# Digital Documentation and a 3-D Model of Beaufort Castle via RTK GNSS, Terrestrial Laser Scanner and UAS-based Photogrammetry

*Yousef* Naanouh[1]* and *Vasyutinskaya Stanislava*[2]

[1, 2]MIIGAiK, Moscow State University of Geodesy and Cartography, Moscow,Russia.

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**Abstract:** Three-dimensional digital technology is important in the maintenance and monitoring of archeological sites. This paper focuses on using a combination of terrestrial laser scanning and unmanned aerial vehicle (Phantom 4 pro) photogrammetry to establish a three-dimensional model and associated digital documentation of Beaufort castle (Arnoun, South Lebanon). The overall discrepancy between the two technologies was sufficient for the generation of convergent data. Thus, the terrestrial laser scanning and phantom 4 photogrammetry data were aligned and merged post-conversion into compatible extensions. A three-D dimensional (3D) model, with planar and perpendicular geometries, based on the hybrid data- point cloud was developed. This study demonstrates the potential of using the integration of terrestrial laser scanning and photogrammetry in 3D digital documentation and spatial analysis of the Lebanese archeological sites.

* Corresponding author: eng.yousefnaanouh@gmail.com

# 1. INTRODUCTION

Laser scanning is a quite efficient survey method to reduce costs. Surveys are realized by a laser scanner which allows quick surveying (scanning) of landscapes and structures: their furnishings and arrangements as well as installations.

Nowadays, laser scanning of buried archaeological elements will provide an effective solution to their visualization. Consequently, this will increase the chance for the community to appreciate these findings, rather than keeping this experience exclusive for archaeologists that took part in the excavation. Laser scanning also allows these archaeologists to proceed with their studies, formulate further hypotheses, and elaborate their research, even when the excavation is closed [1].

Terrestrial 3D laser scanning will become the future standard tool for high-resolution 3D documentation of archaeological excavations, but its capabilities are still underestimated by professional archaeologists, and providers of scanners or, scanning services. The new tool forces archaeologists to consider the extension of archaeological stratigraphy theory. This paper presents examples of the beneficial use of laser scanning and proposes an extended theory [2].

Our project aims to monitor and develop a 3D model of Beaufort Castle (Qala'at Shaqif Arnoun); a historical touristic attraction, and one of the most important Lebanese monuments, using surveying techniques; Laser Scanning, GPS, AutoCAD, and drone. These techniques allow us to construct a 3D surface model by locating points in the ground called ground control points (GCP). And, with known coordinates and elevation, we can obtain accurate results using specific software for drones, to conduct a mission plan before flying.

# 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.

Beaufort castle (Figure 1) was notably important due to its strategic location on the mountain, which stands atop a 300-meter cliff that declines steeply to the river.

**Figure 1.** Beaufort Castle

The overall area of the study area is 7190 m² (Figure 2) as shown in the AutoCAD generated map below.


**Figure 2.** Area of the castle

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 approval from the Lebanese Ministry of Tourism to access the castle and perform the study. An overall workflow of field and office work is depicted below (Figure 3) [3].

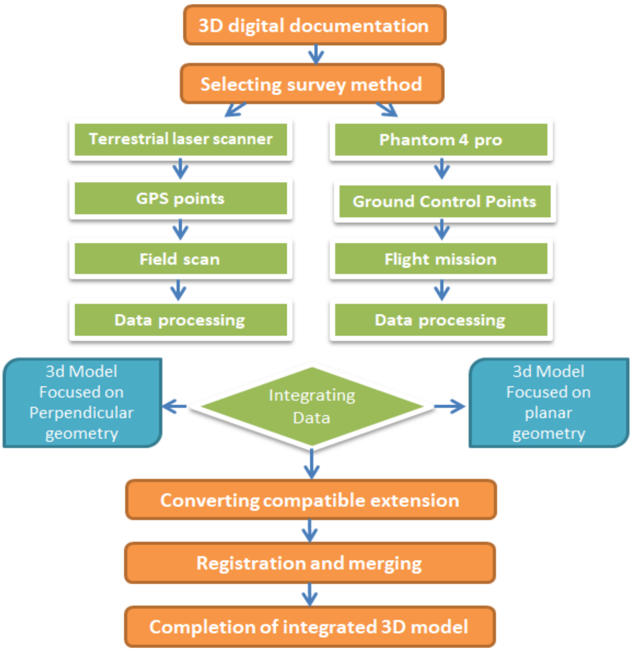


**Figure 3.** Workflow of integrated 3D modeling using TLS & Phantom 4 pro

#### *2.2.1 Global Positioning System (GPS)*

To determine the ground location of an object, Global Positioning System (GPS), a 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. . Based to our work the accuracy could be reach in this instrument from few mm to 1-2 cm which is great result for digital documentation.

#### *2.2.2 3D Laser Scanning*

Within the field of 3D object scanning, laser scanning (also known as lidar) combines controlled steering of laser beams with a laser rangefinder. By taking a distance measurement at every direction the scanner rapidly captures the surface shape of objects, buildings and landscapes. The P30 model is a mix of range, speed, and accuracy that is adaptable for a range of scanning clarifications. In this work, a resolution of 1.6mm @10m was used. Every scan took around 13min.Concerning Image resolution, HDR with the 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 a 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 backsight point (over a tripod or directly on the 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 are edited by adjusting the laser scanner height, and backsight height, before scanning [4].

#### *2.2.4 UAS based data collection*

Phantom 4 Pro is the drone used for the flying portion of this work. To identify the detailed path of the drone, Geo Flight was used for mission planning. The mission included 245 waypoints distributed in 11 lines with a speed of 15 m/s and a 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 [5].

#### *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) |
|---|---|---|---|---|---|
| **4** | 2.24599 | 2.12691 | 3.4843 | 3.09325 | 4.65925 |

## 3. Results

Cloud Compare is a 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 the ICP tool, and by taking the reference: laser Scanner (yellow), and photogrammetry (red) (Figure 4). The error decreases after integrating the photogrammetry cloud with an accurate reference laser scanner cloud.

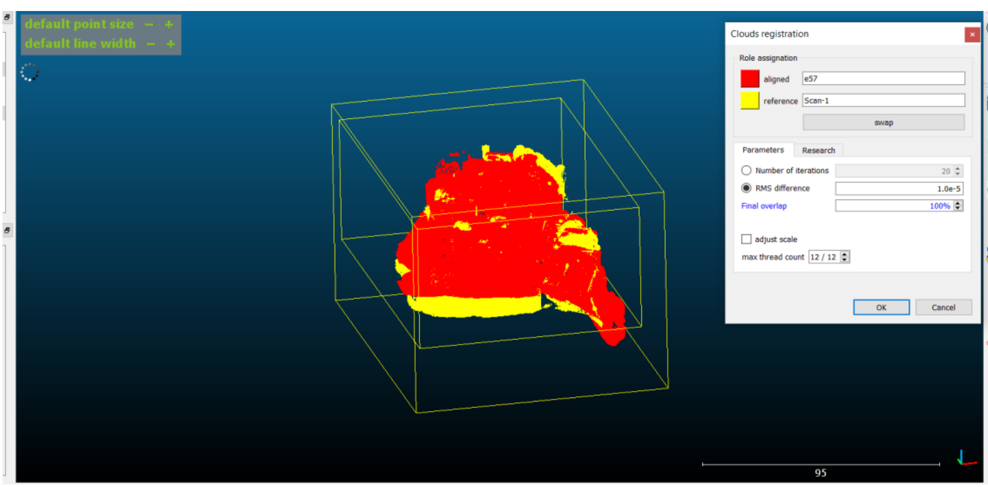


**Figure 4.** ICP registration

**Table 2.** Register Info (cm)

| | | | |
|---|---|---|---|
| **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 5) so now the model is accurate specially it collects the advantages of drone which depend on planner surfaces and advantages of laser which depend on the vertical surfaces.

**Figure 5.** 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 have 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. To wrap things up, 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 our area 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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