cloud Compare is 3D point cloud processing software such as those obtained with a laser scanner or Digital image (point cloud). It can also handle triangular meshes and calibrated images by converting the Digital photos to point cloud (using Agisoft).

The two models are integrated by the registration of point clouds using ICP tool and taking the reference the laser Scanner (yellow) and photogrammetry (red) (Figure 5). The error decreases after integrating the photogrammetry cloud with accurate reference laser scanner cloud.

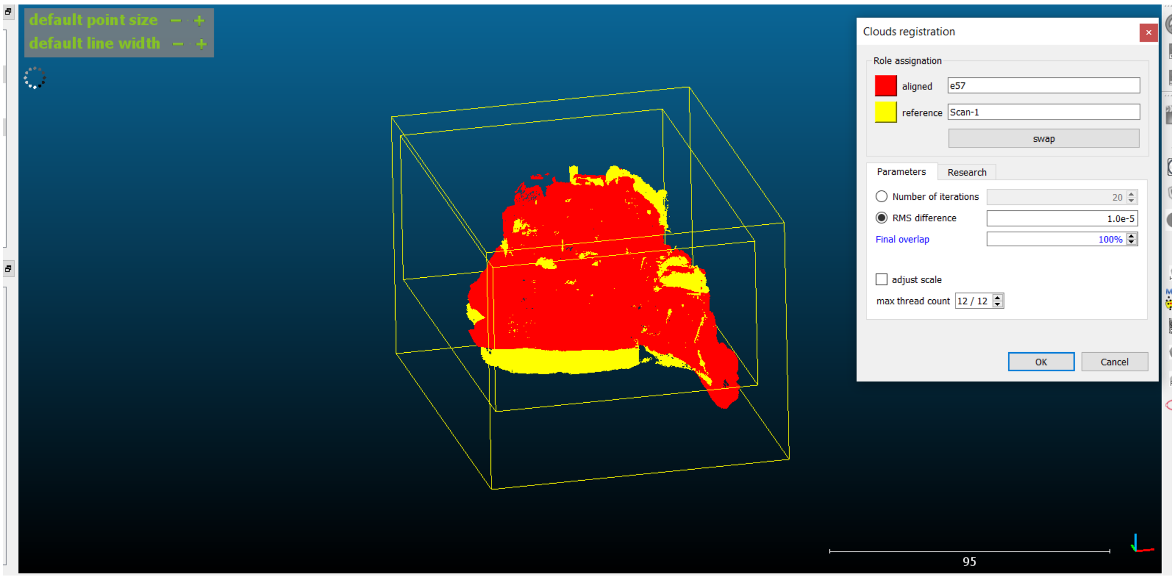

Figure 5. ICP registration

Final RMS:9.03572 CM

Transformation matrix

0.892	-0.063	-0.448	-41887.191
0.016	0.994	-0.108	4821.728
0.000	0.000	0.000	1.000

Scale fixed (1.0)

Theoretical overlap 100%

The final result integrated the two technique instruments in one accurate 3D model for Beaufort castle (Figure 6).

Figure 6. Final integration Model for Beaufort Castle

4. Conclusion

This study has established an accurate 3D model of Beaufort Castle using terrestrial laser scanning and Phantom 4 pro photogrammetry to get digital documentation of the place from different directions.

Laser scanning showed a high data acquisition rate in the perpendicular direction, whereas photogrammetry generated high-level planar point clouds. Such tools proved their efficiency in scanning archaeological sites since they can determine the layout conditions and topographical features based on an orthoimage. Yet, such techniques could still be of limited application if precise survey drawings are required.

Constructing a 3D model of the topography along with building shapes through a hybrid convergence technology was a key issue. The accuracy of the two technologies based on GCPs before their convergence was analyzed: laser scanning has higher positional accuracy than photogrammetry, and the overall discrepancy of the two technologies was sufficient to generate convergent data. The photogrammetric point cloud data was, then, aligned and merged based on the laser scanning results.

Photogrammetry could improve the 3D model by complementing the point cloud data for the upper parts of buildings which are difficult to get through laser scanning, thus increasing the accuracy of the overall topography as well as the shape of an individual building. Documenting archaeological sites and preserving all the information and details about them have always been considered important especially during natural disasters and wars. Nowadays, and with the rise of terrorist attacks in the region as in Iraq and Syria, it has become a national duty to preserve the legacy and revitalize the economy through tourism.

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