The big structures modeling and archiving using terrestrial laser scanner and proposing a new geodetic method for future monitoring

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Abstract. The terrestrial laser scanner (TLS) method was developed to be the optimal digital technology to protect and preserve various objects, including cultural heritage monuments for about 20 years ago. This method allows the high precise measurements of cultural features at archaeological sites in the aim of preserving them for the future generations. However, the traditional geodetic techniques, such as GPS and Total Station (TS) are still needed for assuring the geo-referencing of the resultant model. This article presents the results of the study of the state of the Temple of Jupiter in Baalbek castle, Lebanon. In addition, a 3D virtual model was created using terrestrial laser scanner [1]. A new method for monitoring strain is also proposed for direct and rapid detection of any changes in building structures [3].

Introduction

The article proposes a technology of three-dimensional ground-based laser scanning technique, as an efficient and quick technique for documentation, and then conservation of archaeological sites [2].

Laser scanner covers all the objects in the lens visual field, then the reverse laser beam is processed and records at a speed of 1000 points per second and each point has X, Y and Z coordinates with physical characteristics from the object [4]. The surveyed points are transferred to professional software for creating 3D point cloud model using TLS technique. The model gives the ability to present a very highly detailed model in computer screen. Prior to the laser scanner revolution, the survey was limited to the total station or GPS, which is a point measurement (without building a points cloud), not providing the same TLS details. A perfect example showing the importance of heritage and archaeological site archiving is the Notre Dame Cathedral fire that recently occurred in France.

The main aim of this article is to document and archive the historical temple in Baalbek city by developing a 3D model (inside and outside) to repair and reconstruct it in case of total or partial destruction. In addition, the article will propose a new monitoring method using laser scanning, GPS and Total station techniques which can help in saving the temple from any possible deformations of natural or man-made origin.

1. Case study

Baalbek is a city in northeast Lebanon far from the capital Beirut about 82 km; Baalbek Castle was built in 2000 B.C, it is the famous Romanian castle (Figure 1)
The temple complex of Baalbek is made up of Bacchus and Jupiter Temples. The Temple of Venus is located not far away from the circular structure. Only small part of the staircase remains from the fourth temple dedicated to Mercury, on Sheikh Abdallah hill.

Unfortunately, only a part of the great temple or “the Jupiter Temple” can be seen today. The complete sanctuary is approximately 120 m wide and 270 m long. The complex consists of four sections: The Hexagonal Court, the monumental entrance or Propylaea, large court and the main temple of Jupiter. These fragments give an idea of the huge scale of the original structure. [15]

![Figure 1](image.png)

**Figure 1.** Top View of Jupiter Temple in Baalbek castle, Lebanon: A. monumental entrance, B. hexagonal yard, B. large yard, D. Main temple part.

2. Materials and Methods

2.1. Planning and Networking

Field work included drawing up a terrain plan and selecting the best location for future points of the geodetic network. In addition, the positions of the scanner sites for DLS were planned in order to cover all parts of the temple when taking pictures.

Then it was necessary to create a geodesic coordinate network in kind to perform surveys, orient tachometers and DLS. The network allows you to integrate all types of shooting into the system. In this case, the network was external and internal, both parts are interconnected.

**Table 1.** GPS Observations.

| Name           | Horz RMS (m) | Vert RMS (m) |
|----------------|--------------|--------------|
| Base1–Entrance | 0.002        | 0.003        |
| Base1–Base2    | 0.002        | 0.005        |
| Base1–jupiter  | 0.001        | 0.002        |
| Entrance–Base2 | 0.003        | 0.004        |
| Entrance–jupiter | 0.001      | 0.002        |
| Base2–jupiter  | 0.002        | 0.004        |

First of all, the computing the coordinates Topcon hyper v (Figure 2) was in static mode. By fixing two GPS receivers on two Primary points first order (Base 1 and Base 2 points) while the other two were fixed on the new points (Entrance and Jupiter points) to be measured and computed. Based and according to “Geometric Geodetic Accuracy Standards” [12], the received horizontal RMS errors (Table 1) were within the tolerance.
After the measurements processing in static mode, Topcon total station (Fig.ure 2) was used in the aim of generating 3 traverses between those two points. The first was inside the temple passing through the three squares of it and the two others were outside, at north and south of temple; the most parts of the temple were covered. The measurements were done in direct/reverse mode and using a fixed prism on a tripod, to obtain a high accurate and precise coordinate. The distances and angles were adjusted using the least square adjustment method and the resultant relative accuracy was 1:30000 which is considered as Main Control Traverse class H3 (referring to Accuracy Standards of Control Survey) [13].

![Figure 2. GPS Topcon hyper v and Topcon OS 103 Total station respectively.](image1)

The digital level was used to compute the elevation of control network points, with a sub millimeters accuracy.

2.2 Laser scanning

Laser scanning of the temple was performed at different scanning resolutions with different time intervals. A Leica Scan Station P30 laser scanner was used (Figure 3), which provides high-quality 3D data and HDR images with (Canon EOS camera) based on the phase shift principle.

![Figure 3. Leica P30 lase scanner](image2)

The accuracy of a single measurement at the Leica Scan Station p30 is 1.2 mm + 10 ppm (over the entire scan range). The accuracy of the three-dimensional position is 3 mm at a distance of 50 m; 6 mm per 100 m, and the reflectivity of the surface under study is about 18% at a distance of 120 m. [14].
During the field work on laser scanning, all requirements for the production of works were met. A total of 24 scans were performed in the range from high to low resolution (from 3 to 6 scans per day).

3. Processing
The 3D laser scanner data collected from TLS had been processed to the Leica Cyclone software, one of the popular and powerful software for the point cloud processing (Figure 4) [14].

![Figure 4. Point cloud model of castle.](image)

Importing data and creating the project is the first step of processing, after that all data from all scans are combined into a single point cloud model.

The results of laser scanning can be summarized by an as built created in the format of point clouds, meshes, 3D textures and a site map (TRUVIEW).

4. Results
As a result of the registration process of ground base laser scanning data, produce a very dense and high accurate point cloud of several milliard points. Its error values for coordinates in fixed registration 0.009 m and didn’t exceed 7 mm in horizontal RMS error (Table 2).

![Table 2. Mean error values for coordinates in fixed registration.](table)

5. Monitoring & change detection
All the buildings and structures, including cultural monuments, can change their shape - deform for many reasons, such as climate, weather effects, the impact of natural factors (faults and earthquakes), and also man-made (various types of construction).

The deformation processes monitoring is usually performed at certain time intervals (for example, [8-11]). It is important not to miss the moment of manifestation of critical deformations. In this regard, an important task is to create such a methodology of observation, which will ensure the fixation of the occurrence of critical deformations. A new approach based on the following principles is proposed:
• Determination of stable zones in which it is necessary to fix control (reference) points responsible for the orientation and accuracy of points of the deformation network.
• Installation of stable areas of stationary robotic total stations in such a way as to provide a clear overview of the control points, as well as deformation marks.
• Planning and fixing deformation marks, which are reflective prisms (Figure 5 a).
• Perform permanent measurements
• Automatic processing and interpretation of measurement results

![Deformation mark (Mini prism)](image1.png) ![Motorized Automatic Total Station (Leica TM 50)](image2.png)

**Figure 5.** a) Deformation mark (Mini prism); b) Motorized Automatic Total Station (Leica TM 50)

Monitoring is a millimeter and even sub-millimeters science, therefore instruments (Leica TM 50) with an accuracy of 0.6 mm + 1 ppm are used. Measurements are performed from a stationary point (Figure 5 b) in the forward & backward direction (Direct/Reverse), the data is stored on the server, and then the difference between the measurement cycles is calculated, which helps to obtain the deformation value of the monitored object.

The Table 3 and Figure 6 show the displacement measurements for one prism of the system in different dates. Table 3 shows the results of continuous monitoring for 40 hours. Figure 6 shows the results of monitoring measurements for the same prism for the same period of time (from 12:00 to 23:00), but on different dates (every week).

**Table 3.** Continuous measurements for 40 hours of displacement for one prism

| Time | Delta X | Delta Y | Delta Z |
|------|---------|---------|---------|
| 1    | -0.3    | -0.05   | -0.6    |
| 2    | -0.3    | 0       | -0.7    |
| 3    | -0.3    | -0.1    | -0.5    |
| 4    | -0.2    | 0       | -0.5    |
| 5    | -0.2    | 0.1     | -0.3    |
| 6    | -0.2    | 0.1     | -0.5    |
| 7    | -0.2    | -0.1    | -0.5    |
| 8    | -0.5    | -0.1    | -0.6    |
| 9    | -0.5    | -0.2    | -0.5    |
| 10   | -0.6    | -0.3    | -0.6    |

| Time | Delta X | Delta Y | Delta Z |
|------|---------|---------|---------|
| 11   | -0.6    | -0.3    | -0.5    |
| 12   | -0.6    | -0.3    | -0.5    |
| 13   | -0.6    | -0.3    | -0.5    |
| 14   | -0.6    | -0.3    | -0.5    |
| 15   | -0.4    | -0.4    | -0.6    |
| 16   | -0.4    | -0.4    | -0.7    |
| 17   | -0.4    | -0.4    | -0.8    |
| 18   | -0.4    | -0.4    | -0.8    |
| 19   | -0.4    | -0.4    | -0.8    |
| 20   | -0.5    | -0.4    | -0.8    |

| Time | Delta X | Delta Y | Delta Z |
|------|---------|---------|---------|
| 21   | -0.5    | -0.4    | -0.7    |
| 22   | -0.6    | -0.4    | -0.6    |
| 23   | -0.6    | -0.4    | -0.6    |
| 24   | -0.4    | -0.3    | -0.5    |
| 25   | -0.4    | -0.3    | -0.5    |
| 26   | -0.4    | -0.3    | -0.5    |
| 27   | -0.4    | -0.2    | -0.5    |
| 28   | -0.4    | -0.2    | -0.5    |
| 29   | -0.4    | -0.3    | -0.4    |
| 30   | -0.4    | -0.3    | -0.4    |
| 31   | -0.5    | -0.1    | -0.6    |
| 32   | -0.5    | -0.1    | -0.7    |
| 33   | -0.5    | -0.3    | -0.7    |
| 34   | -0.6    | -0.3    | -0.7    |
| 35   | -0.6    | -0.3    | -0.5    |
| 36   | -0.6    | -0.4    | -0.5    |
| 37   | -0.6    | -0.3    | -0.5    |
| 38   | -0.6    | -0.5    | -0.5    |
| 39   | -0.6    | -0.3    | -0.5    |
| 40   | -0.5    | -0.4    | -0.5    |
Figure 6. Graph showing the displacement of one prism monitored every week in the same period of time.

The measurements are performed continuously or regularly, small deformations are detected, trajectory (vector) of the displacement can be drawn and then early risk assessment can help in avoiding severe consequences, such as erosion or destruction of the structures.

Summary
The article shows two approaches to the different objects’ preservation: buildings and structures, as well as monuments of cultural heritage. The first is based on the use of modern technologies for objects survey (laser scanning and photography from a UAV), ensuring the required model detailing and, thereby, the protected object elements preservation due to the multipoint measurements (point cloud). The second approach is based on the use of permanent, automated high-precise survey technology based on robotic total stations to evaluate the deformation of structures.

The results of laser scanning were performed at one of the famous monuments of the world cultural heritage - the castle of Baalbek.

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