THE MULTISPECTRAL AND 3D STUDY OF THE OBELISK TOMB IN PETRA, JORDAN

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ABSTRACT:

The Obelisk Tomb is the first important façade that a visitor sees while entering to the archaeological site of Petra in Jordan. The rich architectural formations carry Egyptian, Hellenistic and Nabataean influences. The damage that was inflicted on this unique monument led us to study it applying a number of modern digital techniques including 3D scanning, multispectral photography with visible and near infrared images, and thermography. Our results clearly indicate that in addition to visual inspection and visible photography, such techniques allow a better examination of the existing damage in two and three-dimensions by highlighting certain important aspects of weathering causes, as well as shed some light on the causes of the damage. Plants are easily detected by the near IR imagery after contrast enhancement, while thermal imagery accentuates the architectural details of surfaces, showing clearly the edges and any damage they may have incurred. Superimposing different spectral bands much like in remote sensing proves to be a very helpful approach to study weathering damage.

1. INTRODUCTION

The Obelisk Tomb and Bab As-Siq Triclinium (1st century BC - 1st century AD), is the first major monument encountered when entering Wadi Musa on the way to the 1.2 km long Siq, the main gorge entrance to the ancient city of Petra. This complex facing NW is dominating the left side of the road, a few meters down from the Djin blocks. In reality, the Obelisk Tomb is separated into two monuments, stacked on top of each other: the Obelisk Tomb (upper storey); and the Bab as-Siq Triclinium (lower storey), Fig 1. The Obelisk Tomb (also known as 'Nefesh' Tomb) is named after the four obelisks that decorate the top of the entrance of the tomb guarding the rock-hewn cave tomb entrance and was used for burials. The lower storey, the Bab as-Siq Triclinium is decorated in a more classical style and was apparently used for funeral banquets as many such chambers in Petra used for memorial feasts in honor of the dead, a practice that was also common among the Greek and Romans. Through this variety and richness of the decorative and symbolic architectural elements, this complex reflects perfectly the spirit of the late Hellenistic architecture, where architects moved among different cultures create high artistic architectural formations, especially the Baroque nature of the rock-cut sandstone façades. Certainly these different historical architectural treatments at the same monument were not only decorative but they indicate how this family wanted to be seen for the eternity. It is possible; therefore, that this architectural formation may came from that direction.
A Mensi GSI 100 laser scanner together with a Flir B4 thermal infrared camera and a Canon 1Ds Mark III for the visible and near infrared (NIR) images were used to acquire both the metric and multispectral data. The acquisition of the NIR photography required a chase for a visible opaque Kodak Wratten 87 gelatin filter. All the recorded images were eventually draped onto the resulting 3D model. The previous experience of false color composition utilizing NIR paper films and conventional photography to try to enhance the damage and the material variations observed on part of the Palace Tomb Façade (Akasheh, 2000), carved out of Precambrian Sandstone, is adapted and extended herein over 3D models. The results showed that we can easily locate plant infestations no matter how small and even if they are not easily apparent to the naked eye. In addition, UV sensitive films allowed the detection of Limonite veins and infestations even when mixed with dust, clays and other sandstone types.
It is possible to acquire more easily such multispectral data using the faster and more efficient digital techniques. In addition to the acquired images in the field, we have created false color images that revealed more easily the damage and some of its causes, utilizing different bands from the various photos, very much like the Landsat bands utilized in remote sensing. The resulting images render some interesting results that are presented in this paper. The technique of draping either the obtained band combinations of false color images or the field photos onto the 3D model opens up the rendering to enhance the weathering effects and their damages for methods and techniques of cultural heritage documentation. In fact, it allows specialist to examine closer and better the problems threatening the monuments. The work reported next is focus on the Obelisk Tomb.

2. THE OBELISK TOMB

The Obelisk Tomb has several graves housed in it. The Tomb section is characteristic; mostly the floor is clear to the bedrock, the interior consisting of an approximately square chamber (5.80 m x 5.90 m, h. 4m) with a broad recess in the back wall in a form of rectangular arcosolium (2.9 m x 1.7 m, h. 3.1 m) starting 0.2 m above the floor, and decorated with 2 carved pillars (w. 0.49 m) crowned by a segmental arch, and two Loculi, with the approximate dimensions of 2.5 m x 1.25 m, h. 2.3 m, starting 0.12 m above the floor level, and carved on each side of the wall.

There is another grave (2 m x 0.5 m) in the floor towards the front of the chamber, parallel to the left side wall. The facade wall has a slightly raised band on both sides of the doorway and two splayed windows which emerge as slits on either side of the entrance doorway (Fig 2). The doorway width is about 1.35 m and is approached by four steps of 0.4 m width.

The façade (w. 16 m, h. 12.25 m) is remarkable; it is approached by a staircase on the left Fig 2, passing a cistern (2 m x 2.1 m). Across the top part of the Tomb façade there are four obelisks cut free from the rock behind magisterial obelisks, 'pyramids' (Nefesh) with the top part of each weathered away. The left obelisk, which is the longest one, has approximately 7 m height.

Figure 1: Obelisk Tomb (upper storey) approached by a staircase on the left

These obelisks are clearly influenced by the Ptolemaic Egyptian stylistic prototype approach. Between the centre pair in the plain rock faced behind the level of the four obelisks, there is a classical niche carved with a statue in deep bas-relief, with two pillars and anta-type capitals, entablature and a Doric frieze. This bas-relief is quite weathered and has lost its head. However, the four obelisks and bas-relief are properly symbolic representations of the five people buried in the tomb.

The lower part is plain, with a central classical order doorway. It is very weathered with little detail visible clearly. The two doorway pillars had anta-type capitals and the entablature had a Doric frieze (Fig 4). Generally the façade is too weathered for any tooling to be realized.

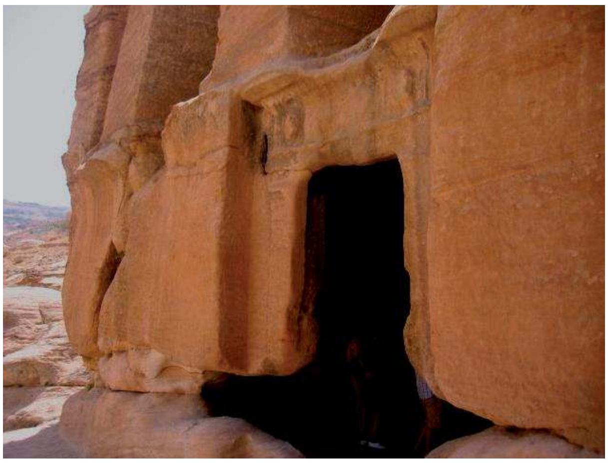


Figure 2: The Obelisk Tomb doorway, pilasters, and entablature

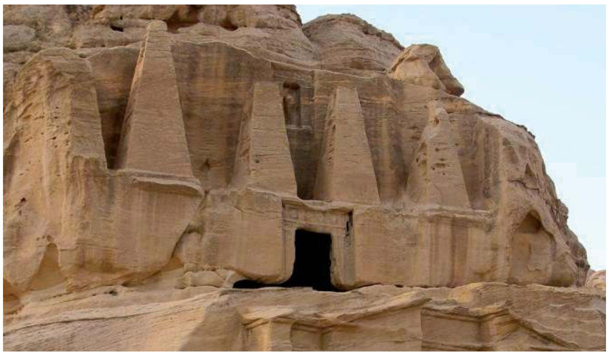
2.1 Chronology

As with many monuments in Petra, it is unclear when these monuments were carved. Some scholars suggest the Obelisk Tomb is older than the Triclinium; others believe that they were built together dated to the mid-first century AD, according to the inscription opposite. This while across the road from them is an inscription in Nabataean and Greek, recording that Abdmank chose this site to build his tomb. This may or may not refer to the tombs across the road. Some believe that the bilingual inscription on the rock-face on the other side of the road, located with all the subtlety of a roadside advertisement, refers to both monuments. The longer Nabataean version reads: *'This is the burial place chosen by 'Abdmank, son of 'Akayus, son of Shullay, son of 'Utaih, for the construction of a tomb for himself, for his heirs and the heirs of his [heirs], for eternity and beyond: [he has made it] in his lifetime, in year ... of Malichus'.*

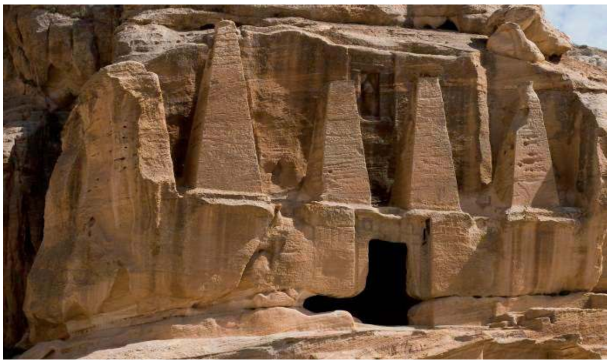
The Greek version is simply a summary: *'Abdomanchos son of Achaios has made this monument for himself and his children'*. However, the Triclinium and the left and first right chambers are finished with neat lines tilted at forty and sixty degrees with a broad band of lines along the edges and lines on the ceiling parallel to the front wall. This tooling is identical with the tooling inside the Obelisk Tomb as indicated by McKenzie (1990). On the other hand, the recess of the doorway at the Obelisk Tomb is a problematic issue in this sequence. Here ancient Eastern traditions mix with Hellenistic architecture

2.2 Visual inspection of the weathering of the Obelisk Tomb

The frontal surfaces of all four obelisks are generally in a good condition except for the rightmost one, which is affected by Eolian weathering. A few alveolis or honeycombs can be observed on this surface (Figure 3). North western winds hitting the frontal surface seem to be responsible for this. The other three Obelisks are only slightly affected by this process. This is evidenced by the small cavity on the third obelisk from the left and the fact that all the frontal surfaces exhibit a certain roughness not common in freshly carved surfaces. The frontal side walls that flank the obelisks are harder hit on the front than the obelisks. More serious is the heavy erosion of the top of the obelisks. This problem appears to be due to down flowing water in combination with wind. The signs of water down flow are obvious on the left sides of the middle two obelisks. The impact of water and wind left these sides seriously honeycombed, with the tops being hardest hit. Thus the middle two obelisks have already lost their pointed tops. The top of the rightmost obelisk shows serious loss of material with granular disintegration as a result and is of the shortest height. While only a small portion of the top of the tallest left most obelisk has been lost, its top is in a relatively good condition but horizontal cracks and left side alveoli at the top threaten a similar fate to this top as for the other obelisks. It seems that as the north westerly wind hits the back surface of the façade eddy currents are created with result that the left surfaces and the top of the obelisks are hardest hit. The back surface shows some alveolar weathering (very high on the right side) with water down flow. The Niche in the center has retained its rectangular shape but the statue in its center suffers from granular disintegration with material loss. The right sides of the obelisks are in a better condition than the left, and are very similar in appearance and roughness as the frontal surfaces.



(a)



(b)

Figure 3a and 3b: Left and front sides of the Obelisk tomb

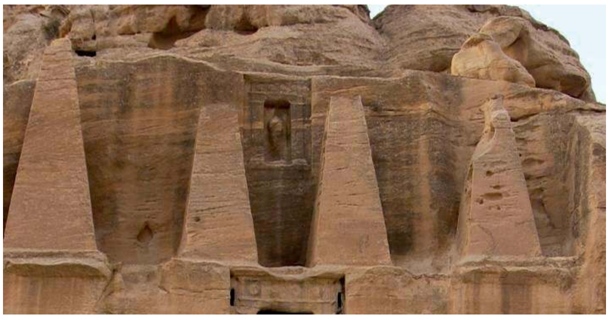


Figure 4: Statue and back face of the Obelisk facade. Water down flow on the surface, alveolar weathering on the right, with weathering granular disintegration and loss of form at statue

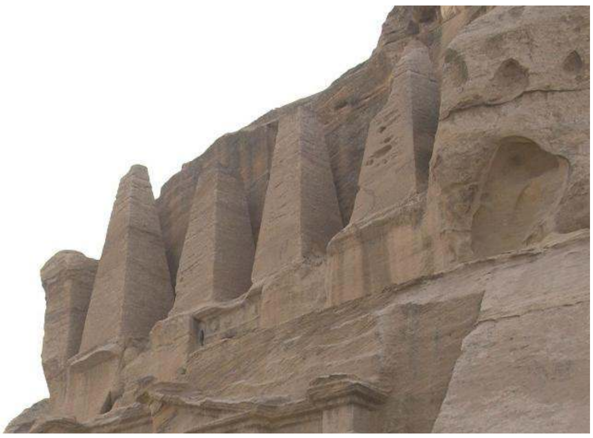


Figure 5: Right sides of the Obelisks

The horizontal surface (entablature) forming the base for the obelisks and topping the lower chamber below has lost some of its edges (double cornice) by water flow. Where complete loss of the cornice occurs, the effect of this flow is very high on the surface below (Figures 3 and 4). Water down flow along the surface below the cornice is very clear on both sides. The base of the leftmost obelisk is adversely affected by this process, since an angular crack, whose vertical inclined edge reaches right to the bottom of the obelisk and whose horizontal edge reaches the side protective wall and right though to the bedrock (Fig. 3b). The same figure shows serious loss of material at the doorway and its sides caused by capillary rise from the horizontal base in front of the entrance. The situation is made worse by the fact that a rectangular cistern and round hole have been dug in this surface and water collection during the rainy season poses an obvious threat, so much so that a big void is left on both side of the entrance.

3. 3D DOCUMENTATION AND MULTISPECTRAL RECORDING OF WEATHERING

3.1 Methodology

Our methodology relies on acquiring the various multispectral images separately. Thus Visible RGB photographs, NIR, and TIR images were acquired using the equipment described above. Initially we examined the weathering state both on the ground and using the visible photos. The results of this extensive analysis is given above. A visual examination of the TIR and NIR images followed. In order to combine the results of the three wavelength ranges we created we extracted the three bands of the visible photos, converted the colour NIR and TIR images to a grey image and then creating false image combinations from any three of the grey bands. This was accomplished using popular image software such as Photoshop. Visual examination of the false colour combinations allows us to see various materials in a different perspective than normally seen in ordinary colour photos. We also found that contrast enhancement of the false colours often discloses better info than the untreated images. At the same time we took 3D scans with the laser scanner and as such we were able to drape all the imagery we have obtained on the 3D model thus allowing us to see in the office all the imagery in 3D and better examine our results. We can vary the observation angle and zoom on particular points to analyze the results and attempt to correlate them to the weathering state.

3.2 Thermal Imagery

In earlier work we conducted a thermal study at the Djin Block No. 9 in Petra (Lerma et al, 2010), and we managed to correlate some of the results with high calcium content especially at the bottom of the south eastern side (Akasheh et al, 2005). Passive thermography has been used in many applications related to cultural heritage (Ludwig et al, 2004; Rosina and Grinzato, 2001; Rosina and Robison, 2002; Rosina et al, 1998). For the Obelisk Tomb, thermal images were taken at different times of the day. An example of these is shown in figure 6. The first thing that one notices is the fact that the images can enhance the architectural details. This is not surprising since the edges tend to warm up and cool faster than the bulk of the rock mass. In Fig. 6 some spots were selected to analyze the variation of temperature during the day. Figure 7 shows a chart of the temperature variation for six samples at different times.

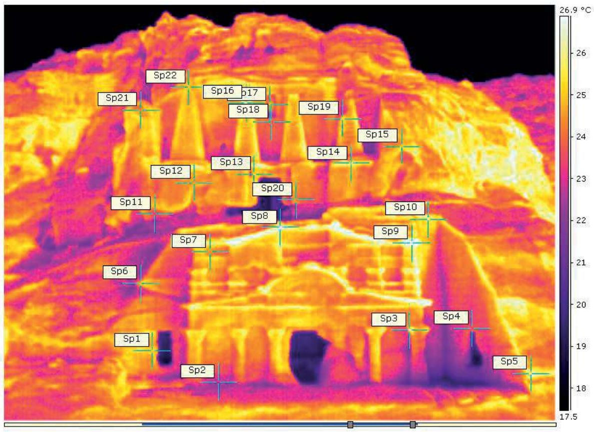


Figure 6: Spots measured on the Obelisk and Bab el Siq Triclinium

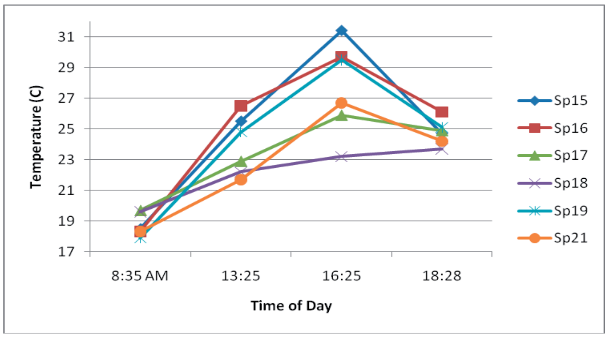


Figure 7: Temperature variations on some of the upper spots on Figure 6

Point	T 8:35 AM	T 1:25 PM	Delta T 1:25 PM	T 4:25 PM	Delta T 4:25 PM	T 6:28 PM	Delta T 6:28 PM
Sp15	18.5	25.5	7	31.4	12.9	24.7	6.2
Sp16	18.3	26.5	8.2	29.7	11.4	26.1	7.8
Sp17	19.7	22.9	3.2	25.9	6.2	24.9	5.2
Sp18	19.6	22.2	2.6	23.2	3.6	23.7	4.1
Sp19	17.9	24.8	6.9	29.5	11.6	25.1	7.2
Sp21	18.3	21.7	3.4	26.7	8.4	24.2	5.9

Table 1. Temperature of selected spots at different times of the day

In Table 1 the results for some spots are shown. Comparison of the temperatures at different spots shows the variation of temperature for these spots at a particular time of day from those at 8:35 am. The spots are highest in temperature at 4:25 pm. It is noted that Spot 15 has the highest temperature difference between 8:35 am and 4:25 pm. This surface to the left of the monuments has large alveolar holes. Attempts to correlate damage with this parameter failed to yield any consistent results. This is expected since earlier work on Djin Block No. 9, insolation was proved to be the less important factor in weathering, whereas water and wind were found to be more important (Akasheh et al, 2005; Heinrichs, 2008; Navarro et al, 2009; Cabrelles et al., 2009, Lerma et al., 2010). A more promising approach has been recently reported (Danese et al, 2010) using visual analytics, although some of the results are not definitive and there is a need to have more focus on the materials of the stone and the salt infestations. This is very important as the properties of the stone material and salt infestations should somehow be related to the NIR and thermal images very much like the yellow colour of Petra sandstones is due to limonite veins while deep red sandstones are attributed to hematite. Both are iron oxides and often the presence of limonite veins creates serious inhomogeneous bulk properties that render the stone more susceptible to weathering. We have previously correlated XRF data and Calcium content on Djin Block No 9 with the extent of damage and plan to study this situation on the Obelisk Tomb as well.

3.3 NIR Imagery and False Colour Band Combinations

NIR bands are very common in satellite imagery (Spot, Landsat, etc.) and have long been used in vegetation analysis and mineral identification form space. The application of this technique to archaeological objects, especially to paintings, has come more recently (cf. Garribba et al, 2001), partly because the cameras involved were very expensive, and because the cultural heritage community took some time to appreciate the value of this technique. Moreover, NIR paper films were subject to rapid deterioration with heat and had to be kept in cold environments.

Figure 8: NIR image of the Obelisk and Bab el Siq Triclinium

Nowadays, with digital imagery, new NIR sensors are available. In fact ordinary digital cameras can be modified to enhance their sensitivity in the NIR region. It is of common knowledge in satellite remote sensing applications that the NIR bands csn easily detect water as well as the chlorophyll in plants so that vegetation cover is more easily detected than by the visible bands. In fact the health of vegetation is easily evaluated by how extensive the NIR absorption due to chlorophyll is. Thus in Figure 8, the NIR image of the tomb is shown. A more useful image is created from the combination of different visible bands either with the NIR or the thermal image, yielding false colour images.

False Images with a TIR band are not very useful when in bamd combinations and the TIR are best examined separately. This is because of the low inherent resolution of TIR photography. However we are continuing to study this issue to perhaps optimize the use of such combination bands. Fig. 9 shows the combination of NIR, Red, and Blue bands. Contrast enhancement leads to Fig. 10. In Figure 9 it is very clear that vegetation is easily detected as is the case in satellite remote sensing (arrows). By contrast vegetation is not always as easily noticeable in visible images. Since vegetation growth is one of the means of biological weathering, NIR is an important tool for conservation of stone monuments. In Figure 10 the pitted surfaces (due to alveolar weathering (circle)) appear in two or more colours, while smoother surfaces appear in one colour even if weathering by smooth granular disintegration appears.

Figure 9: False colour combination of NIR, Red and Blue bands. Vegetation is indicated by an arrow. The lower detail shows how easy it is to see vegetation on the left side on land, as well as small plants on the monument.

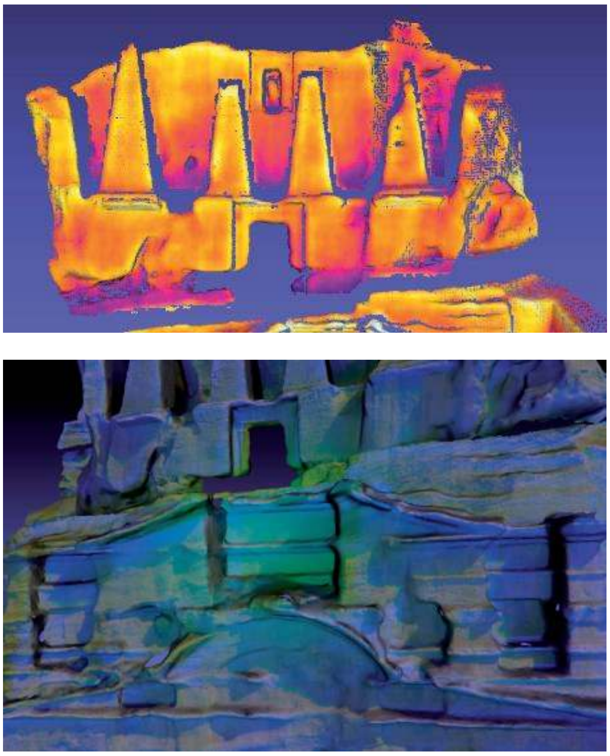
Figure 10: Stretched and enhanced false colour combination of NIR, Red and Green bands. Circles show some of the rough surfaces that appear in two colours. Rectangle shows area where one colour indicates a smoother surface. Arrows show small plants behind one of the obelisks.

Obviously not all the visible observations are enhanced by this technique. However, pitting and large aleveolies still appear in the false colour images with no advantage of one technique over the other.

3.4 3D modelling by terrestrial laser scanning and texturing of the multispectral data

With the advent of digital modern techniques for 3D acquisition, it has become possible to drape images on the three point clouds of objects. This allows examination of the weathering profiles in 3D even in the office, thus by far rendering the analysis of the conditions of damage of the monument easier. Figures 11-12 display the visible, TIR and the false colour (NIR, R, and G) images onto the 3D models, respectively. The advantage of visualizing the multispectral images in 3D is quite obvious. For one thing the visual examination becomes more realistic than examining flat imagery. The office worker can look at the monument and the false colouring from different angles and different resolutions thus reducing the time for field work. Another advantage that can be seen in Figure 12 middle TIR (NIR-G-TIR) and lower image (NIR-G-B) is that the band combination when draped over the model enhances even more clearly the architectural edge details and the damage they have suffered.

Figure 11: Visible image draped over the 3D model



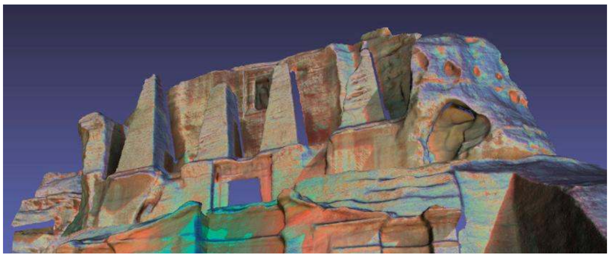


Figure 12: Upper image TIR image draped over the 3D model Middle and Lower Image is for a detail with the NIR-G-TIR band combination. In this case the architectural details are enhanced especially where edge damage is seen.

4. CONCLUSIONS

In order to obtain a correct representation of the existing condition over a large historical complex structure, it is necessary to plan, to introduce and to accept some specific surveys and representation techniques with support of different skills. Hence, it is crucial to choose the correct tools for a multidisciplinary analysis. Remote sensing multispectral imaging, ordinary photography and photogrammetry in addition to visual weathering examination lead to some valuable conclusions on the weathering profile of a monument.

.Documentation of cultural heritage requires the synergy of experts and technologies to study large complex areas such as the Petra Archaeological Park. The research presented herein allowed us to enhance the 3D documentation and 3D monitoring of the Obelisk Tomb owing to the integration of multispectral content which can play a major role in the documentation and the interpretation of the cultural heritage. In this particular research, the multispectral content included visible, near infrared and thermal infrared imagery. The series of thermal images were also used to analyse the thermal contrast and the behaviour of materials and alterations on the Obelisk tomb. While thermal imaging cannot relate solar exposure directly to weathering as it is not the predominant mechanism, it is still a useful tool to follow the extent of damage of architectural details especially when combined with other bands and draped on a 3D model. NIR imagery detects very small plant infestation which can be easily missed by field inspection and visible photography.

This kind of analysis is extremely useful to achieve a real representation of the existing condition of a complex object. However, among the several techniques used for the documentation of solid objects, the integration of multispectral content with 3D laser scanning shows that it has the potential to be of major value to the cultural heritage recording professionals. It is worth mentioning that this will enhance the capability to analyse deeply complex carved architecture in 3D from false colour images. The representations of monuments are enhanced to record weathering effects such as alveolar wind damages, flaking, cracks, and last but not least, moisture.

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