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Stereo-Satellite Imagery for the Creation of DEM and Topographic Maps to Support Site Management of the UNESCO World Heritage Minaret of Jam (Afghanistan)

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Abstract

Remote sensing techniques for the management of cultural heritage sites in Afghanistan have been applied successfully in recent years because the security situation at the ground does not allow activities in the field. Advanced remote sensing technologies were used to generate elevation data from high-resolution satellite stereo-imagery of the Ikonos sensor for the generation of accurate topographic maps. Additional very high-resolution imagery of the WorldView-2 sensor was used to produce orthorectified image maps that facilitate local site management. Terrestrial measurements from previous field surveys were used for image geo-referencing and validation of the DEM from the stereo-imagery. Elevation points were derived in a semi-automatic process and adjusted by stereo-inspection through a human operator. Contour lines and shaded relief maps are created in the next step to be combined with findings from previous archaeological surveys. The superposition of all available information indicates that the existing boundaries of the World Heritage property and buffer zone are to be adjusted. The resulting maps serve as a planning base for future development activities, such as the enforcement of the river embankment to protect the minaret from flooding. The analytical data also serve for future numerical studies of the flooding regime at this particular place. It is argued that all data and cartographic products are required in such complicated cases with access restrictions for intensive fieldwork and should be considered in similar cases by researchers and planners. All activities form part of the international efforts to establish a protection scheme supporting the long-term management and the preservation of the World Heritage property.

Keywords: Remote Sensing, Word Heritage, Site Documentation and Management

Introduction

The management of Cultural Heritage in war-torn countries like Afghanistan remains a challenging task. The Ministry for Culture and Information of the Islamic Republic of Afghanistan holds two institutions to take care of the management of cultural heritage in the country. The Department for the preservation of Historical Monuments (DoHA) and the National Institute of Archaeology (NIA) both share management responsibilities for the tangible heritage. Therefore actions in the field require additional coordination efforts to minimize overlapping areas of activities. Besides the ongoing security issue affecting free movement in large parts of the country, the technical and human resources on the national level remain limited, not only in the culture sector. It will require another generation to be trained for that sufficient scientific expertise is gained to participate in the scientific discourse on an international level. Therefore after the fall of the Taliban regime, the international community pledged for assistance to the rehabilitation of the cultural heritage sector of the ravaged country initiating an international safeguarding campaign coordinated by UNESCO (ICC 2003). A priority action since has been the support for two of the most important sites in the country the Minaret and Archaeological Remains of Jam, and the Archaeological Remains and the Cultural Landscape of the Bamiyan Valley inscribed in 2002 and 2003 as World Heritage under the Convention Concerning the Protection of the World Cultural and Natural Heritage (UNESCO 1972). Out of these, the Minaret of Jam is renowned for the elaborated brickwork construction partially covered with excellent tile work dating from the 12th century. The noteworthy quality of its architecture and decoration, which according to the nomination, represents the culmination of an architectural and artistic tradition in this region is further heightened by its dramatic setting, a deep river valley between towering mountains in the heart of the western Ghur province in Afghanistan (Figure 1).

Both nominations reactivated a process that was initiated already as early as 1982 when the Outstanding Universal Value (OUV) of the sites was already confirmed by the World Heritage Committee, allowing for a rather hasty nomination procedure. The information on the provisional management system, the boundaries and buffer zone for the inscribed property were defined and marked on a map.[1] Boundaries are supposed to follow the contours of the topographical character of the area but are based on outdated topographic maps, raising the concern of ICOMOS in the evaluation of the nomination dossier. Besides, the rather unusual cartographic format, the provided map omits any information concerning more recent or contemporary interventions in this area (including the route of new road constructions under discussion). ICOMOS recommended for the State Party to provide more detailed and accurate cartographic materials to meet these deficiencies (ICOMOS 2002).

The identification of a World Heritage property´s boundaries and an appropriate buffer zone are mandatory according to the Operational Guidelines to the World Heritage Convention. They are considered necessary for the adequate protection and management of sites, but methodologies for their definition may vary following established best practice examples (Martin and Piatti 2009). Therefore the shortcomings in the nomination dossier also reflect the identified needs for further technical assistance to the State Party after more than 25 years of military conflict. To this extent, the maps submitted in the initial nomination dossiers in 2002 and 2003 respectively had to be updated in order to include the latest information available on the extent of the archaeological remains at the site of Jam. The work presented in this paper is part of a larger project within the UNESCO efforts for the preservation of the World Heritage Sites of Jam and Bamiyan and describes the creation of a topographic map for site management purposes based on the analysis of high-resolution satellite imagery.

The Minaret of Jam

The Minaret of Jam (Lat. 34°23’47.6 N, Long. 64°30’57.8 E) is one of the few surviving monuments of the little known Ghurid sultanate, which lasted from the end of the 12th to the beginning of the 13th century CE (Ball 1982). It is regarded as the second tallest ancient minaret in the world, surpassed only by the Qutb Minar in Delhi, which was also built by the Ghurids (Pinder-Wilson 2001). The site of Minaret of Jam is located at the confluence of the Hari Rud with one of its tributaries the Jam Rud (rud [persian] = torrent, river) in the very remote mountainous region of Ghur in Western Afghanistan some 215 km east of Herat at an elevation of around 1900m.

The impressing view of the minaret draws off attention from archaeological remains that are scattered on the steep mountain surface on both sides of the Hari Rud. Buried from erosion, the remains of structures can be traced pin-marked by the existence of holes resulting from illegal excavation activities going on for decades. The minaret structure is rising from an octagonal constructed base, with four superimposed, tapering cylindrical shafts all build from fired bricks. The geometric pattern of the surface of the Minaret consists of delicate haut-relief brickwork visually enhanced with a Kufic inscription in light-blue turquoise tiles at its higher parts. Constructed at some time between 1174 or 1194 CE, the

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[1] The initially submitted map for Jam is available at http://whc.unesco.org/en/list/211/multiple=1&unique_number=234 and for Bamiyan at http://whc.unesco.org/en/list/211/multiple=1&unique_number=230

Figure 1. View of the Minaret of Jam from the south with remains of a castle on the ridge and partly open pits resulting from illegal excavations at the northern slope of the river.

minaret survived considerably well preserved to our days, including its remarkable double helix internal staircase. The quality of its architecture and decoration represents the culmination of an architectural and artistic tradition in this region.

Scientific Exploration and Conservation Activities at the Site and its Surroundings

Since the time of the first scientific explorations of French archaeologists in 1957, it has been suggested that the site probably marks the ancient city of Firuzkuh, the capital of the short-lived Islamic Empire of Ghur that at its height covered a territory from today Western Afghanistan down to the Bay of Bengal until was swept away by the Mongol raid of its capital in 1222 (Maricq and Wiet 1959). A comprehensive summary of the history and the understanding of the site until its inscription as World Heritage is given in (Sourdel-Thomine 2004).

More recently, the research at the site is embedded in the context of the UNESCO preservation activities following the World Heritage nomination. Object finds during limited archaeological field surveys testify the presence of extraordinary luxury goods at this place (Thomas et al. 2004). The collection of this archaeological data was realized in the Minaret of Jam Archaeological Project (MJAP) by the Istituto Italiano per l'Africa e l'Oriente, on behalf of UNESCO and the National Afghan Institute of Archaeology (NAIA) initiated in preparation for a future management plan. Findings yielded rich environmental and geomorphological data that provided the first direct evidence to support the historical account of the "Masjid-i Jami" at Firuzkuh being washed away in a flash flood (Thomas et al. 2006).

The inclination of the minaret of around 3.4° towards the riverbank on its northside is still not explained satisfactorily (Borgia 2002) but raises constant concern on its stability. Therefore with funds from UNESCO within the international support project Emergency Consolidation and Restoration of the Monuments in Herat and Jam in Afghanistan, a series of emergency preservation actions at the site were initiated. The inclination causes an asymmetrical load distribution, which results in overload at the north-northwestern side and decompression at the opposite side. This overload causes horizontal stresses in the brick masonry, resulting in vertical cracks in walls and bricks that may be consistently increased by seismic effects. Therefore, a seismic hazard assessment was done that concluded seismic input not to be the factor governing the structural vulnerability of the minaret, since the highly seismic, subduction zone of the Hindukush region yielded negligible effects at Jam in terms of seismic hazard so far (Menon, Lai and Macchi 2004).

For the long-term preservation of this monument, retrofitting measures were considered to increase the overall structural integrity of the minaret under normal gravity load. Also, massive erosion of the minaret´s base indicates severe flood events during the last eight centuries. Therefore, the lower exterior brick surface was reinforced, and consolidations of the river banks were realized to mitigate the impact of high-rise river waters. Protecting the base of the minaret is regarded as a critical stabilizing measure preventing any further increase of the inclination. A complete overview of these activities is given as an Open-Access publication by UNESCO (Han 2015),

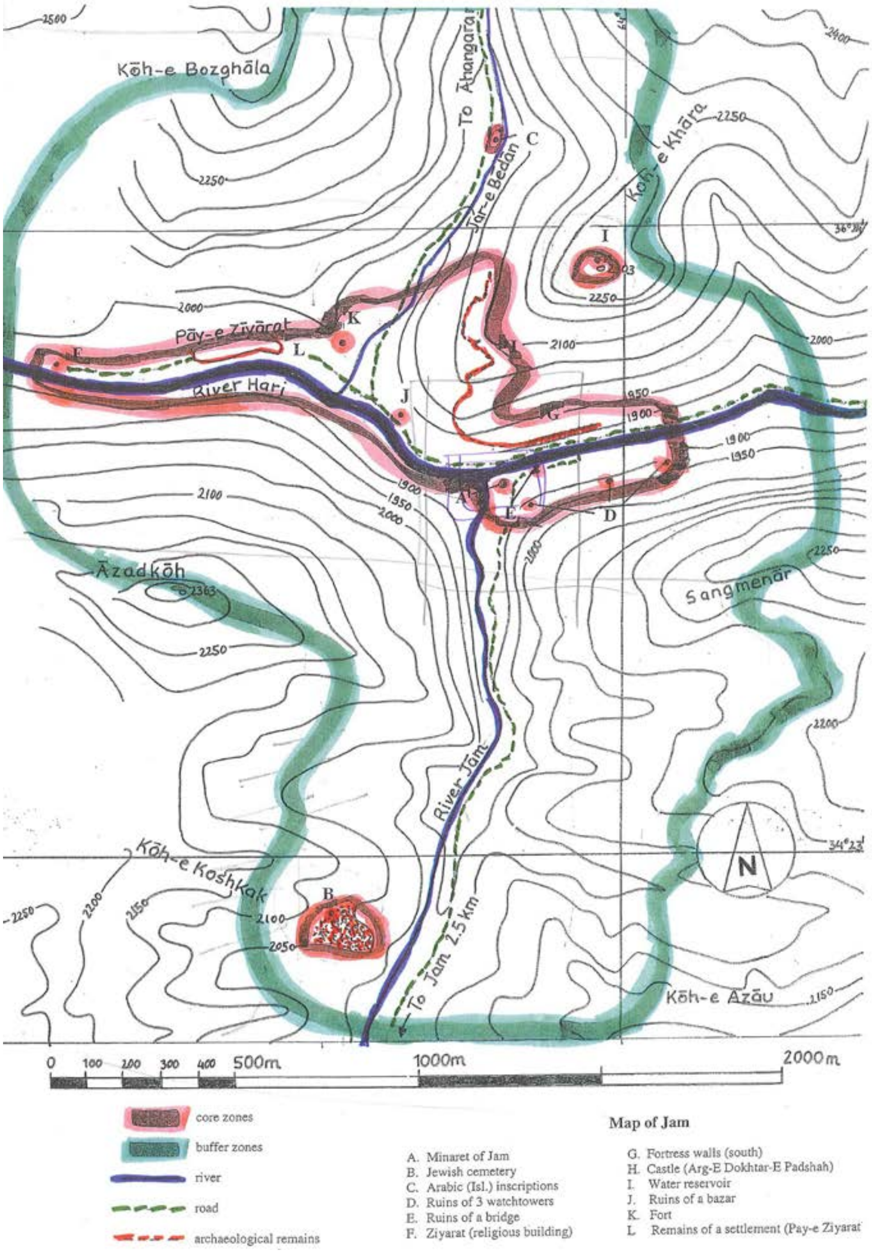

Figure 2. Topographical map of the site as of 2002, the four isolated „core“ areas (red colour) surrounded by a large buffer zone (green) taken from the nomination file (UNESCO World Heritage Centre 2002).

and the authors have compiled the resulting detailed technical reports for future reference (Toubekis et al. 2014).

Mapping Documentation of the Site

In 1973 Werner Herberg and Ghulam Djelani Davary provided accurate hand-measured drawings on the structure of the minaret, and a very basic overview map concluded from large-scale topographic maps available at the time. Already at that time, it is assumed that the entrance to the minaret and its entire foundational base is engulfed in alluvial deposits with a thickness of around 4–6 m, forming a terraced plain above the original river bed. This documentation (Herberg and Davary 1976) also included information on a cemetery two kilometres south of the minaret on a hilltop along the Jam Rud with Judeo-Persian epitaph inscriptions in Hebrew script.[2] Towards the north on the other side of the Hari Rud up the ridge on a first plateau, the remains of an apsidal room partly dug into the rock are considered to have served as a water reservoir. Also, the

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[2] Beside the factual evidence for a Jewish settlement in this area the tombstone inscriptions are indicating towards burials that have taken on a regular basis in the years between 1012 CE until 1220 CE two years before the siege of Firuzkuh by Mongol troops.

List of Standpoints UTM Zone 41N Datum: WGS 84	E063…. Easting (X) in m	N380…. Northing (Y) in m	Ellipsoid Height (Z) in m
101	9357.000	7168.000	1905.000
102	9619.815	7243.653	1901.962
103	9303.959	7231.793	1903.454
104	9369.013	7203.788	1902.831

Table I: List of permanent fix-points and their coordinates at the site of Jam as installed in 2002 and re-established in 2006 (Stevens 2006).

remains of a fortification are visible directly above the confluence of the two rivers surrounded by some modern time houses and further eroded archaeological remains stretching up the hills. All this scattered information has been included in the baseline information for the World Heritage nomination of 2002, resulting in a property composed of four isolated "core" areas (Figure 2).

In preparation for conservation activities on the ground, more precise topographic information and a complete mapping of the site was required. Therefore within the UNESCO safeguarding project as a first measure, a UNESCO mission set out to produce a preliminary map of the site's main features in the terrain and to precisely capture the inclination of the Minaret with reflectorless total station measurements. A local reference system was established, and the geographic coordinates for the initial fix-point 101 were acquired by handheld GPS device resulting in an absolute positional accuracy for this point within the range of some meters. Additional fix-points measured with mm-accuracy referenced to the initial fix point were set up permanently into the ground to ensure the comparability of measurements in the long-term. The measurements showed inclination variances between 3.47gon to 3.97gon (3.13° - 3.57°) for the various shafts with the upper part of the minaret leaning 3.128m out the central axis of the structure having the top of the inclined minaret at 60.41m above the ground at the northern site (Santana Quintero and Stevens 2002). During a monitoring mission in 2006, the inclination of the minaret was controlled, and the local reference system (see Table 1) served as an indicator of quality. Although some of the previous fix-points and secondary reference points had been unearthed and the reference system needed to be re-established again before the new measurements (see Figure 3), the monitoring revealed that in the time interval of four years, no measurable change in the inclination of the minaret took place. The mission also included a component of training for the national staff of the Afghan Department of Historical Monuments in high precision measurement techniques with a total station. A standardized protocol was introduced to monitor the correct location of the fix-points and the inclination of the minaret in the future by measuring some control points installed on the brick surface (Stevens 2006).

The difficulty in access and the overall congested security situation in the country has been disadvantageous in establishing a functioning management system at the site from the beginning. The presence by personnel of the national heritage administration has been limited to some police guards to prevent the looting of the area that has occurred in the past.

The lack of appropriate topographic information that covers the entire valley and the vicinity of the minaret at an appropriate scale has been an obstacle both to the accurate documentation of the small-scale emergency excavations along the riverbed and also for the large-scale riverbank protection measures that were realized within the UNESCO program after a massive flood occurred in 2007. Due to the deteriorating security situation, the activities executed could not be assisted by international experts and did not allow for further survey mission to be realized in the coming years. The significance of the Minaret of Jam has resulted in the necessity to improve the management system, primarily to indicate the extent of the protected areas precisely on the ground.

The efforts for the preservation of the site are challenged, especially in the context of economic development pressure, resulting from envisioned road constructions to connect the remote villages in the

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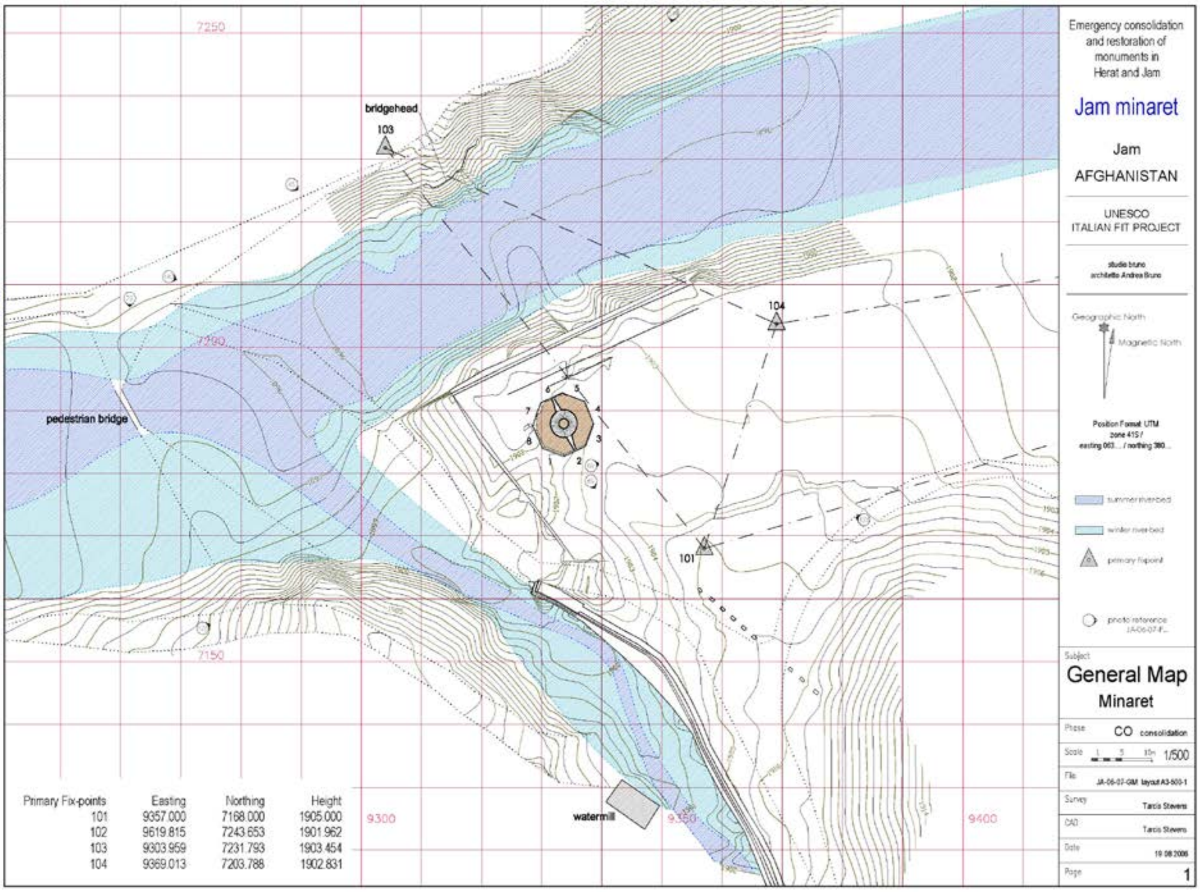

Primary Fix-points	Easting	Northing	Height
101	9357.000	7168.000	1905.000
102	9619.815	7243.653	1901.962
103	9303.959	7231.793	1903.454
104	9369.013	7203.788	1902.831

Figure 3. Topographic map with the location of fix-points in the ground (from Stevens 2006).

vicinity of the minaret, passing directly through the valley. In order to realize a detailed topographic map with sufficient information on the entire site and its surroundings new methodologies from the domain of remote sensing for documentation of cultural heritage sites were applied in the period 2010-2012.

Generation of Topography and Sitemap Based on Remote Sensing Techniques

High-Resolution remote sensing techniques refer to the remote viewing of the world surrounding us by satellite sensors, usually from low-earth orbits (600-800km height). Remote sensing in cultural heritage management is used to determine anthropogenic features in the real world. The mapping methodology includes landscape features but also built structures such as roads, settlements, and individual buildings or monuments and sites. Satellite remote sensing has the advantage of being able to see an entire landscape at different resolutions and scales (Comer and Harrower 2013).

Methodology

Since the aim was to obtain a map at a sufficient high scale to allow for planning of activities at the site, publicly-available satellite imagery via Internet services such a Google Earth or Microsoft Bing were opted out because they did not meet the requirements for reliable topographic information. In contrast, stereo-images allow exploring the scene in three dimensions. With photogrammetric calculations based on real distances and heights known at the ground, it is possible to extract accurate 3D spatial information for the entire image scene, a so-called Digital Elevation Model (DEM), from which precise topographic map information can be generated.

The generation of a DEM by photogrammetric methods is based on the evaluation of the individual images acquired under different viewing geometries (Kraus and Harley 2007). The same points have to be identified in both images referred to as stereo pairs.

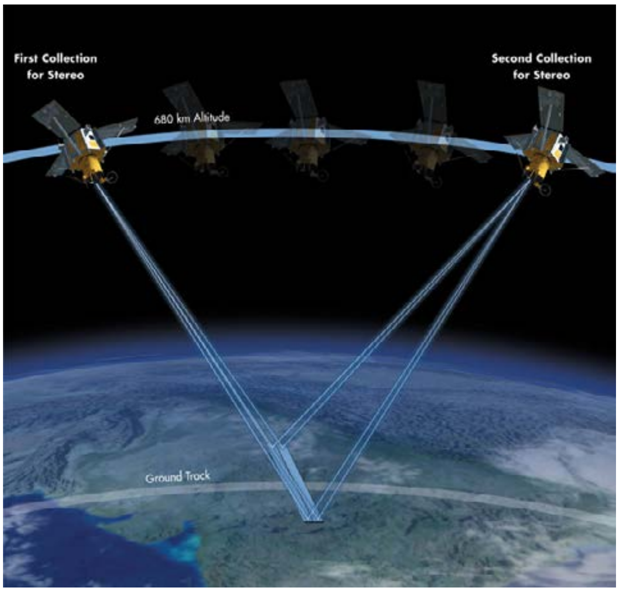

Figure 4. Acquisition method for capturing the topography with high-resolution stereo-image pairs of a linear array CCD sensor that takes images with one overfly. Same pass stereo pairs are advantageous for subsequent processing such as feature extraction because the scene content and lighting conditions are virtually the same for the two images. (Image courtesy Satellite Imaging Corporation).

The differing spatial positions of these homologous points in a stereo pair reveal information about their elevation at this point. The procedure is similar to conventional photogrammetry practised in architectural recording for decades and standard practice in the visual stereo-analysis of analogue aerial image interpretation. In the digital era, however, for automatic image analysis, specialised software, specific photogrammetric skills, and experience are required to obtain useful results (Zhang and Gruen 2006).

The first step is to identify as many identical points as possible in both images. For this purpose, image matching algorithms for a single sensor type are used (Fraser, Baltsavias and Gruen 2002). Homologous points form the basis for the DEM. Their height can be calculated directly from their spatial shift by computational methods. In areas with little distortions (flat areas), many points are available. In areas with moderate or high relief, the number of points to be found in more or less reduced, as the terrain is differently imaged due to the different viewing angles of the sensor (Fraser and Yamakawa 2003). If distortions in the stereo pair exceed a specific limit, the images cannot be matched, and no identical points can be determined. The lack of homologous points is also a problem in areas that are not covered in both images, for example, areas in front of steep cliffs, which overlay the surrounding terrain. It is also a problem also in areas that are not illuminated at all because shadowing is too severe (Gruen, Remondino, and Zhang 2005).

Additional information about the geo-location is necessary to get an absolute geographical position of the points. This information can be derived from orbit parameters of the satellite allowing for a referencing accuracy of a few meters (Fraser and Hanley 2003) that can be improved with the help of ground truth data. In this work, the specific sensor camera model (Grodecki 2001) is provided as additional orbit parameters with the image metadata. Also, the topographic measurement points from the previous field campaigns (Santana Quintero and Stevens 2002; Stevens 2006) were used and served for ground-truthing. The measurement data in ASCII file format was imported to a Geographical Information System (GIS) and transformed into data shapefiles for further use in the GIS.

Acquisition of Satellite Imagery

Due to the complicated mountainous situation in the area of Jam initially, a very high-resolution scene with half-meter per pixel resolution by the commercial GeoEye-1 sensor was envisioned to be ordered. Unfortunately, the satellite provider was not able to provide such a product in the foreseen time window due to unexpected restrictions upon sensitive military areas imposed by U.S. authorities.

Therefore the initial plan was changed, and a satellite stereo-image scene was acquired in April 2012 from the IKONOS sensor (GeoStereo product in 11-Bit GeoTIFF file format, Standard Geometric Correction) covering the area of the minaret of Jam and the surrounding mountainous area with panchromatic (black and white) 1m per pixel and multispectral (blue, green, red, near-infrared bands) 4m per pixel resolution. IKONOS collects the same pass stereo pairs (see Figure 4); that is, the two images constituting the stereo pair are taken on the same orbital overfly. As the satellite approaches the target, it yaws, rolls and pitches, as required, to collect the first leg of the stereo pair while pointing in a forward direction. A hundred or so seconds later, after the first image is collected, the satellite is manoeuvred to image the same area again, this time pointing in

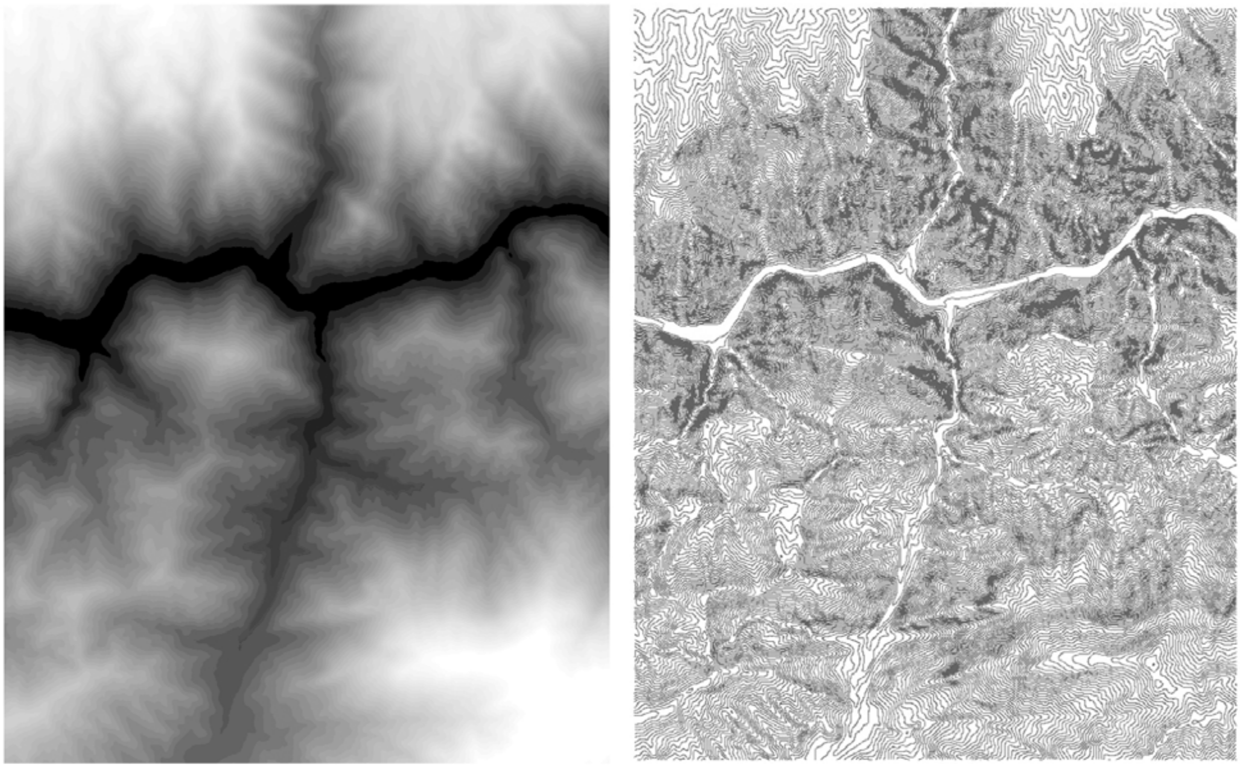

Figure 5. Topographic height information derived from the stereo images: Digital Elevation Model (DEM) as raster image dataset (left) and contour line extraction (10m) as vector dataset (right).

a backward direction (Grodecki and Dial 2001). The coverage of around 100km² resulted in images sizes of 185 million pixels (pan) and 11 million pixels (multispectral) for each image of the stereo-pair. In addition, the archive material of other high-resolution sensors was systematically consulted, and two images (no stereo) of the WorldView-2 sensor (Standard Level 2A product in 16-Bit GeoTIFF file format) were identified, subsequently orthorectified and used with a 5km x 5km (25km²) coverage area. These two images have a small overlapping region, which shows the Minaret of Jam at the edge of their respective image borders at panchromatic (black and white) 0.5m per pixel and multispectral (blue, green, red, near-infrared bands) 2m per pixel resolution. The images have different acquisition dates from March and April 2011 but with similar viewing angles and sun-light illumination conditions.

Processing of Stereo-Scene for Generating a Digital Elevation Model and Ortho-Photos

For image matching of homologous points and stereoscopic processing the ERDAS Imagine/Leica Photogrammetry Suite 9.1 was used in combination with self-programmed tools in C++ for sampling optimization. To achieve the best results, a surface reconstruction algorithm based on Laplacian partial differential equations (Franklin 2000) for interpolation of elevation data is used, giving smooth results even for areas with sparse points. For the complete area, topographic contour lines are derived mainly by an automatic process. In a final stage, a manual correction process has to be accomplished to identify points with corrupted elevation information via stereoscopic viewing. This was done by interpolating and stereoscopically identifying false points by a human operator. From about 200.000 points initially derived by image matching, about 500 points had to be eliminated, iteratively, step by step during this process resulting in a continuous spatial dataset. Elevation extraction via automatic processing was challenging for fast-changing surfaces (steep relief) and was therefore significantly improved by these manual stereoscopic operations.

The resulting DEM (see Figure 5 - left) represents the elevation, including vegetation and buildings,

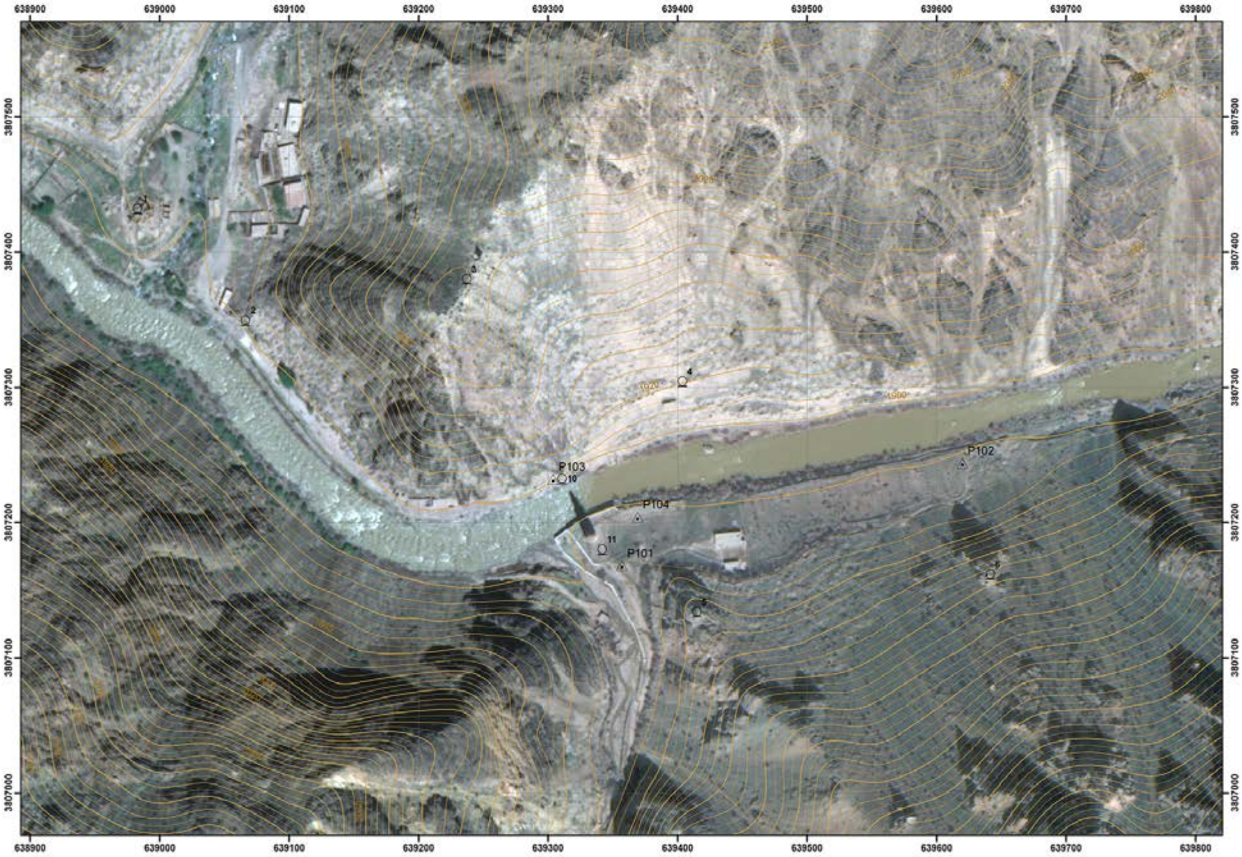

Figure 6. Extract of orthophoto map based on the fusion of two WorldView-2 images overlaid with topographic contour lines extracted from the Ikonos stereo-images (Image: by the Authors/DigitalGlobe).

not only the sole ground (i.e., a digital surface model). Small objects tend to be omitted, and large objects are more likely included in the DEM (large rocks or structures) depending on their dimension. The cell grid of the computed raster image should be small enough to capture the required detail, but also large enough to allow computer storage and analysis to be performed efficiently. (Hutchinson and Gallant 1999).

The recommended grid cell size is a compromising resolution, usually set as the intermediate number between the coarsest and finest resolutions. It can be computed taking the inherent data properties into account, using principles from the general statistics, information theory, and signal processing, and equations to estimate probability density functions (Hengl 2006). A smaller cell size allows capturing more and smaller features in greater accuracy at the cost of larger raster datasets with extensive data storage space requirements, which in turn often lead to longer processing times.

From the stereo-metric processing of the Ikonos Stereo Imagery, the vertical spatial accuracy of the dataset is one meter verified for the immediate surroundings of the minaret where excellent acquisition conditions occur. However, the very steep inclination of the terrain leads to areas with sparse point density, especially in the shadowed parts. To achieve the best results, these areas were treated with special attention through manual operations. Here the self-programmed implementation of the interpolation algorithm (Franklin 2000) provided far better results than the standard functions of the Leica Software and allowed for overall smooth elevation data leading to acceptable results for 90% of the covered area.

Considering the processing power of the available hardware and software[3], the chosen cell grid of the final DEM has a horizontal resolution of 5m

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[3] The processing equipment consisted of desktop computer AMD Phenom II X6 3.0GHz 6-core system with 16GB RAM, NVIDIA Quadro 2000 3D graphics card + NVIDIA 3D stereo glasses.

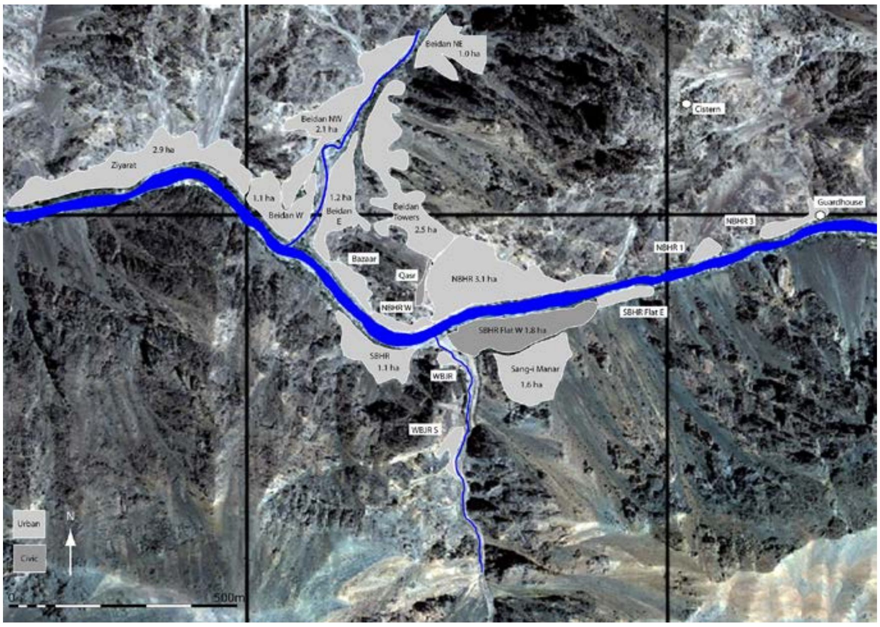

Figure 7. Mapping of the extent of the archaeological remains after field survey (Thomas 2012:340).

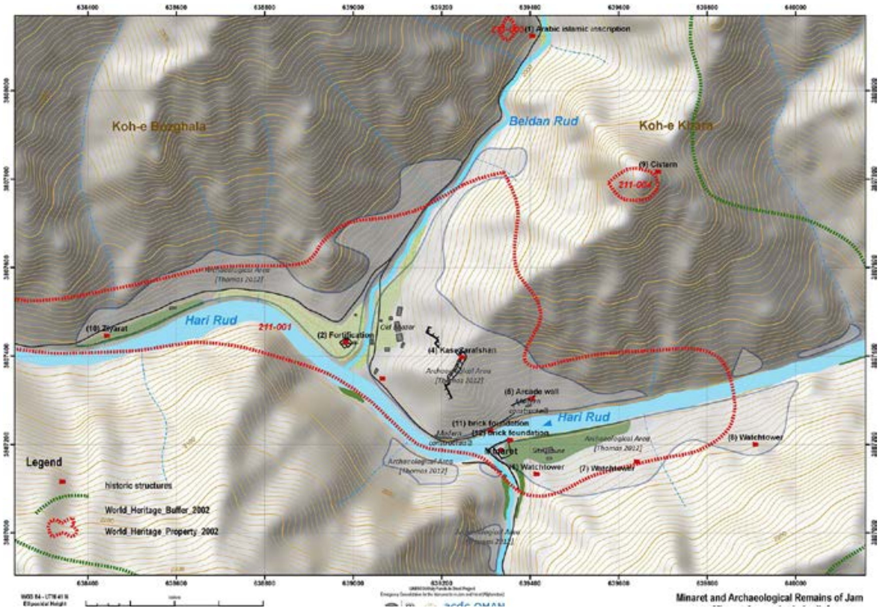

Figure 8. Ortho-rectified and shaded relief map with the central area of the Minaret of Jam and its archaeological remains – note the outline of the red property boundary copied from the nomination map.

since very high-resolution digital elevation models with smaller grid cells only produce slightly better results in terrain analysis tasks (Warren et al. 2004). The DEM covers an area of about 5.5km x 7.3km with elevation values ranging from 1878m to 2766m and approximately 1.600.000 pixels in total. The DEM also proved very suitable for subsequent use in hydrological applications to evaluate dangers arising from the river system, to calculate flood occurrences, and to assess the requirements for river protection measures (Schüttrumpf and Cofalla 2014). The elevation values correspond to WGS84-ellipsoid, which is identical to the GPS coordinate system. The geo-referencing of the satellite imagery is based on orbital parameters delivered as Rational Polynomial Coefficients (RPC) by the provider as part of the metadata of the satellite image and processed within the Leica Photogrammetry Suite. Several points at the UNESCO project house (100m east of the minaret) have been used because these structures could be precisely identified in the satellite imagery and were also measured during the field survey and included in the field survey data.

Considering the scale and functional requirements relative to digital terrain modelling (Weibel

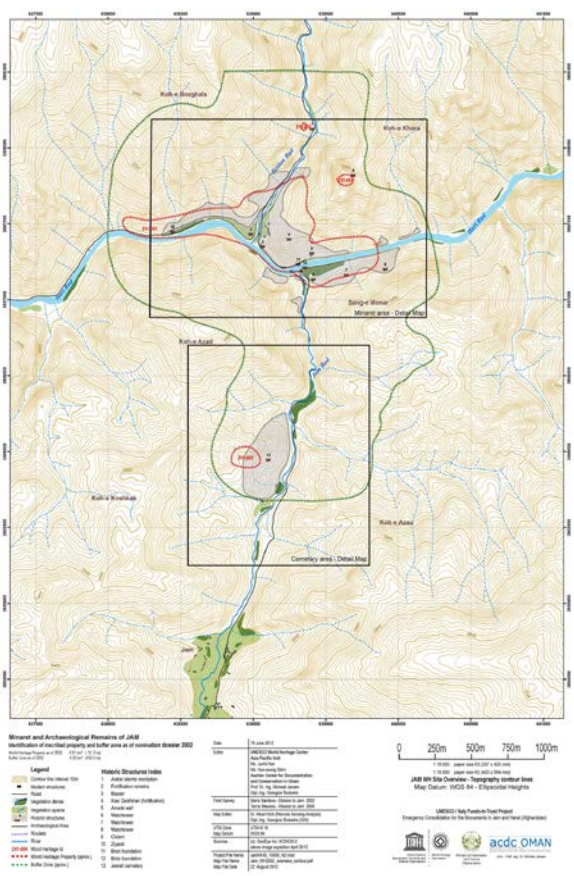

Figure 9. Delineation of inscribed World Heritage property and buffer zone as indicated in the nomination of 2002, projected onto the new topographic map with contour lines.

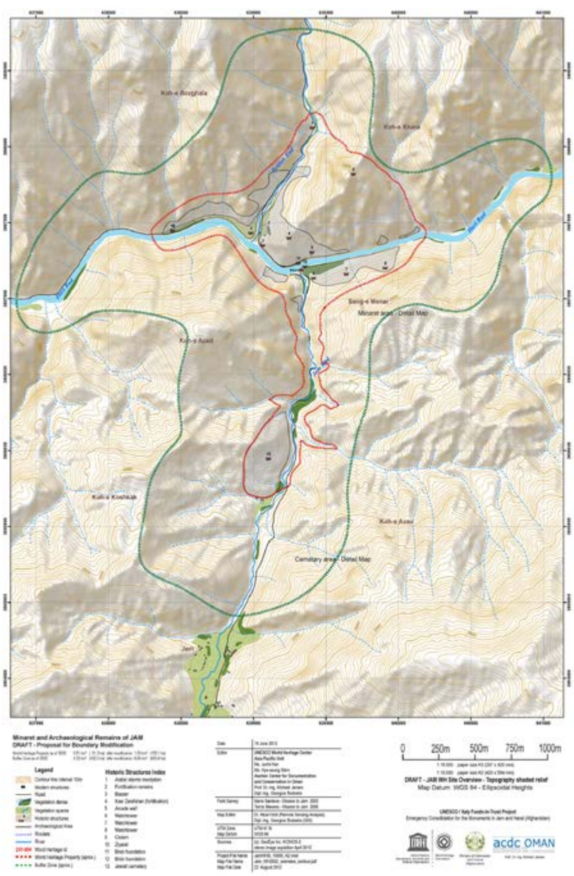

Figure 10. Proposal for minor boundary modification for the outline of the boundary of the property to the extent of the archaeological remains and adjusting the buffer zone based on the new map with shaded relief topography.

and Heller 1991) for the complete area, contour lines with 10m spacing are derived for further cartographic use (see Figure 5– right). This is done mainly by an automatic process and corrected by manual inspection via stereoscopic viewing, as mentioned above. The acquired two very high-resolution satellite images (WorldView-2) were projected onto the processed DEM to generate a geometrically correct orthoimage of the area, which can be used to derive high precision map information (one example see Figure 6). Several maps with scales ranging from 1:500 to 1:50.000 were set up and computed with ESRI ArcGIS 8.3 software.

Both the Ikonos and WorldView-2 satellite images consist of a colour-composite (colour and infrared channel) with 4m (Ikonos) and 2m (WV-2) resolution and a panchromatic (black/white) image with 1.0m (Ikonos) and 0.5m (WV-2) resolution. Pan-sharpening allows using the high resolution of the panchromatic image also for the colour image. By this method, the resolution of the panchromatic image is transformed and merged with the coarser colour-composite image to produce a final colour image with 1.0m per pixel resolution from the Ikonos image set and 0.5m per pixel resolution from the WV-2 image set, respectively.

As two high-resolution WorldView-2 scenes from different acquisition dates have been used, they have to be adjusted to each other to reduce brightness and colour differences and finally to be stitched together to a single scene. By coincidence, the overlapping of the two images was precisely the area around the minaret. Although from different dates, they prove useful to enhance the visual resolution of the scene. The transition between both images is hardly visible, besides a change in the colour of the Hari Rud due to different sediment content and river flow velocity in March and April (see Figure 6).

It has to be clearly stated that the absolute positional accuracy of all datasets (DEM, orthophoto, maps) relies on the quality of the measured points during the 2002/2006 campaign. Any potential shift due to GPS/measurement errors of these points leads to the same shift in all datasets. Relative accuracy, the position of all objects and the terrain to each other, is marginally affected by a potential bias in the measured dataset. Relative horizontal accuracy is 1m evaluated and validated for the surrounding area of the minaret based on the terrestrial range data from the field campaigns. Altogether 2000 points from the 2002 campaign and 1700 points from the 2006 campaign were used to achieve significantly higher geocoding accuracy.

These maps contain elevation information, contour lines, a complete stream network, imagery and objects in different combinations. From the satellite images also built structures can be identified and inserted into the map, which now serves as the basis for the local site management. The method proved to be applicable and very useful, especially under conditions where access to cultural properties is limited due to security reasons.

The Extent of Archaeological Remains

UNESCO initiated limited archaeological explorations in order to receive the information requested by the Afghan authorities concerning possible threats from a motorway project at that time planned to pass the minaret. A second exploration campaign in 2005 by Cambridge University could collect further information to determine the extent of the World Heritage property better. From these scientific explorations (Thomas 2012; Thomas et al. 2004) so far, it is possible to define the extent of the archaeological remains at the site of Jam (Figure 7).

The information at that time was mapped to a high-resolution satellite image, without having the possibility to correct this image geometrically, leading to a considerable displacement of the archaeological areas with the real topographic setting. The archaeological information was therefore transferred to the ortho-rectified map, and the extent of the “core and buffer zone” from the initial nomination dossier was projected onto the real topography (Figure 8). By this procedure, it became clear, that the boundaries of the World Heritage property require a modification to engulf the known areas of archaeological significance correctly.

Conclusions Regarding the World Heritage Property and Buffer Zone

Sufficient detailed information on the topography and the structural remains of the archaeological site of Jam and its surrounding area are now available to correct the shortcomings of the initial site map of the 2002 nomination dossier. The boundary information in the nomination file and the interpretations regarding the extent of archaeological remains were projected onto the new topographic information created from the stereo satellite images. The results are depicted in the new site map for the World Heritage Site of Jam (Figure 9-left).

The superposition of all information demonstrates that the delineation of the inscribed World Heritage property only partly is covering the extent of the archaeological remains in reality. The boundaries are running across steep hills regardless of topographic conditions. The area identified as a cemetery with Hebrew inscriptions located in the south was marked too small in the initial map. The real extent of the cemetery is considerably larger and almost intersects with the delineation of the initial buffer zone.

The authors, therefore, propose the adjustment to the boundaries of the World Heritage property to be considered on behalf of the State party. The national authorities should formally submit a request for a minor modification to the boundaries to the World Heritage Committee for approval as stated in Paragraph 164 and Annex 11 of the Operational Guidelines for the implementation of the World Heritage Convention (UNESCO World Heritage Center 2017). This request is justified considering the identified real-world location of the archaeological remains within the topography and also the essential views onto the monument along the steep valleys and mountain ridges. The authors recommend using the new topographic map and the proposed adjustment to the boundaries of the World Heritage property and the buffer zone as depicted in the shown map (Figure 10 right) to substitute the initial map in the nomination file of 2002.

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Professor Michael Jansen died on 13. July 2022 while on duty as UNESCO expert at the World Her-

itage property of Samarkand – Crossroad of Cultures. He was a renowned scholar in the field of cultural heritage preservation, and his contributions to the international safeguarding campaign for the preservation of Afghanistan's cultural heritage are widely acknowledged. His tireless efforts and dedication to the cause have left an indelible mark on the field.

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