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COMBINED LASER SCANNER AND DENSE STEREO MATCHING TECHNIQUES FOR 3D MODELLING OF HERITAGE SITES: DAR ES-SARAYA MUSEUM

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ABSTRACT

High resolution 3D point cloud recording is a demanding task for generating meshed surface and CAD object models. Accurate, complete and realistic 3D point cloud is expected from the adopted recording technique. Due to the complex structural environments of the heritage sites, complete, yet suitable, object coverage by Terrestrial Laser Scanner (TLS) is not guaranteed. The recent improvements in image stereo matching algorithms allow for an automatic dense point clouds acquisition. Acquiring 3D point cloud using images has many advantages related to flexibility and portability. The choice of the best technique relies on the site configuration and the performance of the selected sensor. This paper demonstrates the potential benefits of integrating TLS and Dense Stereo Matching (DSM) techniques in order to form a complete and detailed representation of Dar Es-Saraya Museum. The paper fully discusses the processing and registration of the TLS and DSM data in creating a 3D point cloud of the museum to be used in a more accurate CAD model.

KEYWORDS: Documentation, Laser Scanner, Dense Stereo Matching, Reveres Engineering, Dar Es-Saraya Museum.

1. INTRODUCTION

Highly realistic geometric models of historical architectures and heritage sites are a fundamental prerequisite for reconstruction or restoration purposes. 3D models allow the visualization of a structure from different angles for historical studies, archaeological research as well as virtual tourism. serving these objectives through photorealistic models is promising to provide high geometric accuracy and details. Commonly, 3D point clouds are basic data source in generating meshed surface models or CAD models of cultural heritage sites and historical buildings. The data is collected using either image-based techniques from close range photogrammetry or by terrestrial laser scanning (TLS). Since laser scanning captures millions of 3D points precisely and reliably, it is considered as the standard tool to generate high quality 3D models of cultural heritage sites (Grussenmeyer et al., 2011).

Cultural heritage applications frequently require data collection in very complex structural environments. Thus, compared to similar applications, a considerable number of measurement stations is necessary to guarantee a suitable coverage by TLS (Lerma Garcia et al., 2008). TLS systems are costly, demanding expertise, and require long acquisition time in the field. Other limitations include equipment weight, size, and the limited range. Furthermore, large time lags among the scan set ups result in different radiometric properties of the collected images; especially for outdoor applications. Such problems may disturb the appearance of the resulting textured model (Buckley et al., 2009).

Recently, the acquisition of high quality 3D data is no longer dominated by the use of laser scanning. Photogrammetric matching algorithms are now capable of producing dense 3D point clouds. These algorithms apply the principles of standard photogrammetry but with full automation process in matching the images in pixel resolution (Dellepiane et al., 2013; Haala & Rothermel, 2012). There are many tools and software available for dense image matching modeling whether web-based or open source with high level of automation (Ahmadabadian et al 2013, Furukawa & Ponse, 2010). Rothermal et al. (2012) present an approach for multi views stereo (MVS) method for the generation of precise and dense 3D point clouds. The implementation is based on the Semi-Global matching algorithm developed by Hirschmuller (2008), followed by a fusion step to merge the redundant depth estimations across single stereo models. Finally, a hierarchical coarse-to-fine algorithm is used to derive search ranges for each pixel individually.

Acquiring 3D surfaces with image matching solutions brings several advantages related to flexibility, cost effectiveness and shorter data collection time on the site with minimal disturbance to the visitors. The new system guarantees a realistic appearance of the final 3D model. This guarantee is supported by two characteristics: firstly, the possibility of collecting the images within the same day time, and secondly the flexibility to have close up shots for fine details (Cefalu et al., 2013). The technique is appropriate for accurate modelling up to sub-millimetre (Grussenmeyer et al., 2012). However, the technique is challenged with the shadows and objects lacking textures. Hence, an optimal technique that is capable of handling all confronted situations is still under search.

One possible approach in finding this optimal technique is a fusion of photogrammetric images and laser scanner data. Most of the works attempting the integration between laser scanning with photogrammetry aimed at the texture mapping, feature extraction and gaps filling rather than the metric survey and fine details reconstruction of objects (Mouses et al., 2013, Grussenmeyer et al., 2012). Here, we integrate Rothermal's approach in Image Stereo Matching with the laser data in order to model and reconstruct in 3D the structure details of Dar Es-Saraya Museum. The 3D digital documentation of the museum is of considerable interest for heritage management besides its importance for conservation, education, virtual visits and as a monitoring system. A complete description of the work carried out at Dar Es-Saraya is discussed, including the acquisition of laser scan and image data processing using dense stereo matching and 3D final CAD modelling.

2. SITE HISTORY AND DESCRIPTION

Dar Es-Saraya is a magnificent old building at the city of Irbid, 80 km to the north of Amman (Figures 1 and 2). It is a big complex composed of several different architectural sections each carrying features related to a different period of time.

Figure 1: Es-Saraya Building in Irbid, 1995.

Figure 2: Es-Saraya Building in Irbid, 1995.

The building's oldest section dates back to probably the 17th Century. The total area of all sections of the complex is about 2400 m², built over an area about 4000 m² at the top of Tel Irbid, an artificial archaeological hill related to the Late-Bronze to Iron Age (~1500-600 BC). The complex surrounds an atrium with area about 700 m².

The inscription, found at the top of the main gate of the building, states it was built during the reign of Sultan Abdul Hamid in 1886, but an architectural analysis of the different phases of the building reveals that there was a reconstruction of a fallen vaulted part where the main gate stands. This part was reconstructed, using construction techniques different from older parts and similar to those on the first floor. Accordingly, it is evident that this date documents the time of the construction of the top floor and the reconstruction of the main gate's fallen part.

The building hosted the Ottoman governor till the twenties of the last century. During the 1930's to 1940's Irbid municipality occupied the building before the Ministry of Agriculture moved in. In 1956 the custody of the building was transferred to the police department which used it as a prison facility. The large vaulted halls inside this building, bordering the courtyard with very thick and massive walls, were the reason for this use by the police. In 1992 the police department evacuated the building and transferring its custody to the municipality which made the decision to demolish it due to its bad condition. The Department of Antiquities blocked the decision, and claimed the building. The DoA decided to restore its fallen parts, preserve the other parts and consolidate its stone elevations in order to convert it into a museum. The need for such a museum and the conservation experience of the department's staff supported the approval of the project which started in 1995 and was commenced in late 2000, (Jamhawi, 2002).

3. LASER DATA COLLECTION AND ANALYSIS

The 3D laser scanning process was performed using the ScanStation C10 Laser Scanner system manufactured by Leica. This scanner features Full 360° x 270° field-of-view. The scanning range of the system allows distance measurements between 0.1 to 300 m, with high scan speed (50k pts/sec). The distance measurement is realized by the time of flight measurement principle based on a green laser at 532 nm. The accuracy of single distance measurements is 4 mm. During data collection, a calibrated video snapshot of 1920 x 1920-pixel resolution was additionally

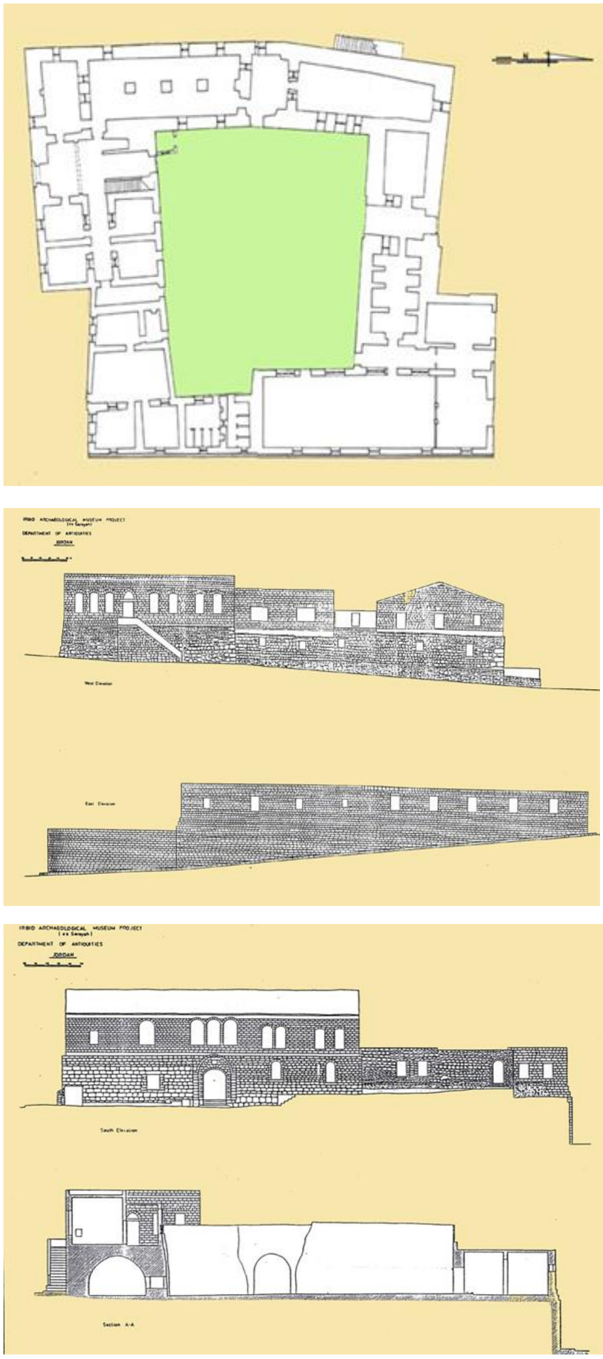

Figure 3: The plan and elevations of Dar Es-Saraya

captured, which was automatically mapped to the corresponding point measurements. Because it was not possible to completely cover such complex 3D structures from a single station without occlusions, different angles were required. Figure 3 depicts laser scanner plan for the ground and upper floor of Es-Saraya, with 80 scan positions been identified to collect laser data. Figure 4 depicts 3D coloured point clouds of different exterior and interior facades of Es-Saraya.

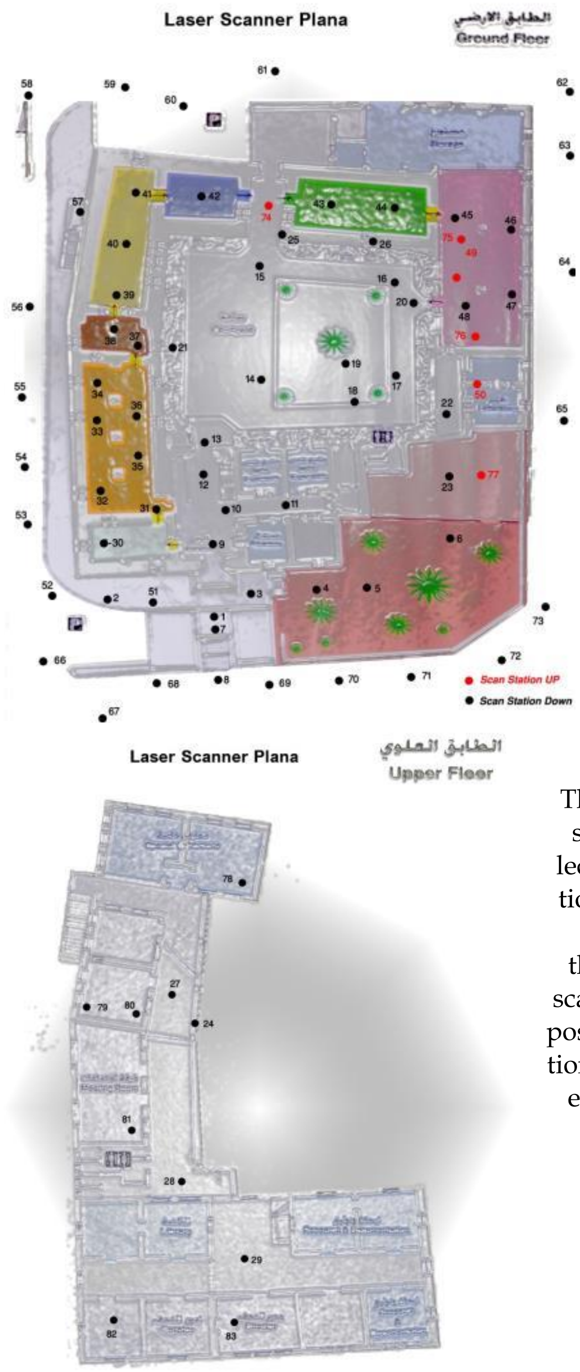

Figure 4: Laser Scanner plan for the ground and upper floor, 80 scan positions

The selection of the scan positions ensured sufficient overlapping regions for subsequent integration. The different processing steps to generate the required 3D models were realized using the Cyclone software from Leica. The post processing steps including registration and merging the scans in one coordinate system, the unifying step of the merged data is to delete the overlapping point clouds, thus each part of the measured object is only described once. Finally, the unified point cloud was converted into meshed surface models. The resulting combination of scans for 3D models generation for Dar Es-Saraya is presented in Figures 5 and 6.

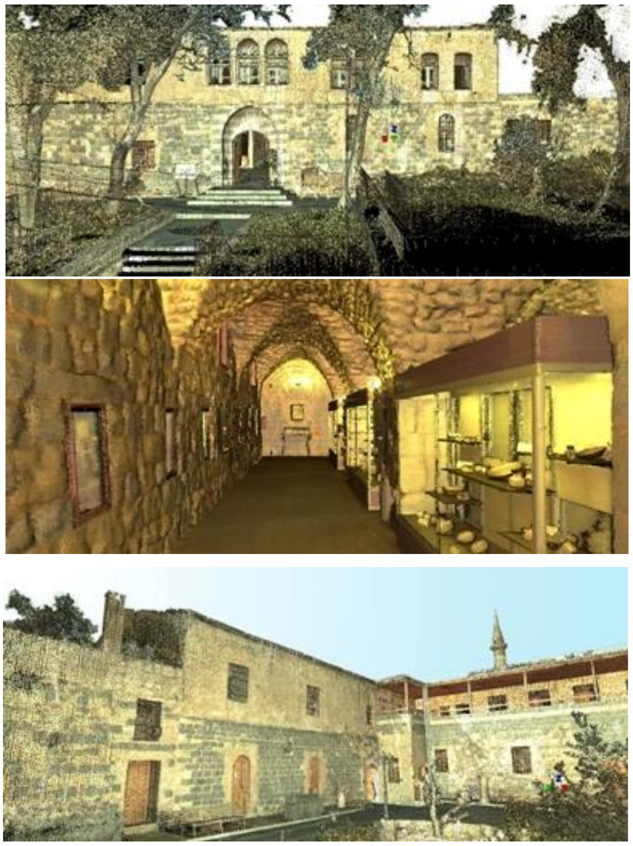

Figure 5: 3D colored point clouds of Dar Es-Saraya using laser scanner

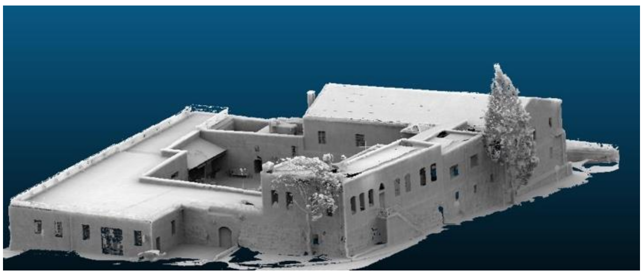

Figure 6: 3D registered point clouds of Dar Es-Saraya

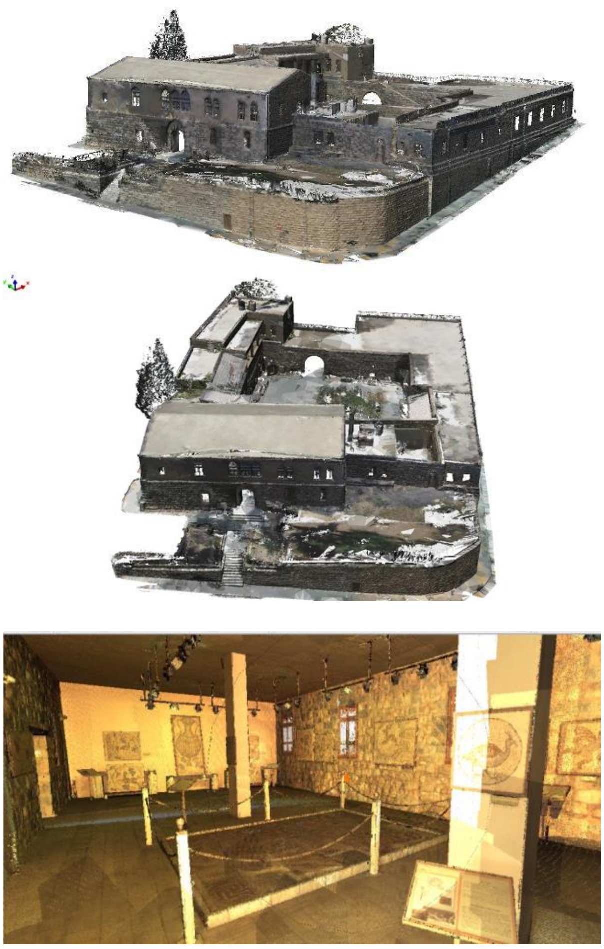

Figure 7: 3D textured model of Dar Es-Saraya using laser scanner

4. PROBLEM OF OCCLUSION

The process of converting laser data to a 3D CAD file is highly dependent on the quality of data collection. A problem arises if the actual scanned product is not quite right and data are incomplete. The resulting CAD file would also suffer lack of accuracy. In our documentation of Dar Es-Saraya, we encountered missed laser data in the scan of the upper windows and for some archaeological objects inside the museum as depicted in figure 7. This was caused by environmental obstacles such as trees and also to the limited view of the scanner due to surrounding buildings. Despite their capacity to produce large point clouds quickly and reliably, the resolution of data from laser scanners can still be insufficient. This case is more evident when scanning edges or linear surfaces like glass materials. The visual appearance of these features becomes very hard to interpret. On the contrary, the digital photogrammetry is more accurate in outline rendition, especially if they are clearly defined in reality. This latter feature inspired our attempt to use photogrammetry for filling the missing data in order to produce a complete representation of the studied scene.

Figure 8: Missed laser point clouds due to obstacles, material type or limited range of view.

5. PHOTOGRAMMETRY AND DENSE IMAGE MATCHING TECHNIQUE

Photogrammetry provides an effective and efficient non-contact 3D data acquisition tool for cultural heritage applications. The technique provides geometric and texture information about the depicted objects. The principle of operation is based on the fact that if a point is depicted in at least two images, its corresponding 3D object coordinates could be determined using mathematical equations called colinearity equations as formulated below (Kraus, 1993).

$$x_a = \frac{-c[r_{11}(X_0 - X_A) + r_{12}(Y_0 - Y_A) + r_{13}(Z_0 - Z_A)]}{[r_{31}(X_0 - X_A) + r_{32}(Y_0 - Y_A) + r_{33}(Z_0 - Z_A)]}$$

$$y_a = \frac{-c[r_{21}(X_0 - X_A) + r_{22}(Y_0 - Y_A) + r_{23}(Z_0 - Z_A)]}{[r_{31}(X_0 - X_A) + r_{32}(Y_0 - Y_A) + r_{33}(Z_0 - Z_A)]}$$

In these equations:

x_a, y_a: an object A's image coordinates.

X_A, Y_A, Z_A: the object's coordinates in object space.

X_0, Y_0, Z_0: the object space coordinates of the camera position.

r_{11}-r_{33}: the coefficients of the orthogonal transformation between the image plane orientation and object space orientation, and are functions of the rotation angles

c: camera focal length.

These equations mathematically formulate the fact that a point in object space (XA, YA, ZA), the projective centre of the optics and the corresponding point in image space (xa, ya) form one straight line. The equations involve two aspects of orientation parameters – interior and exterior. The interior orientation parameters describe the internal camera parameters: the position of the image plane with respect to the centre of projection of the camera, including the camera's focal length (c). The exterior orientation parameters describe position and orientation of the camera at the time of exposure (r11–r33). Both exterior and interior orientation can be reconstructed if the object coordinates are available for a number of so-called control points. Despite this potential, the technique is highly interactive and the identification of points to be measured, being manual or semi automatic, requires a long and tedious work, especially if a considerable number of points has to be captured. Difficulties increase when dealing with reliefs and damaged or irregular surfaces (Alshawabkeh, 2006).

Efficiency of photogrammetric data collection is considerably improved by the integration of digital image processing tools, especially for automatic matching of the corresponding points in the images. Some recent dense image matching algorithms apply pixel-wise matching in the image space. These tools apply the principles of standard photogrammmetry but with full automation process in finding the corresponding points. The process starts by determining the image orientation parameters which can be computed without any a priori information by means of structure-from-motion algorithm. The algorithm has the ability to reconstruct camera exterior orientation and intrinsic camera parameters in addition to sparse point cloud of the surface using distinctive image features (Lowe, 2004). In our application we used Visual SFM software developed by Wu (2011). The software improves the efficiency of structure-from-motion matching algorithm by introducing a pre-emptive feature matching that provides good balance between speed and accuracy. In addition to the camera parameters, sparse point clouds for the surface features can be extracted. Figure 8

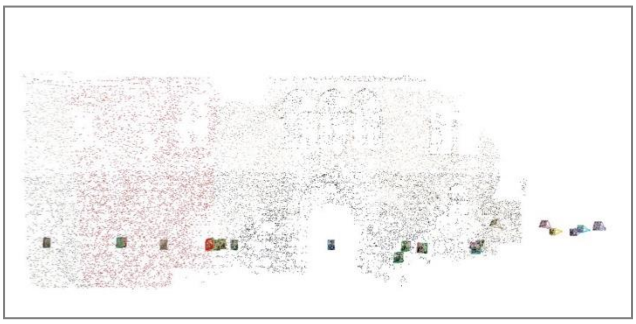

Figure 9: Reconstruct the images positions and orientation parameters using Structure for motion algorithm. The algorithm also generates a sparse point cloud of the faced.

shows the position and orientation of the images taken for front façade of Dar Es-Saraya using Canon 400D calibrated Camera with 12 Mega Pixel.

The intrinsic and extrinsic camera parameters were passed to dense image matching software SURE (Rothermel et al., 2012), The implementation is based on the Semi-Global Matching algorithm developed by (Hirschmuller, 2008). The algorithm is used for producing points for each overlapping pixels as can be depicted in figure 9. Then post processing steps may be needed for filtering the cloud from remaining outliers. Finally, meshing process may be applied for surface generation. Figures 10 and 11 below depicted some results of 3D point clouds of the façade windows and an iron age tomb inside the museum using the dense image matching approach.

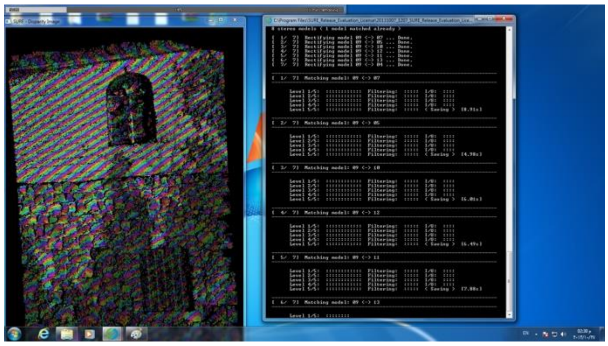

Figure 10: 3D point clouds of the front façade using DSM.

Figure 11: 3D modeling of the façade using DSM.

Figure 12: 3D point clouds using DSM for an iron age tomb in Dar Es-Saraya museum.

6. 3D CAD MODELING

After registering the point clouds using some corresponding points from the both data sets, 3D CAD model is derived. By this way objects can be reproduced completely and precisely as can be depicted in figure 12. Cad model is usually used for the purposes of reverse engineering, reconstruction and 3D animation.

Figure 13: 3D CAD modeling using registered point clouds, the windows were modeled in more realistic and accurate shape.

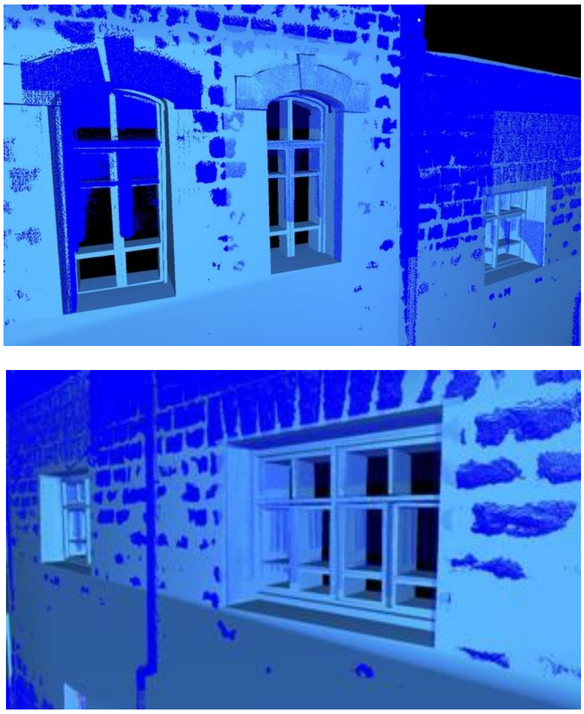

Figure 14: 3D CAD modeling using registered point clouds, the windows were modeled in more realistic and accurate shape.

7. CONCLUSION

The research underlines the possibility and the necessity to integrate dense image matching and laser scanning techniques in cultural heritage documentation. The combined approach optimized the geometric accuracy, the visual quality to have a high resolution textured 3D model of Dar Es-Saraya museum. Stereo matching process offers a cheap, fast and flexible solution to get 3D point clouds. By the combination of both data sources, the shape and fine detailed 3D features can be reconstructed accurately, since the interpretation of point clouds is improved. These features can be added to data from laser scanning in order to generate a more realistic perception of the complete scene.

REFERENCES

Ahmadabadian, A. H., Robson, S., Boehm, J., Shortis, M., Wenzel, K., Fritsch, D. [2013]. A comparison of dense matching algorithms for scaled surface reconstruction using stereo camera rigs. ISPRS Journal of Photogrammetry and Remote Sensing 78, 157-167

Alshawabkeh, Y., 2006. Integration of laser scanner and photogrammetry for heritage documentation. PhD thesis, Institut fur Photogrammetrie der Universitat Stuttgart, Germany.

Alshawabkeh, Y., Bal'awi, F. & Haala, N. [2010]. 3D Digital Documentation, Assessment, and Damage Quantification of the Al-Deir Monument in the Ancient City of Petra, Jordan, in journal of Conservation and Management of Archaeological Sites, Vol. 12 No. 2, May, 2010, 124–45

Buckley, S.J., Schwarz, E., Terlaky, V., Howell, J.A., Arnott, R.W.C. [2009]. Terrestrial laser scanning combined with photogrammetry for digital outcrop modelling. In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 38(B3), pp. 75-80.

Cefalu A., Abdel-Wahab M., Peter M., Wenzel K. & Fritsch, D. [2013]. Image based 3D Reconstruction in Cultural Heritage Preservation. In Proceedings of the 10th International Conference on Informatics in Control, Automation and Robotics, pp. 201-205.

Dellepiane, M., Dell'Unto, N., Callieri, M., Lindgren, S., Scopigno, R. [2013] Archaeological excavation monitoring using dense stereo matching techniques, in "Journal of Cultural Heritage, volume 14, issue 3, pp.201-210.

Furukawa, Y., Ponce, J. [2009]. Accurate, dense and robust Multi-View Stereopsis. IEEE Transactions on Pattern Analysis and Machine Intelligence, 1362–1376

Jamhawi, M,[2002]. Conservation and Tourism: The post 18th century Architectural Heritage of Jordan, PhD thesis, Oxford Brookes University, Oxford, England.

Grussenmeyer, P., Alby, E., Landes, T., Koehl, M., Guillemin, S., Hullo, J.-F., Assali, P., Smigiel, E. [2012]

Recording Approach of Heritage Sites based on Merging Point Clouds from High Resolution Photogrammetry and Terrestrial laser Scanning, in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXIX-B5, 2012 XXII ISPRS Congress, 25 August – 01 September 2012, Melbourne, Australia.

Haala, N., Rothermel, M. [2012]. Dense Multi-Stereo Matching for High Quality Digital Elevation Models in PFG Photogrammetrie, Fernerkundung, Geoinformation. Jahrgang 2012 Heft 4 (2012), p. 331-343.

Hirschmüller, H., [2008]. Stereo Processing by Semi-Global Matching and Mutual Information. IEEE Transactions on Pattern Analysis and Machine Intelligence, 30(2), pp. 328–341.

Kraus, K. (1993). Photogrammetry, Volume I: Fundamentals and Standard Processes. Dümmler, Bonn.

Lerma García, J.L., Van Genechten, B., Heine, E., Santana Quintero M. [2008]. 3D Risk Mapping. Theory and practice on terrestrial laser scanning. Training material based on practical applications. Universidad Politécnica de Valencia, Valencia.

Lowe, D., [2004]. Distinctive Image Features from Scale- Invariant Keypoints. International Journal of Computer Vision,Vol. 60, pp. 91-110

Moussa, W., Abdel-Wahab, M. & Fritsch, D. [2012]. Automatic Fusion of Digital Images and Laser Scanner Data for Heritage Preservation. In: Progress in Cultural Heritage Preservation, Eds. M. Ioannides, D. Fritsch, J. Leissner, R. Davies, F. Remondino, R. Caffo. Lecture Notes in Computer Science (LNCS), Springer, Berlin-Heidelberg, pp. 76-85

Nex, F. , Rinaudo, F. [2008]. "Multi-image matching: an 'old and new' photogrammetric answer to lidar techniques". ISPRS, vol. XXXVII/B5, ISSN: 1682-1750, 2008, PP. 621-626.

Rothermel, M., Wenzel, K., Fritsch, D. & Haala, N. [2012]

SURE: PhotogrammetricSurface Reconstruction from Imagery. Proceedings LCD Workshop, Berlin, December 2012.

Wu, C. [2011]. "VisualSFM: A Visual Structure from Motion System", http://ccwu.me/vsfm/