# Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues

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**Abstract.** This work is part of a thesis for the School of Specialization in Archaeology at the University of Trieste, Italy. The goal of the project is to test and evaluate 3D surveying and modeling methods to document the remaining ancient byzantine city walls of the archaeological site of Aquileia in Friuli Venezia Giulia, Italy. The objectives are threefold: (1) to use 3D data to create maps and sections that provide information useful for archaeological purposes such as the investigation of architectural construction techniques or construction phases, (2) to evaluate and compare photogrammetric and laser scanner data in order to identify the advantages and disadvantages of the two 3D surveying techniques for archaeological applications and needs and (3) draw broader conclusions about the applicability of photogrammetry and laser scanning for documenting and analyzing ancient walls within a particular set of environmental circumstances. The paper presents the employed 3D surveying techniques, the obtained 3D results and some critical comments.

**Keywords:** Photogrammetry, Laser Scanner, 3D Modeling, Survey, Archaeology.

## 1 Introduction

For archaeological research, it is important to appropriately record, document, and survey artifacts and sites because an accurate and complete digital documentation is a prerequisite for further analysis and interpretation of artifacts and archaeological areas. One type of archaeological documentation is the so-called direct survey, which involves measuring in direct contact objects, or excavation units, for example, using a caliper or tape measure: a survey of this type is highly time-consuming and is not so accurate. A second type is related to the use of indirect techniques that make use of, for example, total stations, Global Navigation Satellite System (GNSS) and 3D optical instruments, which offer several advantages over the direct acquisition techniques: (i) the time used to perform the survey is much shorter and the accuracy is higher; (ii)

they do not require contact measurements avoiding possible damages to archaeological objects; (iii) , a wide range of low cost sensors and processing algorithms have recently become available [1].
The digital 3D acquisition of objects and structures is generally performs by means of (i) passive techniques (image-based methods) such as photogrammetry [2], (ii) active sensors (range-based methods) such as laser scanner [3] or (iii) an integration of active and passive techniques [4-8]. The best and most appropriate technique depends on the object to be surveyed or the area to be examined, on the user experience, on the budget, on the time available and on the goals of the research. Photogrammetric surveys are typically cost-effective and time-efficient. Photogrammetry is able to provide, simultaneously, for the necessary 3D geometry and texture, with accuracy values for each determined 3D point, although a known distance or some ground control points are necessary in order to derive metric 3D results. A simple a consumer grade digital camera, calibrated using ad-hoc algorithms and procedures in the lab, can be used for the surveying and successive 3D modeling. On the other hand, active sensors, such as laser scanners, collect directly metric 3D point clouds of artifacts or sites that can afterwards be used to produce highly accurate and detailed 3D models. The use of laser scanners in the archaeological sites, however, is unusual because of the high costs of instruments [9].
In this paper, we present a research that compares these two different 3D surveying techniques (photogrammetry and laser scanning) for archaeological documentation needs 3D models are produced critically comparing different the employed software and instruments.


**Fig. 1.** The position of the archaeological area in Aquileia: the city walls are clearly visible from satellite images (left). Highlighted in the zoomed image (right) is the part of the walls used in this research.

## 2 The test site

The Byzantine walls of Aquileia (Fig.1) were chosen as a test field as they have many unresolved questions and do not have an adequate topographical documentation that is required to carry out further research. In addition, the site has been recently investigated as part of an operation to clean-up the structures in preparation to reopen the site to the public. The walls probably belong to the last fortress of Aquileia that when built, divided the ancient city. While remains of the fortifications are visible on the ground and in the modern cadastral divisions in the western part of the city, it was Luisa Bertacchi, in the 1960s, who recognized the path of the walls and realized that it was the same structures documented by the Austrians in 1871-1872 and which are correlated to the river arbor, excavated by Giovanni Brusin in the southern part of the city. The city walls are located in the NW part of Aquileia and are generally dated to the end of the fifth century AD or to the middle part of the sixth century AD. These dates were determined by a study of the masonry technique that identified a technical element using shells in the mortar. This element appears, for example, in the mortar of the walls the baptistery of Elijah in Grado, from the second half of sixth century, but is already present in the Byzantine walls of Leptis Magna, built after the Justinian's reconquest (post 533 A.D.). It also appears in the tomb of St. Peter under the Vatican Basilica, also dating back to Byzantine times [10].

## 3 3D Surveying techniques and 3D modeling

Photogrammetry can be described as a passive technique to derive reliable and precise measurements by means of photographs/images or as the art of turning images into 3D models [11]. To build a 3D model using photogrammetry, many types of images can be used like satellite, airborne, balloon, UAVs, terrestrial and even underwater images. It is however necessary to have at least 2 overlapping images of the same scene in order to derive 3D information.

Laser scanning uses active devices capable of emitting an electromagnetic signal (laser light) or a pattern that derive 3D coordinates using the Time-of-Flight (TOF) or the triangulation measurement principle [3] [12]. A TOF laser scanner sends a laser impulse towards an object and then the distance between the instrument and the object is computed using either the time of flight of the transmitted and reflected signal (PW scanners) or a phase difference of the transmitted and reflected signal (CW scanners). Triangulation-based active sensors project a laser line or a pattern onto the surveyed object and an imaging sensor located at a predetermined and calibrated distance (baseline) records the reflected signal in order to derive the 3D geometry of the object.

All the above mentioned techniques are surveying techniques, e.g. they deliver only sparse 3D point clouds. The 3D modeling phase starts only afterwards during the processing of the recorded data. We can thus clarify:

- 3D surveying measures a scene or an object using a metric space in three dimensions. An unstructured 3D point cloud is derived to approximately describe a scene or an object. Reality-based techniques are used such as photogrammetry, laser scanning, GNSS, radar, etc.
- 3D modeling is the processing of the unstructured point cloud in order to mathematically derive structured data (e.g., polygonal mesh). 3D modeling normally consists of a geometric and appearance (texture) part.

In case of large and complex sites, the combination of image-based techniques such as photogrammetry, computer vision, etc. and range-based techniques such as laser scanners, radar, etc., a good balance among geometric resolution, costs, and time can be achieved.

# 4 Data collection

The starting point of the work in Aquileia was the collection of both photogrammetric and laser scanner data of the site. First, a survey was made with a Topcon 3005N total station to acquire ground control points to geo-reference and bring the two models into a common reference system. Second, a laser scanner survey was made on the entire site. Third, two types of photogrammetric data were collected: (1) an Unmanned Aerial Vehicle (UAV) survey collected data for the entire site; (2) a terrestrial photogrammetric survey was used only on a sub-set of walls that were in an ideally-suited (standing with no or few presence of grass, etc.) for 3D modeling purposes.

## 4.1 Range data acquisition

To collect range data, a Leica HDS 7000 laser scanner was used. Based on TOF measuring principle, this scanner allows a wide field of view (360° H x 320° V) and the acquisition of max of 1 million points per second with millimetric resolution and accuracy. In total, 22 scans were performed, resulting in a dataset of ca. 96 million points (Tab. 1). The first seven scans, captured an external perspective of the site, used collected data at a distance of 10 m to achieve a sampling test of 3.1 mm. The remaining fifteen scans captured data inside the site in order to acquire more details of the structures, and collected data with an average sampling distance of 12.6 mm. These values were chosen as an acceptable compromise between level of detail of the final 3D model and computing resources needed for data processing. The laser scanner data will be used (i) as metric reference to scale the image data, (ii) for a geometric comparison with the photogrammetric data (still under-going) and (iii) for the creation of archaeological sections of the site.

## 4.2 Photogrammetric data acquisition

As mentioned, the terrestrial photogrammetry technique was applied only to some walls. A calibrated Canon 60D camera was used. The camera features 18 megapixel camera with a 22.3 x 14.9mm CMOS sensor coupled with an 18-200 mm objective. Approximately 400 images were acquired in three surveys carried out in three different months: the first in January, the second in March and the third in May 2012. The images were acquired keeping the camera at the minimum focal length (18 mm), while the image resolution was set at the highest level (5138 x 3456 pixels) in order to acquire good quality textures. The distance to which the images were taken is variable (2-5 m) due to the articulation of the archaeological site. In some cases, it was not possible to stand more than 2 m from the wall. The images were taken both convergent and nadir, and the overlap is about 40% (Fig.2).

**Fig. 2.** Example of images of a wall taken for terrestrial photogrammetry.

The UAV survey was done with the Quadcopter Gaui 300X-S that weighs about 400 grams without batteries. The maximum payload is around 700 grams. A compact camera Canon IXUS 85 IS (35 mm focal length) was mounted onboard, the image resolution was set at 3648 x 2736 pixels, and about 150 images were acquired (Fig.3). The UAV did not have any GNSS or INS on-board and it was manually piloted leading to a flight altitude variable between 15 and 25 m. The aim of the UAV data is to create an overview orthoimage of the site and produce and up-to-date map.

**Fig. 3.** Examples of images taken with the UAV.

## 5 Data processing

The collected images and range data were processed independently. The laser scanning data were treated using three different software, Geomagic, Cyclone and Polyworks. The images were processed with four different photogrammetric software: a free web-based tool (Autodesk 123D Catch), and two commercial packages (Agisoft Photoscan and Photomodeler Scanner).

**Fig. 4.** The textured 3D model created from the UAV images using Agisoft Photoscan.

The laser scanner data will serve, as well as a control to compare the accuracy and precision of the different photogrammetric results, to derive a map of the site (correlated to the mesh derived from the UAV images), sections and other information useful for a complete study and analysis of the site.

### 5.1 The 3D model from photogrammetric data

The UAV data processing (Fig.4) and a sub-set of the terrestrial images (56) were used for the 3D modeling of the site and walls, respectively. The average ground sample distance (GSD) of the UAV images is approximately 6-8 mm while terrestrial images have a GSD of 5 mm. The image data were processed with different packages:
- Autodesk 123D Catch (Fig.5a) is an automated software that works via web. The program is essentially a black box that automatically processes the imported images without permitting users any interaction or editing. The unique result of the processing is a textured mesh that is sufficient for 3D visualization (it is also possible to create videos), but is not useful for measurement or other analytical purposes. Even scaling the model is very difficult, for example, as it must be done a posteriori on the mesh model..
- Agisoft Photoscan (Fig.5b) is a commercial software able to create 3D content from still images. Both image alignment and 3D model reconstruction are fully automated but the user can interact. The results are quite dense and complete and it is also possible to create an orthoimage from the 3D model,
- Photomodeler Scanner (Fig.5c) is a commercial photogrammetric software. The processing is done in steps, with manual interaction of the user. A quite dense point cloud of the surveyed object can be automatically generated processing pairs of images although the entire pipeline is often time consuming.

(a) (b) (c)

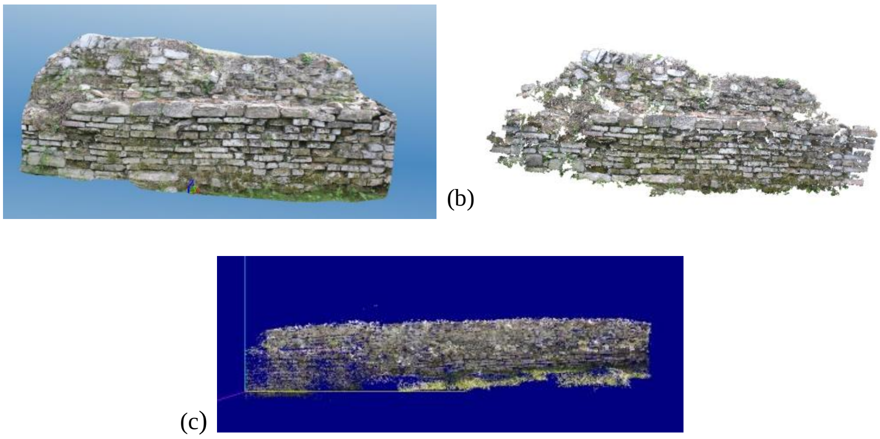
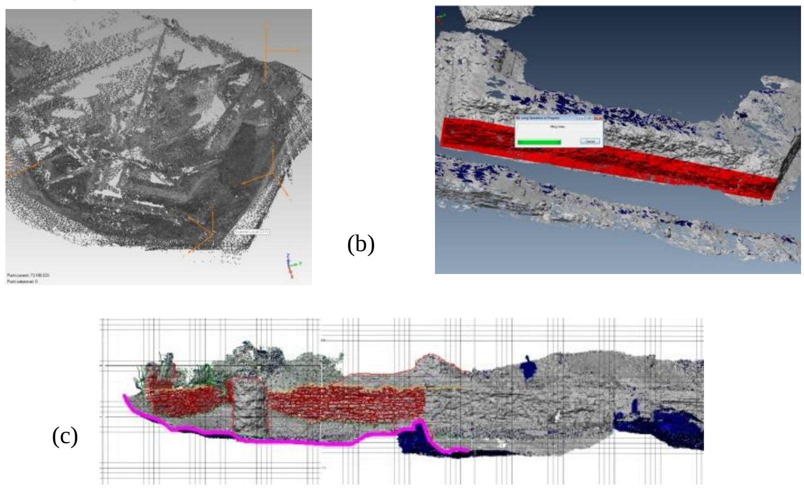


**Fig. 5.** The wall 3D models produced using the three different software: 123D Catch (a), Agisoft Photoscan (b) and Photomodeler Scanner (c).

After these tests, it can be said that photogrammetry is a technique that requires a lot of experience, starting from the acquisition of the data on site. It took three different survey campaigns to have decent data to use (this because the images were acquired by a non-expert), and although this, the data are not yet ideal for all the software in order to have a good result in terms of reconstructed 3D geometry and texture. Indeed, the other problem is that the so-called black box software (in particular the Structure from Motion tools) have the disadvantage of denying any interaction with the process. Photomodeler, although leading to long processing time, allows much more interaction, the detection of the homologous points is done by the operator but even if the process is much more controlled than in the other software, the software operates autonomously during the extraction of the 3D point cloud and the mesh, allowing the possibility to correct the result if is needed. Last but not least, the image-base processing needs always some known distances or GCPs in order to get metric results.

## 5.2 The 3D model from laser scanner data

In order to process the laser scanning data (Tab. 1), the 22 scans were cleaned using Cyclone and aligned in Polyworks due to incompatibility of data format. Using Geomagic and Polyworks a complete cleaning and alignment were done (Fig.6a). Then the registered point clouds were converted into a mesh and the holes automatically filled (Fig.6b). Finally the archaeological sections were extracted in order to be digitized (Fig.6c).



(a) (b) (c)

**Fig. 6.** The alignment of the scans (a), the filling of the holes on the mesh (b), and the section with the metric grid imported in AutoCAD for the digitalization (c).

The problem of the non-compatibility of the extensions of the laser scanner file is something that has not been solved yet. Each brand/instrument has its own file extension and a specific software to work with, so every time you have to deal with files

coming from different laser scanner it's always necessary to convert them, using different tools. Another bottleneck of the range-based data processing pipeline is the long editing / working time: all the process for generating a completed and suitable polygonal model for other uses is really time consuming. It took several days to clean the point cloud, align all the scans, create the mesh and at the end have the 3D model with all the holes filled, ready to use. In addition, usually the 3D model is heavy, even with a decimation of the triangles, and a computer or a laptop with medium characteristics are not suitable to manage large datasets. Last but not least, a good texture is normally missing, requiring texture mapping procedures to map high resolution images onto the range-based 3D geometry.
Nevertheless a laser scanner instrument is very easy to be used, a3D data from laser scanner data are very useful because as accurate and often detailed, the derived geometric models are the exact /metric copy of the original object and different analyses and studies can be performed.

| | **Dataset 1** | **Dataset 2** |
|---|---|---|
| Number of scans | 7 | 15 |
| Geometric resolution | 3.1 mm @ 10 m | 12.6 mm @ 10 m |
| Num. of acquired points | ca. 84 millions | ca. 75 millions |
| Num. of final polygons | ca 127 millions | |

**Table 1.** Comparison of the two different datasets acquired with the laser scanner and the total number of polygons after the geometric processing.

## 6 Conclusions

Using reality-based 3D models it is possible to derive metric data that are useful for archaeological investigations. Some examples include generating orthoimages, detailed site maps, sections for ancient walls, and segmented high-resolution 3D models to highlight construction techniques, sequences, restorations, etc. Textured 3D models of archaeological sites are also useful for visualization purposes to engage the public and assist archaeologists in interpretations of past uses of space. The photogrammetric techniques require experience and the images have to be properly acquired, otherwise the results are incorrect, in particular with fully automated black-boxes tools. Automated and reliable procedure for the extraction of image correspondences and phototriangulation are already available, but most of the approaches for the extraction of the data are still based on manual measurements, as more reliable and accurate, in particular at production level. The laser scanner, on the other hand, is not so difficult to use during the survey, but it requires a lot of time and experience during the processing in the lab. The choice of the technique depends on different factors and it is often strictly related to the budget of the project. Both modeling processes have their advantages and disadvantages (Tab. 2). A good solution seems to be the combination of the methods, as each one has attributes and elements that balance one another, in particular when surveying large and complex sites [8], in order to: (i) use the fundamental strengths of each technique, (ii) make up for weaknesses of the methods, (iii) obtain different geometric Levels of Detail (LoD) of the scene and (iv) achieve more accurate and complete geometric surveying for modeling, understanding, representation and digital conservation issues. Anyway, for both approaches, the modeling part (from point cloud to surface) is still rich of problems and often the most time consuming.

| | **Photogrammetry** (Image-Based modeling) | **Laser Scanner** (Range-Based modeling) |
|---|---|---|
| **Characteristics** | | |
| Cost of the instruments (HW and SW) | Low | High |
| Manageability / Portability | Excellent | Sufficient |
| Time of data acquisition | Quite short | High |
| Time for modeling | Quite short, experience required | Often long |
| 3D information | To be derived | Direct |
| Distance's dependence | Independent | Dependent |
| Dimension's dependence | Independent | Dependent |
| Material's dependence | Almost independent | Dependent |
| Light's dependence | Dependent | Almost/totally independent |
| Geometry's dependence | Quite dependent | Independent |
| Texture's dependence | Dependent | Independent |
| Scale | Absent | Implicit (1:1) |
| Data volume | Dependent on the images resolution and on the measurements | Dense point cloud |
| Detail's modeling | Good/excellent | Generally excellent |
| Texture | Included | Absent/Low resolution |
| Edges | Excellent | Quite problematic |
| Statistics | For each calculated point | Global |
| Open-source software | Some | A few |

**Table 2.** Synthesis of photogrammetry and laser scanner data characteristics.

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