Using Terrestrial Laser Scanning for the 3D Reconstruction of Petra /Jordan

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ABSTRACT

The use of 3D laser scanner in documenting heritage sites has increased significantely over the past few years. This is maily due to advances of such systems which allow for the fast and reliable generation of millions of 3D points. Despite the considerable progress of these approaches, the highest possible degree in efficiency and flexibility of data collection will be possible, if other techniques are combined during data processing. Within the paper the potential of combining terrestrial laser scanning and close range photogrammetry for the documentation of heritage sites is discussed. Besides improving the geometry of the model, the integration aims on supporting the visual quality of the linear features like edges and cracks in the historical scenes. Additionally, we present an effective approach for projective texture mapping from photographs onto triangulated surfaces from 3D laser scanning. By these means, the effort to generate photo-realistic models of complex shaped objects can be reduced considerably. In order to handle the resulting problem of occlusions, the visibility of the model areas in the respective images has to be established. For this purpose an efficient algorithm addressing the image fusion and visibility is used. The investigations and implementation of the experiments are based on data from Al-Khasneh, a well-known monument in Petra, Jordan.

1. INTRODUCTION

The generation of 3D models of historical buildings is frequently required during the documentation of heritage sites i.e. for tourism purposes or to provide education resources for students and researchers. During the generation of these models, requirements such as high geometric accuracy, availability of all details, efficiency in the model size and photo realism have to be met by the different approaches used for data collection [EL-Hakim et al 2002]. One well-accepted technique frequently applied in the context of heritage site documentation is close range photogrammetry [Gruen et al 2002, and Debevec 1996]. In the past decade, these traditional terrestrial approaches have also benefited from the fact that digital image collection is now feasible with of-the-shelf cameras. Thus the efficiency of photogrammetric data collection could be improved considerably by the integration of semi-automatic tools based on digital image processing. Recently, laser scanning has become a standard tool for 3D data collection for the generation of high quality 3D models of cultural heritage sites and historical buildings [Boehler and Marbs 2002]. These systems allow for the fast and reliable generation of millions of 3D points based on the run-time of reflected light pulses. This results in a very effective and dense measurement of surface geometry.

Despite the considerable progress of these approaches, there are still some limitations, which have an effect on the quality of the final 3D model. Even though current laser scanners can produce large point clouds fast and reliably, the resolution of this data can still be insufficient, especially if edges and linear surface features have to be collected. In addition to geometric data collection, texture mapping is particular important in the area of cultural heritage to have more complete documentation. Some commercial 3D systems already provide model-registered color texture by capturing the RGB values of each LIDAR point using a camera already integrated in the system. However, these images frequently are not sufficient for high quality texturing, since the ideal conditions for taking the images may not coincide with those for laser scanning. This may disturb the appearance of the resulting textured model.

In the contrary, the digital photogrammetry is more accurate in outline rendition, especially if they are clearly defined in the reality. Additionally, high-resolution color images collected at optimal position and time can be precisely mapped into the geometric model provided that the camera position and orientation is known in the coordinate system of the geometric model. On the other hand, image based modeling alone is difficult or even impractical for parts of surfaces, which contain irregular and unmarked geometrics details.

In our approach the combination of both techniques is applied to improve the geometry and visual quality of the collected 3D model. During data collection the information on edges and linear surface features like cracks is based on the analysis of the images, whereas information on object geometry is provided from the laser data. Additionally, we presented a new automatic technique to enhance the 3D geometric model of real world objects with texture reconstructed from separate sets of photographs. The purpose is to generate photo-realistic models of complex shaped objects with minimal effort. Within the paper the presented approaches are demonstrated in the framework of a project aiming at the generation of a 3D virtual model of the Al-Khasneh, a well-known monument in Petra, Jordan.

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. One of the project goals is the generation of a 3D documentation of the Al-Khasneh monument in Petra city, Jordan, which is depicted in Figure 1.

2.1. Al-Kasneh 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 (Sedlaczek, 2000).

2.2. Sensors Applied And Measurement Configuration

Depending on the application and the complexity of the environment, achieving high geometric and realism 3D model may require a large number of 3D and 2D images. In our project, 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 realized 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. Because it is not possible to have a complete 3D coverage for outdoor complex structured sites based on data collected from a single station, different viewpoints have to be done to resolve the occlusion. As it can be seen in the top row of figure 1, the different acquisition time of the images results in considerable differences in brightness and colour. This will definitely disturb the appearance of the textured 3D model. For this reason, additional images were collected by a Fuji S1 Pro camera, which provides a resolution of 1536x2034 pixel with a focal length of 20 mm. These images depicted in the bottom row of figure 1 were collected at almost the same time.

Figure 1. Alkasneh, Petra. In the first row Mensi laser scanner images (768x576), second row shows images collected using Fuji camera (2304x1536).

2.3. Data Preprocessing

During the data collection of Al-Khasneh 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 the mountainous environment surrounding Al-Khasneh restricts potential sensor stations. 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 an absolute coordinate system. After registration of the scans using corresponding points, the software constructs a non-redundant surface representation, where each part of the measured object is only described once. The produced model has an average resolution of 2 cm with more than 10 million triangles, depicted in figure 2. In additional to the outer survey, a 360-degree scanning from a station in the interior of the Al-Khasneh had been taken, which resulted in 19 million points. This scan depicted in figure 2 with color information overlaid.

3. AUTOMATIC EXTRACTION OF LINAR SURFACE FEATURES

Although the 3D model produced by laser scanner contains a large number of triangles, which are representing the surfaces, it can still difficult to recognize and localize the outlines of the surface features. An example for this type of features, which are clearly visible in an image is depicted in figure 3. This data was collected from the left door of Al-Khasneh. As it can be seen from the corresponding 3D meshed model that depicted in figure 4, these cracks and the edges outlines are lost beyond the resolution in the available laser data. In order to support the visual quality of such details, a hybrid approach combining data from the laser scanner and the digital imagery was developed. Additionally, the approach applies a semi-automated feature extraction from images to bridge gaps in the laser scanner data.

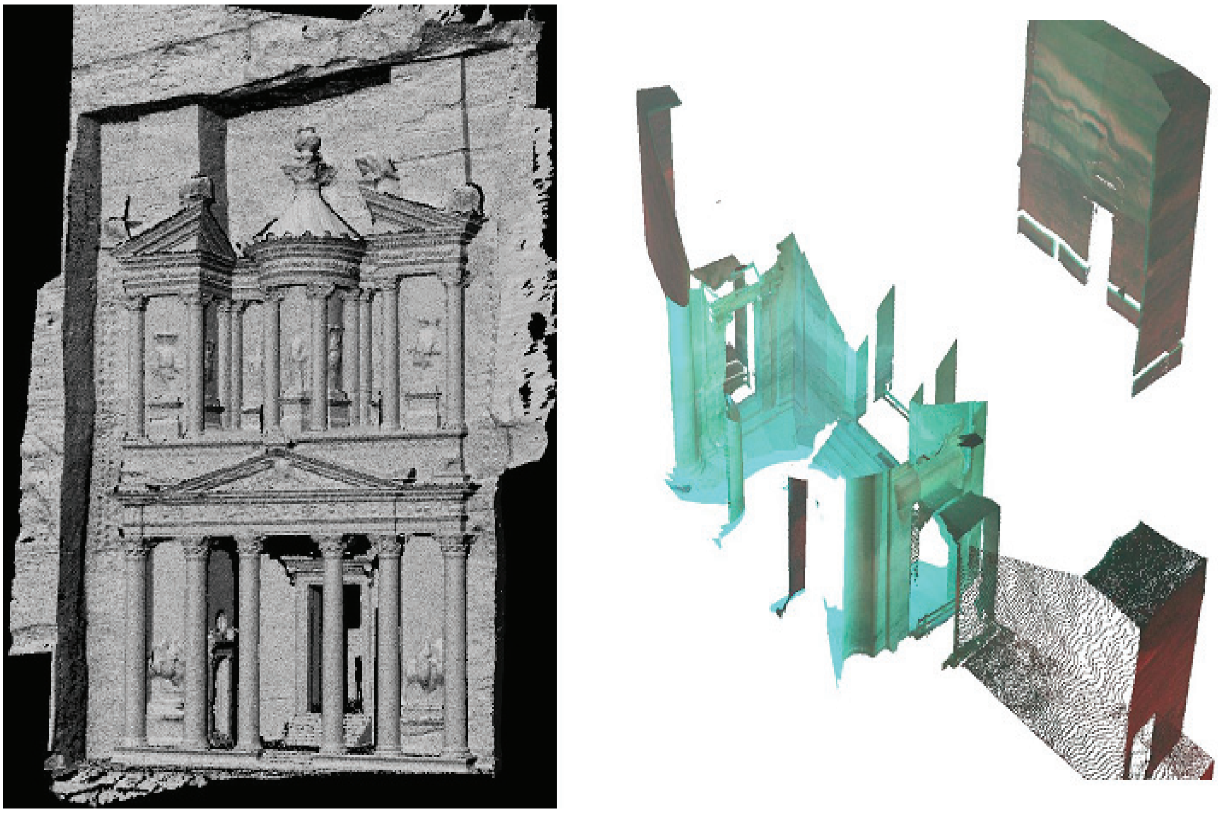

Figure 2. The left image shows 3D model of Al-Khasneh created from 5 scans, the right image shows 360 degree scanning for the inner part of Al-Khasneh.

3.1. Data Coregistration and Distance Image Generation

The quality of the registration process, which aligns the laser scanner data with the imagery, is a crucial factor for the aspired combined processing. Since the accurate detection and measurement of point correspondences can be difficult especially for the point clouds from laser scanning, straight lines are measured in the image and the laser data as corresponding elements. These lines are then used by a shape matching followed by a modified spatial resection. After the image coordinates are co-registered to the laser scanner coordinate system, the collinearity equations are applied to generate a distance image based on the available point clouds. For our exemplary scene, the point cloud was collected from a close viewpoint resulting in 1 cm average resolution. Three distance images were generated for the three images available from different camera stations as it can be depicted in figure 5.

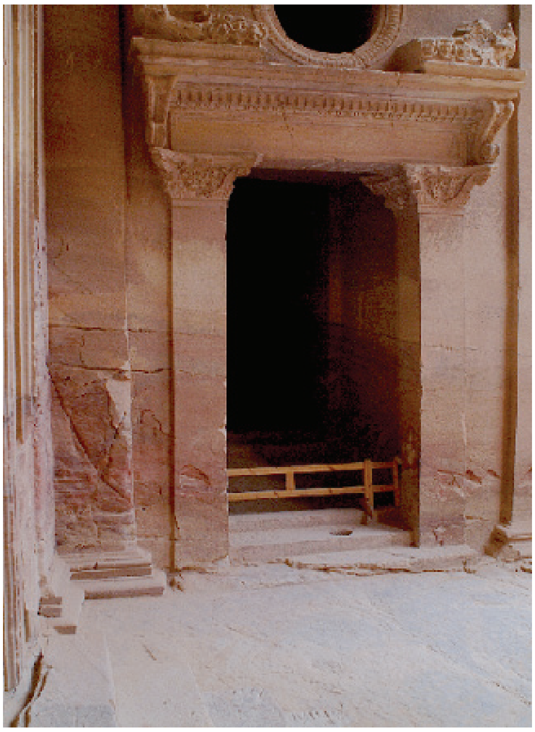

Figure 3. The left door of Al-Khasneh.

Figure 4. Meshed model for the left door

Figure 5. The distance image of the left door projected on the corresponding image.

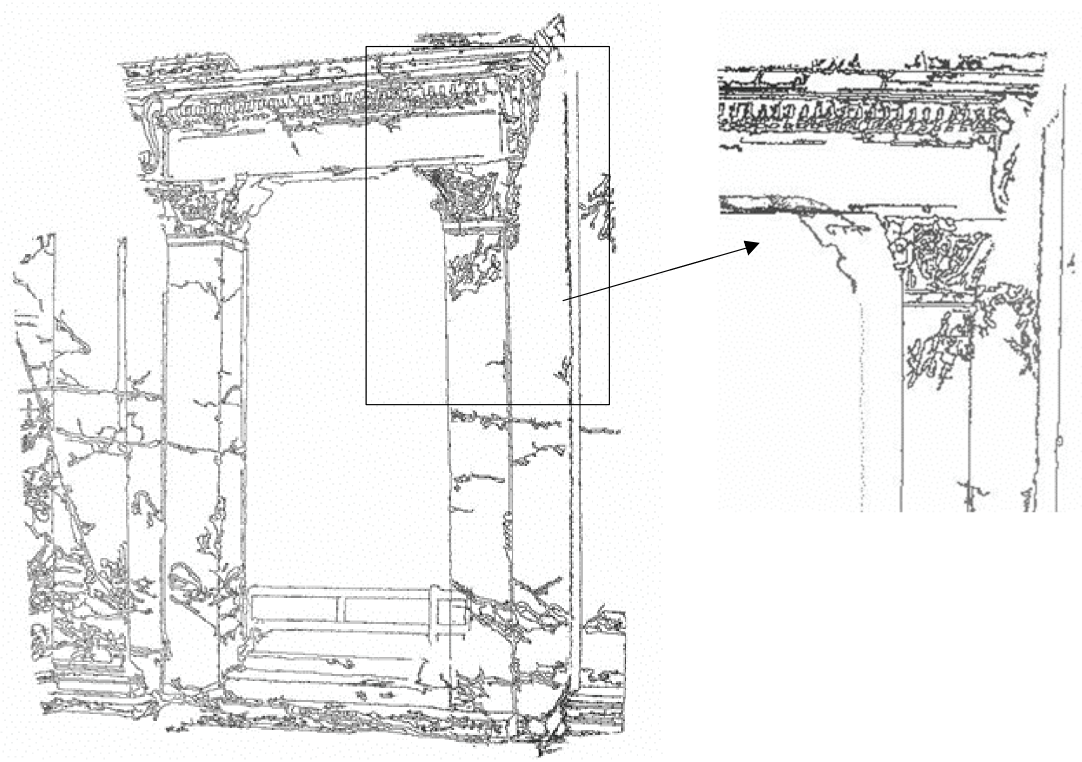

Figure 6. 3D features extracted for the left door of Al-Khasneh, the inner edge of the column is added from image based measurements.

3.2. 3D Feature Exraction

The segmentation process is used to automatically extract the 2D 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 3 imagery images. The third dimension of the segmented outlines is provided from the distance images. Figure 6, depicts the final 3D features extracted for the left door of Al-Khasneh. It can be seen that the data contains all of the edges and linear surface features in a clearly outlines. In total the feature-based representation contains 143.6 thousand points, whereas the original point cloud of the same portion has 1.1 million points. It can be seen from the 3D features presented in figure 4 that due to the position of the laser scanner, the inner edge of the right column of the door could not be captured. The occluded edge can be added based on semiautomatic evaluation of digital imagery to have a complete data set for the scene. The occluded edge is added to the 3D features as it can be shown in the right part of figure 6.

4. TEXTURE MAPPING

The purpose of texture processing is to integrate the 3D measurements from the laser scanner with 2D information taken with external or internal camera. Our approach allows taking the images at different time from laser scanning and at whatever locations that will be the best for texturing. Since the triangles are relatively small, no perspective correction was applied, and the original high-resolution 2D images are used for processing. In order to guarantee high quality texture mapping, preprocessing steps for generating geometric and radiometric distortion free images is necessary. Otherwise artefacts such as line discontinuity will be visible at common edges of adjacent triangles mapped from different images. Before performing projective texture mapping, we need to compute visibility information to map the image only onto the portions of the scene that are visible from its camera viewpoint. In this section an overview of the procedure will be presented, Alkasneh model will be used to demonstrate the steps of the approach.

4.1. Camera Calibration and Colour Correction

Distortion free images and the homogenous illumination between the photographs are crucial factor for getting a realistic looking nature of the model. This requires an accurate determination of the cameras interior and exterior orientation parameters. For our investigations the interior orientation parameters were computed using a calibration computed by the Australis software. These parameters were used to creating zero distortion images as intermediate step. For high realistic 3D texture mapping the artifacts due to illumination changes between photographs have to be removed. We use ENVI 4.1 software to perform the histogram equalization for all three channels in all textured images in order to diffuse the texture.

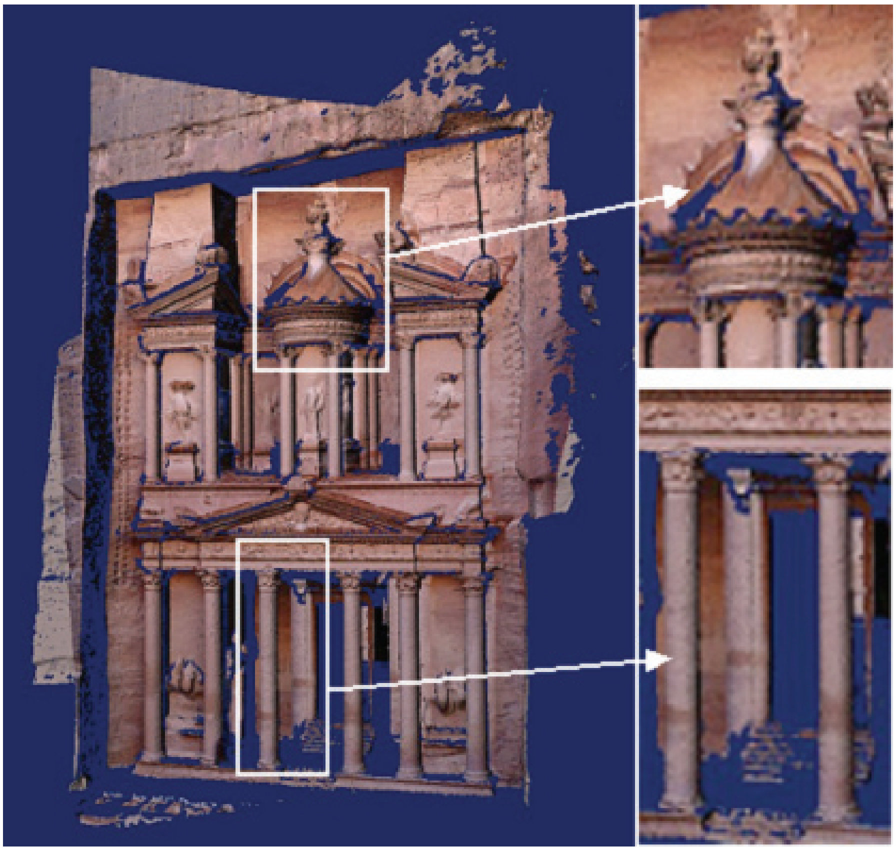

Figure 7. Double projection problem

4.2. Summary of the Overall Procedure:

During texture mapping every point on the surface of the object (in x, y, z coordinates) must be mapped to some point (in u, v coordinates) on the texture image. If no special care is taken, then erroneous pixel values are extracted for the occluded parts of the scene as it can be seen in figure 7. In order to handle the resulting problem of occlusions, the visibility of the model areas in the respective images has to be established. For this purpose an efficient algorithm addressing the image fusion and visibility is used. The algorithm works in both image and object space and efficiently detects ambient, back-face and view frustum occlusions. Invalid pixels that belong to theshadow polygons will be identified and marked as can be depicted in figure. Then the occluding parts are masked out with their connectivity, and they are used as input model for the second selected textured image. The process for checking visibility and separating will be repeated automatically until the model is textured from all the available images. The separated parts merge with the master image part to have the final model, which is depicted in figure 9. For Alkasneh texture mapping, we have used five coloured images 2304 x 1536 pixels for texturing 2 millions triangles. The performance analysis has been conducted on a standard PC with an Intel 4, 3GHz Processor, and 1GB RAM. In our approach VRML modelling language is used.

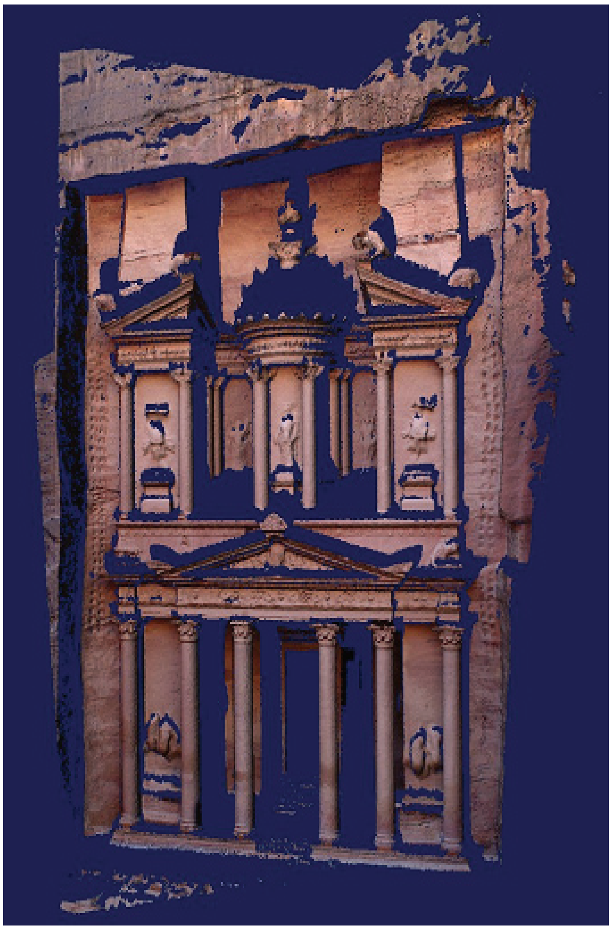

Figure 8. 3D textured model using master image after separating of the occluding parts

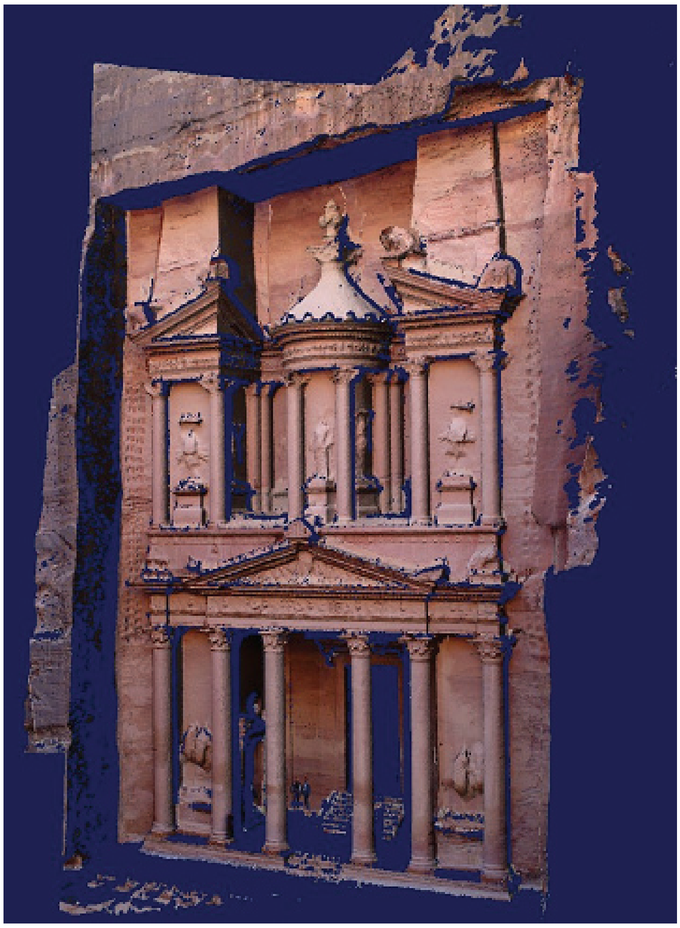

Figure 9. Final textured model of Alkasneh using 5 images

5. CONCLUSION

The work described in this paper was developed as a part of an ongoing project which aims to underline the necessity to integrate image based measurements and laser scanner techniques in order to optimize the geometric accuracy and the visual quality of 3D data capture for historical scenes. In our approach, the segmentation process is used as an intermediate step to extract information on edges and linear surface features. Whereas the 3D information of theses details is provided from the laser scanner data. Additionally, we present an effective automatic approach to the problem of high-resolution photo-realistic texture mapping onto 3D complex model generated from range images. Our approach allows taking the images at different time from laser scanning and at whatever locations that will be the best for texturing. For this purpose an efficient algorithm addressing the image fusion and visibility is used. One advantage of our algorithm that it is easily allows the visibility detection of different resolution of 3D geometric models and 2D images. The approach has been demonstrated for texture mapping Alkasneh monument and other heritage sites in Jordan, the results are extremely realistic 3D models.

6. REFERENCES

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