Automation in Laser Scanning for Cultural Heritage Applications

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ABSTRACT: Within the paper we present the current activities of the Institute for Photogrammetry in cultural heritage documentation in Jordan. In particular two sites, Petra and Jerash, were recorded using terrestrial laser scanning (TLS). We present the results and the current status of the recording. Experiences drawn from these projects have led us to investigate more automated approaches to TLS data processing. We detail two approaches within this work. The automation of georeferencing for TLS data is presented along with our approach for automated feature extraction.

1 INTRODUCTION

Terrestrial laser scanning in spite of its costs has become a popular tool for the documentation of cultural heritage sites (Boehler & Marbs, 2002). No other measurement system can parallel the speed, range and accuracy of its dense point cloud acquisition. Naturally TLS was the first choice of methods, when the cooperation in the documentation of cultural heritage sites in Jordan was established in-between the Institute for Photogrammetry of the Universität Stuttgart, Germany and the Queen Rania's Institute for Tourism and Cultural Heritage of the Hashemite University. The first part of this paper is dedicated to the results which have been achieved so far in this cooperation. We present the sites, that have been selected for documentation and we give an overview of the results obtained from laser scanning. The second part of this paper is dedicated to our approaches of further automation in TLS a prerequisite for the widespread application of this technology.

2 DATA COLLECTION AND PREPROCESSING

The collection of the data, which has been used for our investigations, was performed in cooperation with the Hashemite University of Jordan. The project aims on the exemplarily generation of 3D documentations for the two main heritage sites in Jordan, Petra and the ancient city of Jerash. In the following sections we will give a short introduction to the two sites and their historic significance.

2.1 *Al-Khasneh Monument*

The ancient Nabataean city of Petra has often been called the eighth wonder of the ancient world. Petra city in southwestern Jordan prospered as the capital of the Nabataean empire from 400 B.C. to A.D. 106. Petra's temples, tombs, theaters and other buildings are scattered over 400 square miles, these architectures are carved into rose-colored sandstone cliffs. After a visitor enters Petra via Al-Siq, a two-kilometer impressive crack in the mountain, the first facade to be seen is Al-Khasneh, which is considered as the best-known monuments in Petra city. The Al-Khasneh facade is 40m high and remarkably well preserved, probably because the confined space in which it was built has protected it from the effects of erosion. The name Al-Khasneh, as the Arabs call it, means treasury or tax house for passing camel caravans, while others have proposed that the Al-Khasneh Monument was a tomb. Behind the impressive facade of Al-Khasneh, large square rooms have been carved out of the rock. An image of the Al-Khasneh facade is depicted in Figure 1.

2.2 *Jerash*

Jerash, which was selected as the second test area, is probably one of the best preserved Roman provincial cities worldwide. Built in the 2nd century BC, it was conquered in 63 BC by the Roman emperor Pompey. The ancient Arabic name of Garshu was changed to Gerasa, and Jerash became part of the Roman Empire. Jerash's prosperity reached its zenith in the 1st and 2nd century AC under the emperors Trajan and Hadrian, when the city was ranked as a Roman Colony and became the administrative, civic, commercial and cultural center of the Province of Arabia.

The decline of the city began after Persian invasion 614 AD, in the 13th century the city was abandoned, completely. The rediscovery of Jerash came about in 1806, when a German traveler recognized a small section of the ruins buried in sand. Significant archeological work took place since 1928 when the city has been gradually revealed through a series of excavations. Due to the exceptional condition of its colonnaded streets, baths, theaters, plazas and arches the city Jerash is probably the second most frequently visited tourist site after Petra in Jordan.

Within the project image and LIDAR data was collected for two theatres, an exemplary view of the so-called North Theatre is depicted in Figure 2.

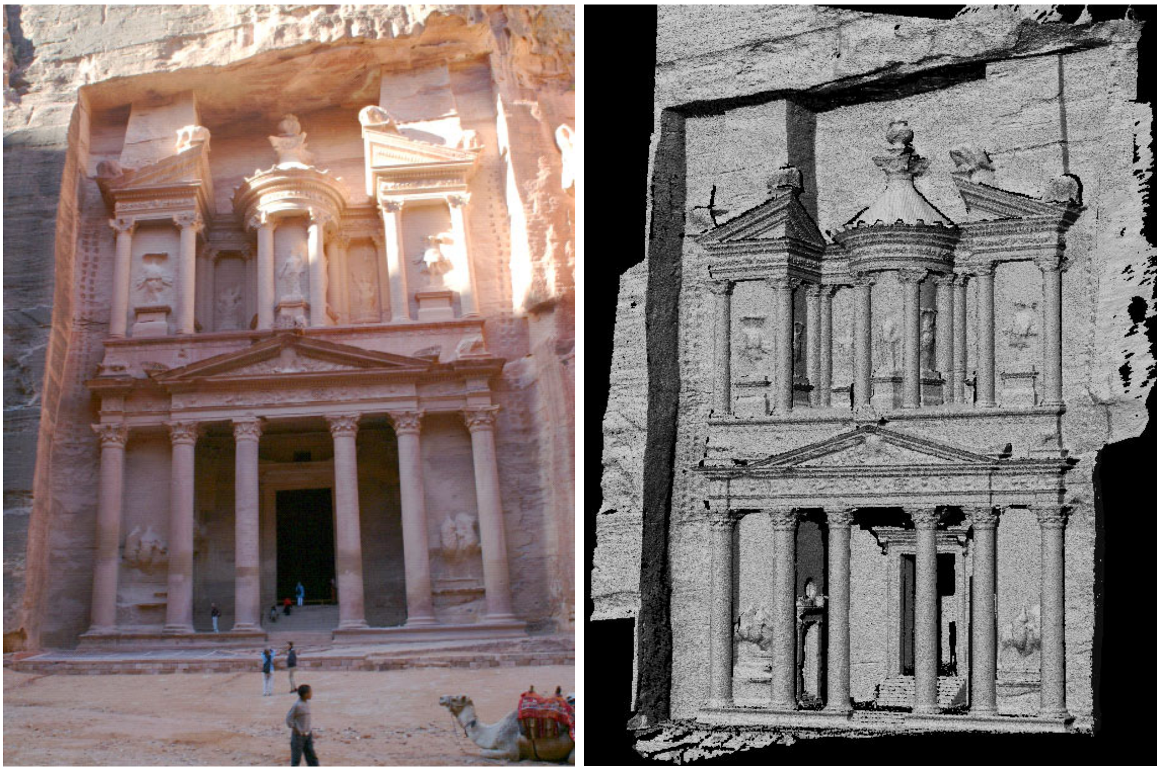


Figure 1. Image and 3D model of the Al-Khasneh facade in Petra.

Figure 2. Data collection for the North Theatre in Jerash. The recording with the laser scanner is carried out together with surveying work using a total station.

2.3 *Sensors Applied*

For point collection, the 3D laser scanning system GS100, manufactured by Mensi S.A., France was applied. The scanner features a field of view of 360° in the horizontal and 60° in the vertical direction, enabling the collection of full panoramic views. The distance measurement is performed by the time of flight measurement principle based on a green laser at 532 nm. The scanning range of the system allows distance measurements between 2 and 100 meters. The scanner's spot size is 3 mm at a distance of 50 meters; the standard deviation of the distance measurement is 6 mm for a single shot. The system is able to measure 5000 points per second. During data collection a calibrated video snapshot of 768x576 pixel resolution is additionally captured, which is automatically mapped to the corresponding point measurements.

In addition to the laser data, digital images were captured for photogrammetric processing using a Fuji S1 Pro camera. The camera provides a resolution of 1536x2034 pixels and is able to store the images in raw format. We used a high quality lens with a focal length of 20 mm. The camera was calibrated before and after the campaign at the institute's calibration lab to ensure the stability of the interior orientation. Due to the strict photogrammetric calibration we can compute the exterior orientation of each camera station using simple spatial resection from natural control points extracted from the TLS point cloud. The oriented images can thus be used both for texturing the point cloud and for further three-dimensional reconstruction and feature extraction.

2.4 *Measurement Configuration*

Because it is not possible to have a complete 3D coverage for the Al-Khasneh facade based on data collected from a single station, three different viewpoints with five scans were done to resolve the occlusions. The problem to choose the viewpoint positions represents an important phase of the survey for such a monument since potential sensor stations are restricted by the mountainous environment surrounding Al-Khasneh. Furthermore since large parts of the monument are not accessible without a scaffold, which was beyond the scope of this project, it is difficult to place a sufficient number of artificial targets in the field of view of the scanner. Therefore a sufficient overlap of the scans is required to ensure registration of the point clouds based solely on ICP is possible.

Three positions were selected, from the entrance area of the monument, from the left of the monument, and one scan was collected from an elevated viewpoint. Since the vertical field of view of the laser scanner from these positions could not cover all of the facade from one scan, the left and top scanning were done using 2 scans from the same position, taking into consideration sufficient overlapping regions to allow for a subsequent integration. In total, the five scans resulted in almost 5 million collected points.

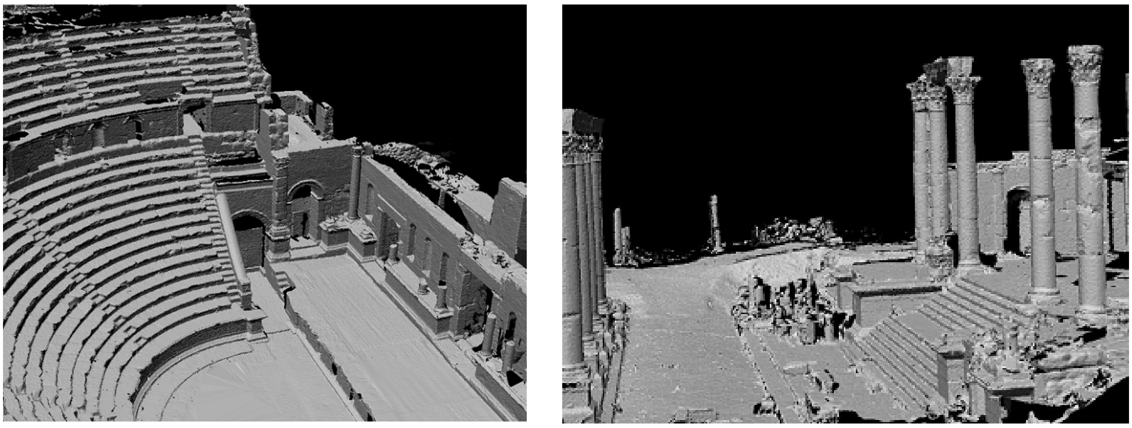


Figure 3. LIDAR data collected at North Theater, Jerash.

All the acquired 3D models have been processed using Innovmetric Software, PolyWorks. The model of Al-Khasneh facade resulted from merging the five scans in an independent coordinate system into a common coordinate system. After registration of the scans using a variation of the ICP algorithm, the software constructs a non-redundant surface representation, where each part of the measured object is only described once. The result of the combination of the five laser scans is given in the right picture Figure 1. The produced model has an average resolution of 2 cm with more than 10 million triangles.

In contrast to Petra, where data collection as hindered by the fact, that most monuments are located in a narrow canyon, viewpoints could be selected more freely during data collection in Jerash. Figure 3 gives two rendered views of the 3D data collected at this site.

2.5 *Lessons learned*

Within the extensive projects we have carried out in the field of cultural heritage so far, we have kept close to the workflow of TLS data processing as it is suggested by laser scanner and software vendors, strictly using commercially available tools. The advantage of TLS systems is the high degree of automation in acquiring dense three-dimensional point clouds. Once the measurement volume has been determined, the points are measured completely automatic by the push of a button. But this level of automation is not maintained throughout the processing pipeline. As we move further down along the chain of processing towards registration and modeling, we see a steep decline in the level of automation. This situation is depicted in Figure 4.

For the registration process manual placement, measurement and identification of artificial targets is still frequently encountered in commercial systems. If georeferencing is desired in addition to registration in a local coordinate system, the situation is even worse. Since none of the currently available commercial TLS systems can be used to perform the tasks of a total station or a leveling instrument, it is not possible to transfer the information from separately given planar or height control points to full three-dimensional control points. Therefore at least one addi-

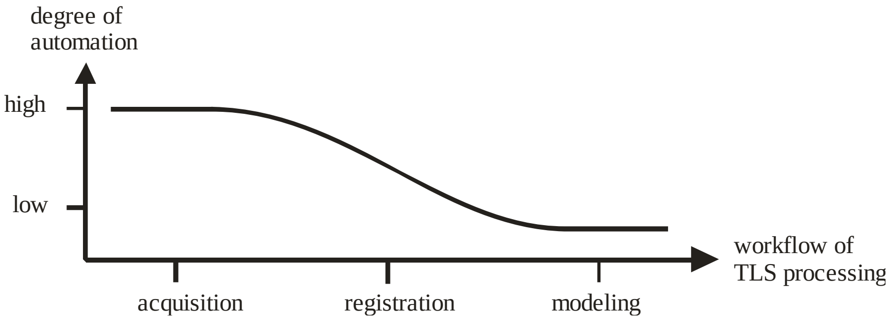


Figure 4. The degree of automation decreases in later stages of data processing.

tional instrument has to be used to perform this transfer and establish the required control points.

The least degree of automation is encountered at the modeling stage in TLS data processing. Most of the software tools are focused on industrial applications. For these applications the assumption is made, that the surfaces visible in the scan can be described by simple geometric primitives, usually ruled surfaces. Alternatively the data is fit to predefined objects from a library such as steel section or pipes. But for application in cultural heritage these assumptions do not hold. Here we deal with the delicate and complex surfaces and structures of ornaments and statues and other highly individual objects. These can not be represented with surface primitives or library objects. Therefore we usually desire the conversion of the TLS point data into a TIN representation, which provides the most adequate representation and also allows the easy creation of sections.

These experiences and observations have led us to start developments to increase the level of automation for the later stages in the TLS workflow. One task we have addressed is point cloud registration and georeferencing. Our approaches to the automation of registration and georeferencing will be discussed in the next section. Another topic we present is the automation of feature extraction which addresses the modeling stage.

3 AUTOMATED GEOREFERENCING

In order to automate registration and georeferencing of TLS point clouds we have devised a sensor-based approach. The approach is well known in aerial photogrammetry and in mobile mapping, where IMU and GPS sensors are combined to determine a scanners trajectory. We have adapted this approach to TLS, which is a stationary measurement and thus is less demanding on the orientation sensors used. For our task we use a low-cost GPS and a digital compass and pan / tilt sensor, which are mounted on top of the laser scanner. This sensor is depicted Figure 5. Both sensors, the compass and the GPS receiver, have a wireless connection via Bluetooth to the laptop which is also used to control the scanner.

Digital compasses such as the applied TCMVR-50 can in principle provide the azimuth at standard deviation below 1°. However, these systems are vulnerable to distortion. Especially in build-up areas the Earth’s magnetic field can be influenced by cars or electrical installations. These disturbances usually reduce the accuracy of digital compasses to approximately 6° (Hoff & Azuma, 2000). The GPS receiver is based on the SIRF II chip. Thus it can be operated in differential mode, using the EGNOS (European Geostationary Navigation Overlay Service) correction signal where available. Similar systems, which provide a correction signal generated from information of different ground stations by geostationary satellites are the American WAAS and the Japanese MSAS system. By these means the accuracy of GPS positioning can be improved from 5-25m to approximately 2m. This was verified in experiments by comparison to a high-end geodetic GPS receiver.

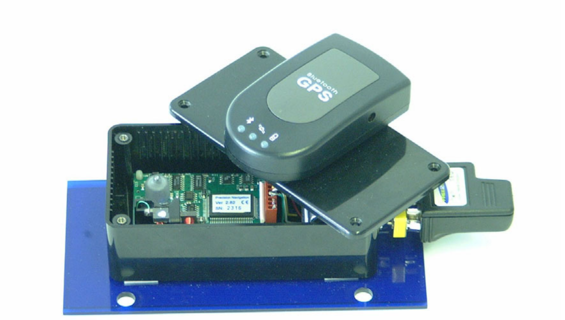


Figure 5. Integrated orientation device, consisting of a low-cost GPS and a compass and pan / tilt sensor. The sensors have a wireless connection to a laptop via Bluetooth.

To verify our approach we carried out a measurement campaign at Schloss Rosenstein, a palace built just outside the city center of Stuttgart. The main goal was to acquire dense range data of the facades on all sides of the palace. Five stations were selected around the palace, which has a length of about 80 meters on one side. The scanner we used for these measurements is the Leica HDS 3000.

Normally when the point cloud data is acquired each of the scans is defined in its own local reference frame, with the origin at the laser station and an arbitrary rotation, which is dependent on the direction, the scanner is pointing to. This situation is depicted in Figure 6 on the top left. However when the GPS and the compass measurements are integrated with the point cloud measurements, this gives a global orientation of the scanner head in a common reference frame for each station. This alignment of the point clouds is depicted in Figure 6 on the top right. In addition to a local alignment the laser scanner data is directly georeferenced instantaneous to the measurement itself and the data can immediately be super-imposed with other geodata, as shown in Figure 6 on the bottom right

Comparing the low-cost to the high-end GPS measurements over the five stations, the mean absolute error is about 1 meter in position and 2 meters in height. The mean absolute errors in on signalized control points, which were established transferring the geodetic GPS measurements onto targets, is about 3 meters in position and 2 meters in height for full georeferencing. It is obvious, that the errors in position are larger than the deviations of the low-cost GPS alone, since compass errors are added with a lever of about 50 meters, whereas the height is not influenced by compass measurements.

Since the alignment obtained from direct georeferencing is seldom sufficient for applications in cultural heritage this solution needs further refinement. This can be accomplished using the iterative closest point (ICP) algorithm introduced by Besl & McKay (1992). The result of the direct georeferencing is used as an initial value for the iterative registration of the laser scans. Since the initial approximation of the direct georeferencing is within the convergence radius of the ICP algorithm this approach allows for an automated alignment of TLS data as shown in Figure 6 on the bottom left.

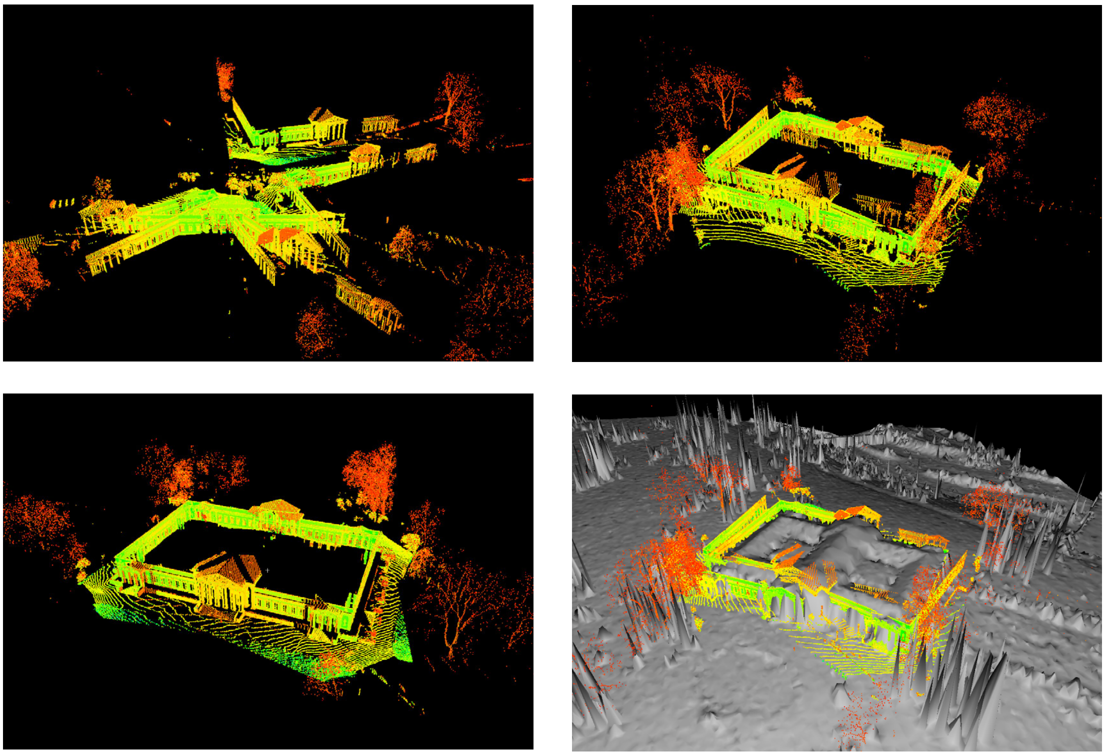


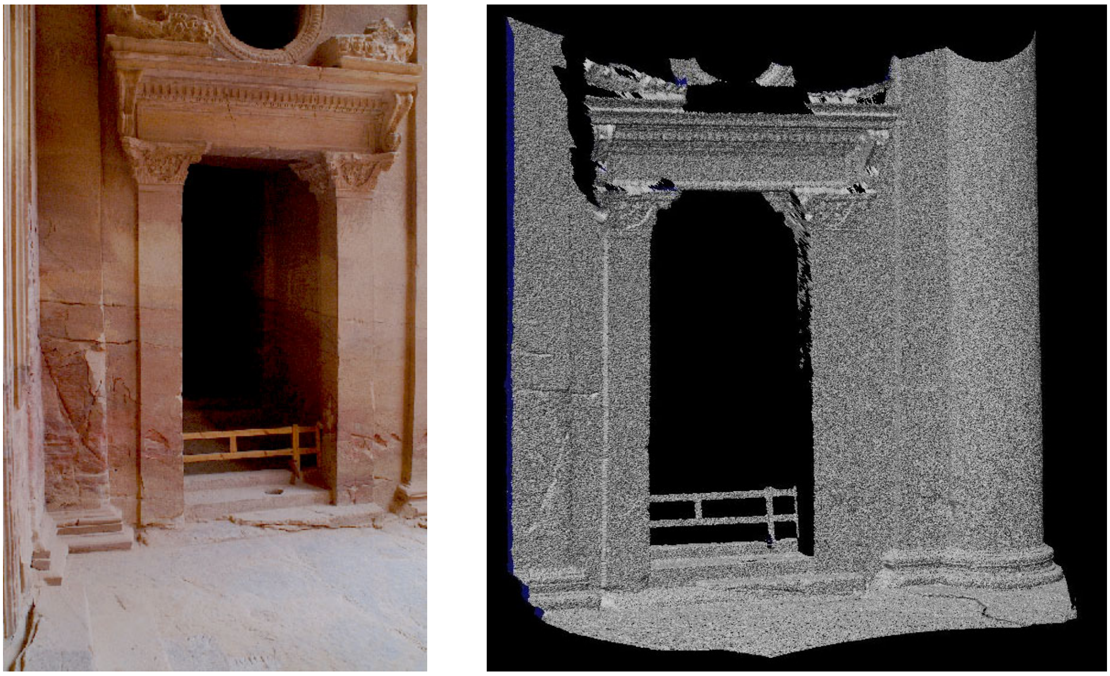
Figure 6. An example for automated georeferencing of TLS data. Top left: The unregistered point clouds collected at five stations. Top right: Results obtained from the integrated orientation device. Bottom left: Result after iterative improvement using ICP. Bottom right: Super-imposition of TLS data and aerial LIDAR data.

4 AUTOMATED FEATURE EXTRACTION

Even tough the three-dimensional point cloud acquired with the laser scanner contains a large number of points, representing the object's surface, it is still difficult to localize and extract all the details and outlines of the surfaces in the point cloud even manually. An example for typical features, which are clearly visible in an image, is depicted in Figure 7 to the left. This data was collected from the left door of Al-Khasneh. As it can be seen from the corresponding three-dimensional meshed model shown to the right, these cracks and the edges outlines are lost in the laser data due to the limited resolution.

To enable the automated extraction of such details, a hybrid approach combining point cloud data and digital imagery was developed Alshawabkeh & Haala (2004). Before the datasets can be integrated they have to be registered. Since we are using a calibrated camera this can be performed by photogrammetric processing as mentioned earlier. After position and orientation parameters are computed for the camera stations, distance images are generated from the point cloud in order to provide the missing third dimension in the available images. Finally, an integrated segmentation process based on the image data is be used in order to support the extraction of the details and the surface features outlines from distance images.

The segmentation process is used to automatically extract the two-dimensional coordinates of the linear features from three different digital images. For this purpose, an edge detection based on the Lanser filter has been applied on the images. The third dimension of the segmented lines is extracted from the distance images. Figure 8 depicts the final three-dimensional features extracted for the left door of Al-Khasneh.



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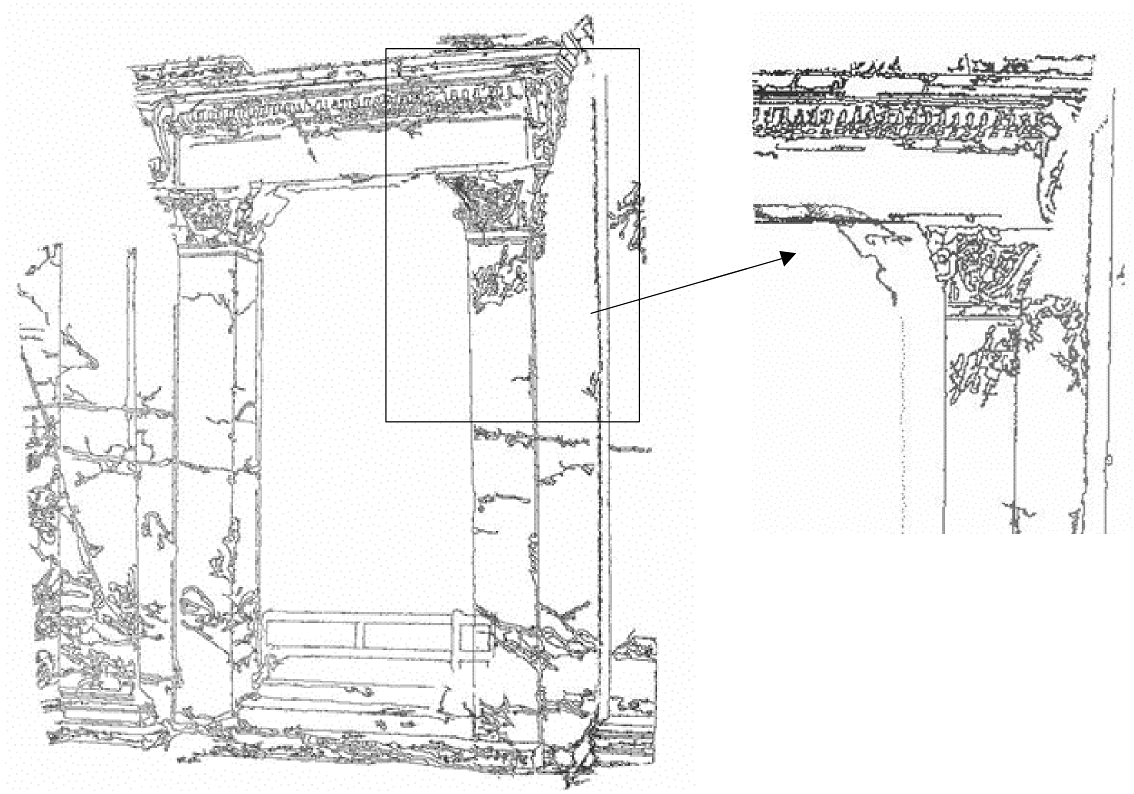

Figure 8. Three-dimensional edges of the left door of Al-Kasneh.

5 SUMMARY

We have presented the results and the current activities and efforts for cultural heritage documentation. The results obtained at two sites, Petra and Jerash, using TLS were shown. Two suggestions to the further automation in TLS data processing were made. Automated georeferencing of TLS data and automated feature extraction from digital images in combination with TLS range data are a first step in increasing the overall degree of automation.

6 RFERENCES

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