

SPATIAL DOCUMENTATION OF THE PETRA WORLD HERITAGE SITE

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Abstract

This paper describes the spatial documentation of the UNESCO World Heritage Site Petra Archaeological Park (PAP), Jordan, as commissioned by UNESCO and executed by the Zamani research team at the University of Cape Town. The project reported in this paper is a holistic approach, both in the variety of spatial technologies as well as the near complete cover of the major monuments and the landscape, including the natural access canyon to Petra, known as the Siq. The documentation was realised with laser scans, 360 degree panoramic images, photogrammetry and RTK-GPS. The vast majority of the acquired data was incorporated into a Geographic Information System (GIS). A substantial portion of the 3D models are also integrated into a largely completed 3D Virtual Tour of the site that will be used for scientific and touristic purposes (Wessels et al, 2014). The documentation was a component of the “Siq Stability – Sustainable Monitoring Techniques for Assessing Instability of Slopes in the Siq of Petra” project for the long-term monitoring of potentially unstable rock slopes in the Siq. The 3D laser scan model of the 1.2 km long canyon project was employed as an analysis and management tool for the monitoring initiative.

The various output data produced and their practical applications in the conservation work done at Petra are discussed as well as the challenges faced during the fieldwork and data processing phases. A brief description of the Zamani Project, University of Cape Town, is included.

1. Introduction

The UNESCO World Heritage site of Petra is located halfway between the Dead Sea and the Gulf of Aqaba, in Jordan. Once a thriving centre of trade at the juncture of major trading routes, Petra was the capital city of the Nabataeans, a nomadic people whose empire rose to its peak between 300 BC and 300 AD. The site was listed as a UNESCO World Heritage Site in 1985. Throughout its existence, the rock-hewn tombs, tricliniums and dwellings of Petra, as well as its freestanding palaces, colonnades and temples have been threatened by catastrophic events of earthquakes and floods as well as slow natural weathering through the forces of temperature

variations, wind and rain. Today, the more than 2000 tourists who visit Petra, on average, every day add an additional factor to the multitude of threats facing the site.

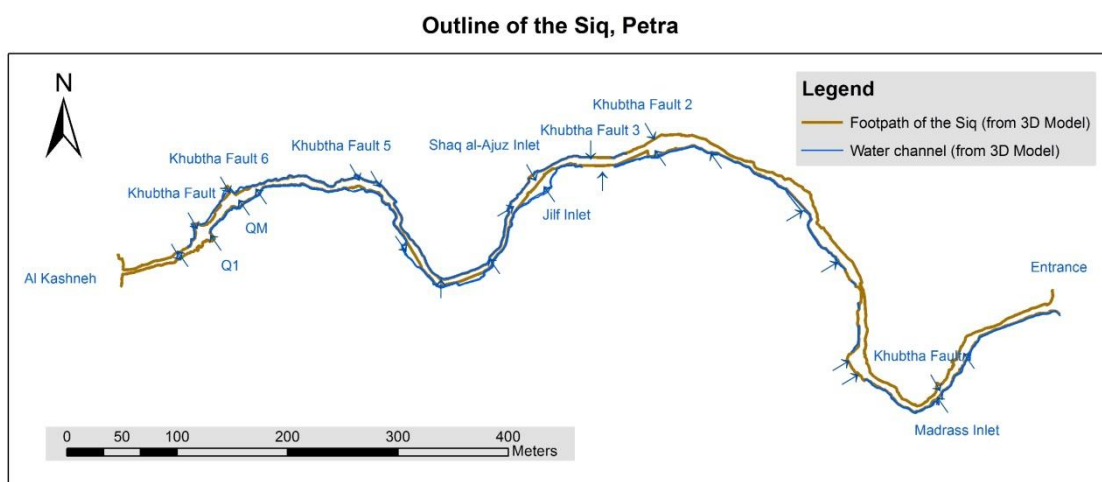
This paper describes the spatial documentation of Petra as part of the Siq Stability project, which is a "Funds In Trust" project of the Italian Ministry of Foreign Affairs for UNESCO. The project is managed by the UNESCO Amman Office and has as main partners Italian geological experts from ISPRA (Italian Institute for Environmental Protection and Research - Geological Survey of Italy), the Zamani Research Group (Ruether et al., 2009), and the Petra National Trust. It is undertaken in cooperation with the Department of Antiquities of Jordan (DOA) and the Petra Development and Tourism Region Authority (PDTRA).

The principal objectives of the project are the development of a:

- Monitoring system aimed at detecting potentially unstable rocks and at-risk areas.
- Guidelines for implementation of sustainable landslide mitigation strategies and for management of the Petra area.
- A GIS platform for storage, analysis and management of data relevant for the Petra Archaeological Park area.
- A 3D computer model of the Siq and the major structures and landscape of the site.
- A virtual tour of Petra.

The Zamani group was responsible for the 3D modelling of the Siq, the access route to the site, based on terrestrial laser scanning and aerial photography, the creation of a comprehensive site GIS and database, a Virtual Tour, and 3D documentation of the important tombs and structures.

2. Documentation of the Siq



The Siq (Fig. 1, 2a, 2b), which is the principal entry to the ancient city of Petra, is a dramatic, narrow and high canyon that has been used as an access to Petra for over 2000 years. The walls of the Siq are decorated with many man-made features including votive niches carved into the rock walls. The Nabataeans (Taylor, 2007) also constructed rock-cut water channels and terracotta water pipes that run on the inner walls of the Siq. Many natural water inlets from the surrounding mountains, which are now blocked off by small dams, also feed into the Siq. These were constructed to prevent or limit flash floods that have caused several deaths in the past. Among other responsibilities the Zamani team was tasked with the creation of a 3D model of the Siq to be used for the development of appropriate techniques for establishment of monitoring systems throughout the Siq. Figures 2a and 2b show the floor and the top of the Siq.

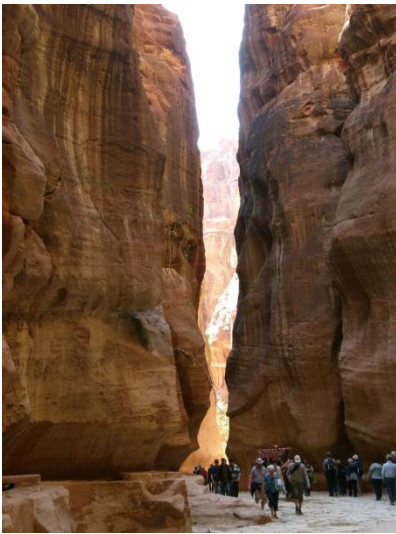


Figure 2a: The Siq



Figure 2b: View of the top of the Siq

3.1 Data capture in the Siq

It was obvious from the outset of the project that any expectation that a complete hole-free model of the contorted, tall and narrow Siq with its overhanging rock walls and inaccessible upper sections was unrealistic. The width of the 1.2 km long Siq varies from 3 to 15 meters and its rock walls reached heights of up to 120 meters. Combinations of aerial and close range photogrammetry, the use of UAVs, balloons, scaffolds and poles was considered as spatial data capture methods but eventually rejected because of their complexity, because of light conditions, data volume, extensive demands on time, high cost and in some places absolute impossibility of applying any of the considered techniques. An additional complication arose from the absence of GPS signals over the entire length of the canyon floor.

It was therefore accepted that the documentation had generally to be restricted to the lower 20 metres of the rock walls. However, in a number of cases scanning up to heights of 100 metres was possible from the Siq floor (Fig. 7 and 8). In some places it was also possible to physically climb to and scan the upper edges of the canyon's rock walls. In these cases donkeys and horses were used

to move the equipment as far as possible up steep rock trails after which the instruments had to be hauled to the top on foot.

Practical difficulties arose from the continuous flow of tourists past the scan stations while working on the Siq floor. This did not only result in considerable inconvenience during scanning but more importantly, added hours of tedious point cloud cleaning to the processing time.

Over 200 laser scans of the Siq were acquired, using a variety of scanners including Leica HDS 3000, Leica HDS 6000, Z+F 5010, Z+F 5010c, Leica C10 and Trimble FX. More than 6 billion points of the Siq walls were captured. The continuous presence of tourist throughout the day became even more of an obstacle when acquiring the more than 100 HDR full-dome panoramas which were captured at 10m intervals along the Siq. It was practically impossible to keep the panorama photography entirely free of people but attempts were made to wait for moments with minimal or no people in the scene.

3.2 Processing the Siq data

The 200 laser scans were registered using an Iterative closest point algorithm (Besl et al., 1992) as opposed to target based registration. The authors' experiences gained during the registration of over ten thousand scans in large projects over the past eight years showed that ICP registration without targets is more than adequate for architectural and similar applications (Rüther et al., 2012). Moreover, the application of targets would have been highly impractical as it is undesirable and generally forbidden to physically modify any World Heritage Site and as attaching targets would have required professional climbers. It was therefore decided to apply the target-free approach to the registration of the Siq scans. After registration and modelling of the entire 1.2 km long point cloud, the model was geo-referenced to GPS points captured at either end of the Siq. From a survey perspective it is not satisfactory to control the traverse-like point cloud of over one kilometer length at the two ends of the point cloud only, but unfortunately any attempts to receive GPS signals anywhere inside the Siq proved futile. The accuracy of the point cloud "traverse" as derived from the geo-referencing was surprisingly high with a difference between the GPS and the point cloud results being an average of 5cm. However, this accuracy measure must be seen with some reservation as it is based on a comparison at the ends of the 1.2 km long point cloud traverse. A high precision total station traverse will be added in the future for further, albeit still limited, basis for comparison and accuracy assessment.

3.3 The modelling process

As detailed in section 4 of this paper, the Siq has been divided in "sectors". Due to the

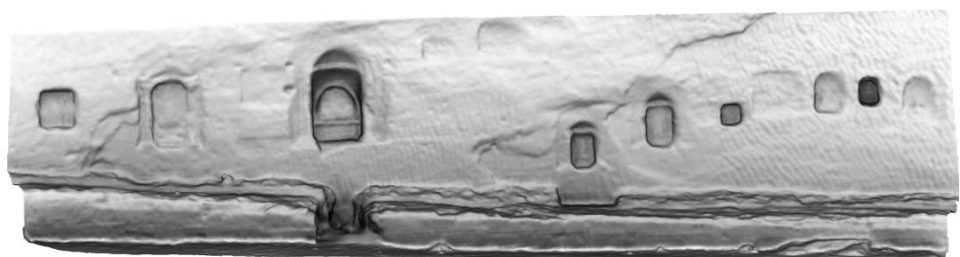


Figure 3: Niches and water channels in the Siq

large data volume of the Siq, the different sectors have been modelled separately. The models created capture the overall structure of large walls as well as the nuances of the small structures. The detailed shapes of niche and water channels can be seen in Figure 3. Individual stones on the floor of the Siq can be seen from the modeled laser scans in Figure 6. Figure 5 shows the difficulty in capturing all the convoluted shapes of the Siq, using a terrestrial laser scanner. The parts marked in red were not captured by the scanners, as they were not visible from the Siq floor and could thus not be scanned (Fig. 5).

Figures 3, 4 and 6 show parts of the Siq containing detailed man made features that have been captured to high detail by the laser scanners.

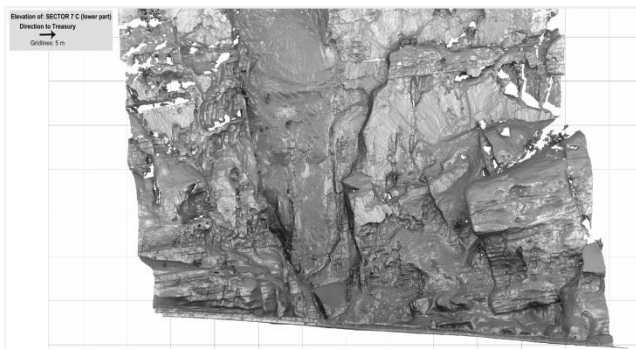


Figure 4: Example elevation of the Siq



Figure 5: Cross section at 300m from entrance of Siq

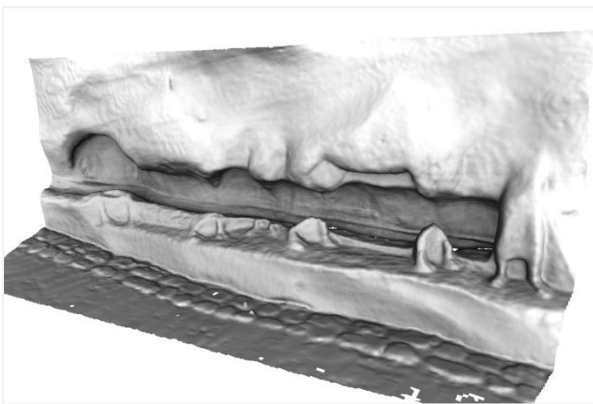


Figure 6: Caravan in the Siq

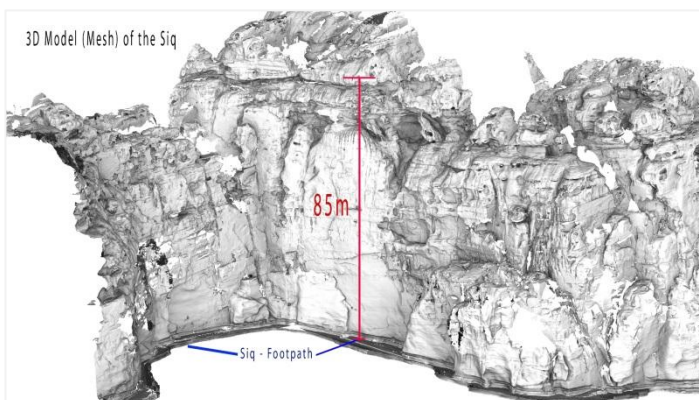


Figure 8: Cut out section, showing a rock face where scanning from both bottom and top was possible



Figure 7: Photo showing the steep walls of the Siq

3. Documenting the monuments of Petra

3.1 Registration and geo-referencing of the laser scans

The fully registered and geo-referenced point cloud combines all structures and the landscape of Petra and stretches over a distance of 3 km. The limitation experienced in the comparison of accuracies obtained in the Siq as discussed above, did not apply here, as the 1.8 km of scans in Wadi Musa from the end of the Siq to the Qasr Al Bint were in open areas where some 10 GPS points could be observed in RTK mode and used for geo-referencing and checking.

3.2 Modeling of the monuments of Petra

The resulting point cloud of the whole of Petra is comprised of some 20 billion surface points. The point cloud includes scans of, besides the rock walls of the Siq, the outside and inside of some 30 major structures in the two principal wadis of Petra, including the famous Treasury, Monastery, the Royal Tombs, the Soldier Tomb, the Garden Tomb, the Renaissance Tomb, the Amphitheater, Qasr al Bint, Urn Tomb, Winged Lion Temple and the Great Temple. All structures were fully scanned in high detail (less than 1 cm point interval) inside and outside and in some cases included underground tunnels. Also scanned were the general mountain terrain and much of the landscape surrounding the site. Figures 8, 9, 10 and 11 show various textured and untextured models of the major structures in Petra.

During the modelling process it became obvious that it is crucial to restrict the data capturing process to as short a time period as possible to avoid conflicts as a result of changes in surface. In Petra such changes occurred over the extent of the project due to moving sand and conservation interventions.

It is worthy to note that the Petra GIS proved to be an extremely valuable management tool at many stages in the data processing pipeline. Positions of scans, panoramas, still images, and GPS points could be readily retrieved when needed. The processing of the data required many man-months to complete and more than 10 TB of hard disk space, excluding backups and redundancies was generated.

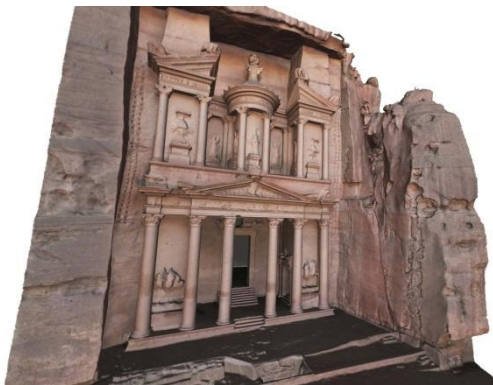


Figure 9: 3D model of the Treasury



Figure 10: 3D model of the Amphitheatre



Figure 11: 3D model of the Royal Tombs

4. GIS of the Petra Archaeological Park

The newly developed Petra GIS, created by the Zamani team, of the Petra Archaeological Park consists of existing and newly created data. Already existing GIS data (images and shapefiles) from different sources provided by UNESCO and international researchers, were migrated through co-ordinate transformation and geo-referencing into the new Petra GIS. New data acquired by the Zamani team through 3D laser scanning, RTK GPS surveys, aerial and close range photogrammetry and panorama photography form the main body of the GIS. The GIS software ArcMap from Esri's ArcGIS suite of geospatial processing programs was chosen to incorporate all existing and newly acquired data under one system.

One of the challenges was to make all output data, including 3D models, plans, sections, elevations and full dome panoramas, directly retrievable from the GIS. This applies especially to the display of the 3D Models (meshes) and the full dome panorama imagery which relies on specific software, such as Meshlab (Cignoni et al., 2008) to view 3D models or FSP-Viewer (FSoft s.r.l, 2014) to display full-dome panoramas.

4.1 Co-ordinate system

Incorporation of the various GIS data created over time, first in hardcopy format and later in digital form, into the GIS produced in the framework of the Siq Stability project had to be carried out in two steps.

Inspections of the existing data, scanned diagrams and drawing in books, satellite and aerial images, maps, ground plans and previously generated shapefiles, revealed that the spatial data were referenced to different co-ordinate systems on different ellipsoids and different datums. This necessitate the transformation of all existing datasets to the new Petra GIS which is based on 146 RTK-GPS recorded in the Universal Transvers Mercator (UTM) Projection, UTM Zone 36N on the WGS84 reference ellipsoid.

After completion of this first step, simultaneous display of the various coverages showed, in some cases, significant discrepancies in the positions of the same features on different shape files. The reasons, some of which relate to the history of the survey of Jordan, for these discrepancies are varied and cannot be discussed here. A separate project is underway at UCT which investigates this area.

Because of these discrepancies a second step was required to combine the old and new data. This involved the manipulation of shape-files to new positions. In this process shape-files were either geo-referenced by identifying common features on the old and new GIS layers and moving the old ones to the new GIS or, in cases where no common features could not be found, by identifying well defined feature points on old maps, carrying out a RTK-GPS survey of these points and then geo-referencing the old maps to these GPS points, which were recorded in the reference frame of the new GIS.

4.2 Incorporation of laser scan models into the GIS

The generated 3D models and their derivatives were added into the Petra GIS in various forms. These were 3D models of the Siq and individual man-made structures, elevations and cross sections of the latter, together with models of the surrounding landscape (Fig. 12).

For the Siq two “Orthographic Top Views” (images) of the 3D model were created (Fig. 1), one which shows the outline of the footpath (ground level) of the Siq using the intersection of the footpath with the rock walls on either side of the Siq, and one indicating the water channels along the footpath which are cut in the rock at an elevation of about 1m. The plans were then geo-referenced through GPS control points.

The Siq model was divided into sectors for which high resolution 3D models (2-3cm mesh) were generated together with corresponding elevations, in the form of orthogonal images of the rock wall models on

either side of the Siq. Cross sections at right angles to the centre line of the canyon were generated from the point cloud at 10m intervals throughout the entire extent of the Siq.

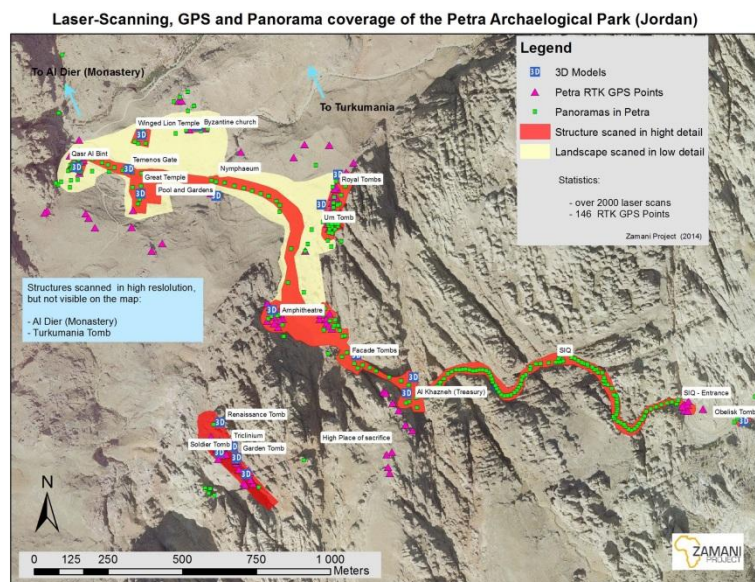


Figure 12: Structures and Landscape scanned in high- and low detail, Positions of high resolution 3D Models, GPS points and panoramas.

In addition to the laser survey, the PAP area was recorded by means of some 450 full dome panoramas and close to 10000 photos for photogrammetric processing and texturing. Each panorama was geo-referenced by visual inspection on the Petra orthophoto and hyperlinked to the GIS.

The FSP-Viewer software was incorporated into the GIS to automatically open the panoramas. In this approach the panorama tour capability was retained allowing the virtual site visitor to move via so called “hot spots” from one panorama to the next. The user of the GIS thus has the option to enter a panorama at a selected point and navigate or “walk” through the entire Wadi Musa and Wadi Farasa, from the entrance of the Siq towards the Treasury and further past the Amphitheatre, Urn-Tomb, Qsar Al Bint ending the tour at the monastery with a side excursion down Wadi Farasa. For all documented structures a ground plan, elevations and sections were derived from the 3D model and incorporated into the GIS.

All data were geo-referenced and hyperlinked in ArcMap enabling viewing of images, plans, sections and elevations in a 2D viewer, while 3D models can be inspected in a 3D viewer (Meshlab).

5. A virtual tour of Petra

Digital spatial documentation of cultural heritage sites is well-established and digital libraries and museums now host large quantities of digital data of heritage sites (Ott et al., 2010). Displaying this digital data to the public in an interesting and engaging manner is a challenge which needs to be addressed. Demand for 3D data has grown in a world which is becoming increasingly aware of the 3D capability of various media and it seems prudent to exploit this interest (Roussou, 2002). An example of displaying digital data can be found on the Smithsonian website, X3D, where individual models of heritage artefacts can be interactively viewed online (Smithsonian institute, 2014). Other projects such as Discover Babylon let a user interactively explore a Virtual Museum as part of a game, learning about heritage sites in the process (Lucey-Roper, 2006).

It is with this in mind that the Zamani project has created a 3D Virtual Tour of Petra, using the data captured in Petra and processed at the University of Cape Town (Wessels et al., 2014). The Virtual Tour is intended for use in site management and education, for archaeological and scientific analysis, and in visitors’ centres and museums. The data incorporated into the Virtual Tour include the DTM, orthophoto, 3D models which were textured where possible, 360 degree panoramas, selected GIS data, sections and elevations. The Virtual Tour is described in detail in Wessels, 2014.

6. The African Cultural Heritage Sites and Landscape Database

The documentation of Petra was realised by the Zamani team in the Geomatics division of the

University of Cape Town, where the group is involved in similar projects within the framework of the African Cultural Heritage Sites and Landscapes Database project. This project is dedicated to recording cultural heritage monuments and landscapes throughout the African continent with state-of-the-art technologies, thus contributing to the virtual preservation and in some cases physical conservation of Africa's heritage. The project recognizes the urgent need to:

- create metrically correct digital (3D) documentations of African Heritage Sites for future generations
- provide spatial information of heritage sites for conservation and restoration
- provide spatial information of heritage sites for education and research
- promote awareness of Architectural African Heritage (historical sites, buildings and towns) within Africa and worldwide
- provide management tools for site management at local and regional level

The output of the project is made available by the JStor digital library, New York (<http://JStor.org> and <http://aluka.org>) where full data sets are available for research, education, conservation and restoration projects. A subset of the data can be viewed on <http://www.zamaniproject.org> and some videos with site examples can be found on <http://www.youtube.com/user/zamaniproject>

The Zamani group has to date documented some 45 heritage sites in Africa and the Middle East including sites in Jordan, UAE, Ghana, Mali, Mozambique, Tanzania, Kenya, Ethiopia, Sudan, Egypt, Algeria, Zimbabwe, Cameroon, Uganda and South Africa. All projects are executed by members of the unit, with the support of staff members of Antiquities or equivalent Government Departments.

The deliverables of the project are:

- an integrated database consisting of a Spatial/Geographic Information System (GIS)
- 3D computer models of structures and parts of towns and landscapes
- elevations, sections, ground plans and roof plans
- computer visualisations with walk-through and other inspection capabilities
- full dome panorama tours
- contextual photographs
- site related digitised documents, scientific papers, excavation reports and similar material

During the process of creating the database, a methodology for the documentation of African heritage sites has been developed and optimal ways were explored in which the data can be presented in a form where they can be used by African heritage authorities and by museum officials and researchers in Africa and worldwide (Ruther et al., 2012).

7. Conclusions

The spatial documentation of the Petra World Heritage Site resulted in the most complete spatial documentation of the site to date and this holistic collection of spatial data is the first of its kind for Petra. All major man-made structures, the surrounding landscape and the Siq, were thoroughly documented with high accuracy and reliability. Both the scientific and touristic community is expected to benefit from this collection and from the 3D Virtual Tour that will host all spatial data in a single, easy to use environment. It is hoped that the exploration of the data collected by the Zamani project will open new avenues for research and lead to new understanding of the site. The acquired data are specifically relevant in the context of the Siq Stability project as the data acquired for the Siq and its immediate surrounding area are at present being used for rock mechanical analysis, monitoring and planning purposes.

8. Acknowledgements

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