PRESERVATION AND MANAGEMENT OF THE UNESCO WORLD HERITAGE SITE OF BAMIYAN: LASER SCAN DOCUMENTATION AND VIRTUAL RECONSTRUCTION OF THE DESTROYED BUDDHA FIGURES AND THE ARCHAEOLOGICAL REMAINS

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ABSTRACT:

Since the destruction of the Giant Buddhas in Bamiyan in the year 2001 consolidation and emergency stabilization works under the auspices of UNESCO and ICOMOS have progressed. The more than 1000m spanning cliff wall was scanned with a terrestrial laser scan system and a 3D model of the cliff was derived from the measurements. After removing the large fragments from the niche of the Eastern 38m Buddha a detailed laser scan was conducted and a textured 3D model of the empty niche generated in order to study the damages of the back wall in detail. From historic images and contour line drawings a 3D surface model of the destroyed 38m Buddha figure was created and successfully integrated into the 3D textured model of the scanned niche. The result has been processed for presentation in an immersive 3D *Cave Automated Virtual environment - CAVE* at the Virtual Reality Center at RWTH Aachen University. The complex real-time stereo projection is computed by a high-end computer cluster and adapts the projected image to the spectator eyes and movement by head tracking with infrared devices. The previous state can be compared to the actual condition and serves as a communication and planning tool among the different expert groups working on the site for discussion on ongoing stabilization and restoration measures and future consolidation works. It is now possible to generate conventional 2D documentation material (sections, plans) precisely from any part of the virtual model in order to plan and conduct further detailed damage assessments and analysis on site. The virtual model incorporates the results of scientific explorations and detailed damage assessments. It will serve as demonstration and experimentation model when exploring the possibilities of a future anastylosis of portions of the figure. The system was adapted to the needs of an exhibition on Gandhara Art in Germany in a special installation set-up reducing the amount of data to a minimum in order to achieve a real time rendering of the 3D model of the entire cliff and the reconstructed 38m Buddha figure with limited computer resources. The documentation work and the virtual reconstruction is embedded in the long term management plan for the entire World Heritage Site.

1 INTRODUCTION AND HISTORY OF THE SITE

The Bamiyan Valley in Afghanistan is located at a height of 2500m around 250km NW of the capital Kabul within the Hindu-Kush mountain range backed by 4000-5000m high massive peaks. The valley extends for several kilometers following the Bamiyan river as a tributary to the Kunduz river system and part of the large Amudarya water basin known as the Oxus River in ancient times. The Buddhist monastic cave sanctuaries and dwellings line up for several kilometers on the north side of the valley facing south leaving the fertile plane open for agriculture (Fig. 2).
The site of the Giant Buddha figures extends for 1,5km comprising more than one thousand caves located at the broadest part of the valley. Situated within the crossroads of the civilizations of the East and the West Bamiyan is regarded as an exceptional testimony and outstanding representation of Buddhist art in the Central Asia region. Remarkable archaeological remains of fortifications and settlements from the Islamic Ghaznavid and Ghurid period are also located in the proximity. During many centuries these valleys served as passageway for the intercontinental trade along the routes of the Silk Road. The caves at the site of the Bamiyan Buddhas have been carved into the cliff during the 3rd to 8th century A.D.

(a) 1974 (b) 2002

Figure 1: Condition of Eastern 38m Buddha before and after the destruction (a), (b)

The ensemble of the Giant Buddha figures of Bamiyan has been known as the world largest depiction of a standing Buddha figure from the first written records by the traveling Chinese monk Xu-

Figure 2: The site of the Bamiyan Buddhas in October 2004 with the empty niches (view in NE direction)

anzang who visited Bamiyan in 629 A.D. Carved deeply into the soft conglomerate of the cliff the "Big" Western Buddha measured 55m and in a distance of 800m to the east the so called "Small" Eastern Buddha raised up 38m. In between the two standing figures several seated figures of Buddha were carved out also from the sedimentary rock. The Giant Buddha figures mark the most western extension of the early Buddhist Gandhara school of art. Due to the artistic expression of its mural paintings Bamiyan became a genuine center for Buddhist art in the Hindu-Kush region in the course of time.

First illustrations of the Bamiyan Buddhas were presented in the first half of the 19th century by Alexander Burnes as part of his travel memoirs from India to Persia (Burnes, 1834) and copied various times by others travelers. In the beginning of the 20th century the Délégation Archéologique Française en Afghanistan (DAFA) initiated comprehensive research on the site. The French mission conducted first conservation works on the mural paintings and executed emergency restoration in endangered instable caves. An accurate topographic map of the the valley was drawn by Jacques Meunie in 1936 and a comprehensive photographic documentation of the condition of the monument was elaborated (Hackin and Meunie, 1933, Hackin et al., 1959). The political instability in the region following World War II led to an interruption of research activities. Bamiyan and its special cave art came into focus again in the second half of the 20th century (Miyaji, 1976, Tarzi, 1977, Klimburg-Salter, 1989). In that period also a year long restoration campaign started initiated by national authorities with the aid of the Government of India dedicated to prepare the site for tourism activities.

Special mention has to be given to the remarkable documentation and interpretation activities that where carried out by Japanese research teams in the 1960-1970´s; first by Nagoya university and then by the Kyoto University Archaeological Mission to Central Asia. They conducted a year long photographic survey of all cave structures around the vicinity of the Giant Buddhas and also in the nearby Kakrak and Foladi Valley using contemporary stereographic and photogrammetric techniques during the documentation process (Higuchi, 1984). With the Soviet invasion and outbreak of a long year war in that region silence came over Bamiyan until the worldwide outcry against their destruction at the very beginning of the 21st century. International intervention and protest could not prevent the complete destruction of the Giant Buddha figures ordered by the Taleban leadership in March 2001.

By the end of 2003 the Cultural Landscape and Archaeological Remains of the Bamiyan Valley have been nominated a UNESCO World Heritage Site according the 1972 World Heritage Convention as a serial nomination of eight individual areas representing artistic and religious developments from the 1st to the 13th century AD.

2 UNESCO/ICOMOS SAFEGUARDING CAMPAIGN FOR THE PRESERVATION OF THE BAMIYAN SITE

Already very early after the fall of the Taliban regime in 2002 an UNESCO expert fact finding mission took place to Bamiyan in which Prof. Michael Jansen of RWTH Aachen University, Prof. Michael Petzet President of the International Council on Monuments and Sites (ICOMOS) and Prof. Kosaku Maeda for National Research Institute of Cultural Properties Tokyo (NRICPT) among other international experts examined the situation on the site. The technical aspects of the mission revealed that within the rubble of dust and sand many fragments from the destroyed figures could be found with original surface features. While the detonations destroyed the Western Buddha 1(b)) almost entirely at the site of the Eastern Buddha portions of the figure survived the explosion (Santana, 2002).

A concept for the preservation of these fragments and the long term conservation of the remains has been first presented by (Petzet, 2002). Conservation activities started in 2003 with the UNESCO Campaign for the Preservation of the Bamiyan Site funded by the Japanese Government. A Japanese survey team by PASCO Inc. set up the coordinates for a site reference system and produced a detailed topographic map of the central Bamiyan valley based on ground-truethed analysis of Quickbird satellite data and aerial images provided by the Afghan Geodesy and Cartography Head Office (AGCHO). The PASCO team also realized a 3D laser scan of the entire cliff, the niches of the Giant Buddhas and several caves in order to document the condition after the detonation and to prepare site plan material for the next stages of the program (PASCO, 2003).

Figure 3: Tangible Heritage Elements of the Cultural Landscape of Bamiyan

Damage assessments on the condition of the mural paintings could be elaborated by the Japanese team of Prof. Kosaku Maeda and Kazuya Yamauchi of National Research Institute for Cultural Properties Tokyo (NRICP, 2004). Furthermore the Japan Center for International Cooperation in Conservation initiated a comprehensive conservation intervention in selected caves in order to prevent further deterioration of the murals. The scientific analysis revealed many new findings that are discussed in detail in (Yamauchi et al., 2007). On the lateral sides of the niches that were in danger to collapse completely due to the impact of the detonationsemergency consolidations had to realized by the Italian rock-climbers from RODIO Inc. (Margottini et al., 2005).

With funding from the Culture Section of the German Foreign Office ICOMOS is actively involved in the international expert campaign of UNESCO for the Safeguarding of the Bamiyan World Heritage Site (ICOMOS, 2005). Aim is to salvage the remaining rock fragments exposed to the forces of wind and water and to store them in temporary shelters. Furthermore the stabilization of the detached mud plaster surfaces in situ is being carried out and the investigation on treatment solutions for their preservation on the long term. RWTH Aachen Center for Documentation and Conservation (RWTHacdc) is documenting the recovery works of the Buddha fragments in close collaboration with restorers and stone conservators of ICOMOS and UNESCO. Also in this context RWTHacdc conducted a survey on the vernacular architecture of the valley and its important traditional irrigation techniques (Fig. 3). From the finding RWTHacdc elaborated a Cultural Master Plan for Bamiyan. The new plan provides a more detailed picture on the cultural assets of the area than the map that was the basis for the inscription as World Heritage Site.

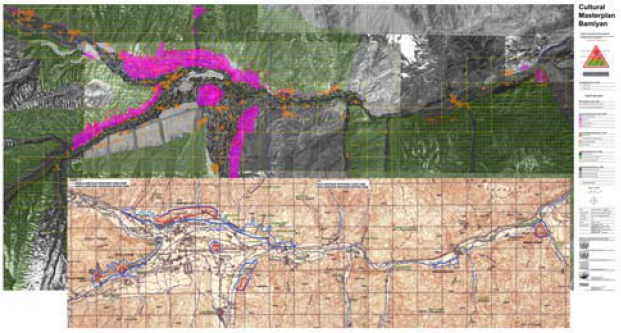

Figure 4: Cultural Master Plan of the Bamiyan valley and map from UNESCO nomination file

This Master Plan was adopted by the Afghan authorities in March 2006 and serves as guideline for the sustainable development of the entire valley promoting the cultural and ecological values of Bamiyan (Fig. 4).

Due to the heavy contamination of the area with unexploded ordnance remaining from year long fighting in this area all activities on the site have to be executed under the supervision of national de-mining experts together with the Afghan Ministry for Culture. All works are embedded in the recommendations of the UNESCO Expert Working Group for the Preservation of the Bamiyan Site (UNESCO, 2006) which is coordinating the efforts of the different international teams.

3 THREE-DIMENSIONAL DOCUMENTATION AND VIRTUAL ENVIRONMENTS FOR VISUALIZATION AND COMMUNICATION

While the works at the site of the Western Buddha (55m) niche are still ongoing the removal of debris in the niche of the Eastern Buddha (38m) was completed by autumn 2006. In cooperation with the Technical University of Vienna (Dept. Art History - Prof. Marina Döring) a 3D Laser Scan could be realized (Fig. 6) to document the condition of the cleaned niche prior to the installation of a scaffold for the following consolidation works at the back wall. A Riegl Laser Measurement System Z420i (Fig. 5(a)) in combination with a Canon EOS 1Ds (f=20mm, 10 Megapixel) digital camera mounted on top of the scanner was used. The scanner allows a very flexible alignment of the resolution according to the scan size and the scan distance (1,2m up to 1000m) by adjusting the angle of the moving laser light $(0,12-0,02degree)$. Additionally to the measured point cloud of the laser scanner a set of pictures is taken automatically after each scan by the on top mounted digital camera. Every time the digital camera is mounted on the scanner body a manual calibration (mounting calibration) has to be performed by manually assigning characteristic features visible in the scan to the digital pictures. Due to the known internal calibration values the color information of each pixel from the digital image is automatically assigned to the measured point cloud. The used commercial software package RiScan Pro 1.2 is provided by the laser scanner manufacturer Riegl.

(a) Riegl Z420i (b) Detail of back wall

Figure 5: Laser Scanner (a) and detail of laser scan (b)

Figure 6: Final result of Laser Scan in shaded mode

A LEICA Total Station TCR 1105 was used for measuring all scan positions exactly and for linking the newly obtained measurements with the UTM reference-system and the Site Control

Points established by the Japanese survey team of PASCO. To reach a sufficient precision of the final model the resolution was set to ensure a point distance equal $8mm$ on the surface of the cliff stone. For triangulation of the final mesh from the measurement points of the Eastern Buddha niche the Software *QTSculptor v2.85* of Polygon Technology was used. In this case 1.2 million triangles were created by the software out of the 77 million measurement points. The last step is the assignment of the digital images on the mesh. The images have been applied automatically using the mounting calibration assigned on site. The scan procedure and the generation of the 3D model of the Eastern Buddha has been described in detail in (Jansen et al., 2008).

Photogrammetric methods for the documentation of the entire Bamiyan Cliff have been explored first by Yoshiyuki Ushikawa of the National Research Institute for Cultural Properties in Nara in the course of the Japanese explorations between 1970-1978 (Higuchi, 1984). The entire cliff was documented by means of stereoscopic analysis of metric images taken during the field campaign. A full scale isoline drawing of the entire cliff was drawn afterwards including both Giant Buddha figures. The Western Buddha (55m) was also documented with stereometric means by a Swiss survey team (Kostka, 1974) during a topographical exploration of undocumented valleys in Eastern Afghanistan. Automated methods for 3D model generation of the Western Buddha (55m) based on the Swiss image pairs of 1974 have been discussed by (Grün et al., 2002).

From the documentation of the site prepared by the Archaeological Mission to Central Asia at Kyoto University in the years 1972-1978 the team at RWTH Aachen obtained a high resolution scan (6800x10400 pixel) of the original 1/50 scale ink drawing of the contour line interpretation from the Eastern Buddha (38m) sculpture. In this drawing each of the 10 cm isohypse contour lines

(a) Drawing courtesy Prof. Higuchi of Kyoto Archaeological Mission to Central Asia

(b) 3d surface model

Figure 7: Eastern Buddha 38(m) derived from isoline drawing

is clearly readable and was manually digitized. The 3D surface of the Eastern Buddha was generated with *Geomagic Studio v.10* Software (Fig. 7(b)). Based on characteristic features visible in the contour line drawings and still traceable at the site the surface model could be orientated within the 3D model of the niche generated from the laser scans by manual alignments.

The results where presented first time on the occasion of the 5th UNESCO Expert Working Group Meeting for the Preservation of the Bamiyan Site in December 2006 at RWTH Aachen University. The immersive virtual environment BARCO CAVE™(Cave Automatic Virtual Environment) at the Virtual Reality Centre of

Figure 8: Textured 3d model of Eastern 38m Buddha integrated in model of niche

RWTH Aachen University represents an advanced version of the system (Cruz-Neira et al., 1993) and is used for research of multimodal and interactive 3D interactions and visualization of complex numerical and technical simulations in real time. The CAVE system is a cube of 3x3m that allows a five sided projection of stereo images onto the walls and ceiling. The resolution of images or videos projected is 1600x1200 pixels per plane using ten BARCO Sim6 Ultra projectors that project the stereo images. The user of the Cave wears a pair of polarized glasses with attached reflectors so that his position in spaces is constantly measured by an optical tracking system based on six ARTtrack1 cameras. To create a complete immersive 3D experience the viewpoint of the spectator is processed in real time and the stereo images are rendered accordingly by a PC Cluster of a total of ten Render Clients (Pentium IV,4GB RAM Memory) connected to the projectors. One Master Station (Dual Xeon System - 4GB RAM Memory - NVIDIA GeForce 6800 GT) controls the synchronization of all calculations with a specially designed application programmed in VISTA a cross platform VR Toolkit under development at RWTH Aachen. Up to five spectators with untracked polarized glasses

Figure 9: Immersive Virtual Environment CAVE

fit into the projection space and can share the experience of the tracked user. Although the system can be folded up to a four segment screen of 12m length the spatial limitations and bulky projector installations are an obstacle in presenting this technology at other occasions than the research environment. Since it was desired to present the results to a larger audience at the Federal Exhibition Hall of Germany in Bonn within the context of the exhibition of Gandhara Art a passive stereo projection was realized by the Collaborative Virtual and Augmented Environments Group of Fraunhofer Institute for Applied Information Technol-

ogy (FIT) in Bonn/Birlinghoven.
A space of $50m^2$ with a 3x4m projection screen was designed to be used by 40 people at a time and a standard stereoscopic setting was chosen using low cost polarized paper glasses. A 3D Space Mouse was installed in the middle of the room to allow user interaction by moving the controller cap to simultaneously pan, zoom, and rotate on the fly. A set of fixed viewpoints were defined in the 3D scene and approached automatically when no user interaction took place. The setting allowed the user at any time to take over the navigation or let himself follow the predefined viewpoint that were approached automatically after a certain time interval. The installation was realized with the MORGAN framework developed by the Fraunhofer Institute. MORGAN is an extensible component based AR/VR framework, enabling sophisticated dynamic multi user AR and VR projects by addressing a large variety of input devices and by providing a sophisticated render engine. (Ohlenburg et al., 2004). In order to realize the real time rendering of the entire cliff scene including the niche of the Eastern Buddha and the reconstructed 3D model with the used computer system (Dell Precision T7400, Quad Core Xeon Extreme Processor, 4GB RAM, NVidia Quadro FX 4600) the data had to be reduced significantly to a total amount of 200.000 triangles.

4 RESTORATION AND MANAGEMENT

From the final 3D model further plans such as sections, views and orthophotos have been created from all viewpoints. The plans obtained from the high-precision measurements are the basis for the documentation of the geological profile of this portion of the cliff. Tests on site revealed that the geological features of each fragment allow a precise identification of the composition of the conglomerate stone which is suitable to identify its place of origin based on geological profile matching (Urbat and Krumsiek, 2004). The plans also serve as basis for further planning of necessary consolidation works conducted by ICOMOS. They give precise information on the existing geometry and the location and gradient of dangerous cracks. Based on these plans restoration works are currently underway by ICOMOS to reconstruct the destroyed separation walls between the ceremony halls at the bottom backside of the niche of the Eastern Buddha.

(a) Geological Profile (b) Section

Figure 10: Various Maps from 3D Model

Cultural heritage management includes the documentation of past and present conditions the evaluation of conservation concepts as well as the execution of measures. Decisive knowledge and a living framework of partners and methods are essential for conservators, architects, site managers and urban/regional planners as well as capacities that enable cooperation and support of involved stakeholder in order to ensure long term preservation goals. The situation in developing and post-conflict countries furthermore is dominated by insecurity issues with a devastating impact of the human resource sector. In the case of Afghanistan educational institutions have to be rebuilt simultaneously as the country has lost the experiences and knowledge accumulated by prior generations. In order to bridge the gap an intergenerational cooperation has to be initiated reactivating the accumulated knowledge of the Past. New channels of communication have to be established as the involved experts are dispersed globally crossing languages and research methods. Facing such problems conservation activities have to be prioritized and integrated in sustainable development plans that both meet the requirements of protection the inherit value of a cultural site and the necessity to identify economic and social benefits such as tourism activities to the local communities.

The multidisciplinary approach within the various departments involved at RWTH Aachen University gave the opportunity to address some of these issues from a socio-technological viewpoint. Together with the Dept. for Databases and Information Systems it is being examined how far current developments in collaborative work on multimedia artifacts and web-based learning approaches are applicable to Cultural Heritage Management scenarios. One of the outcomes of this highly experimental oriented cooperation is the establishment of an Internet Community Portal dedicated to the sustainable development of the entire Bamiyan Valley (*www.bamiyan-development.org*). The addressed requirements include the promotion of awareness and knowledge raising activities about the existence and value of cultural sites to an growing amount of people by making use of contemporary technologies from Information and Communication Technologies domain. It is possible to combine conventional Low-Tech documentation approaches easily with small scale smart devices (e.g.GPS enabled camera) to ensure systematic collection of semantic pieces of information otherwise neglected. Such an approach allows the recontextualisation of the multimedia artifact at a later stage.
Also the situation on the ground has to be reflected realistically bearing in mind that ongoing looting of historical sites is a fact and that available human resources remain limited. Capacity building activities in cultural heritage management and preservation remain an urgent priority and they have to be carried out in very close cooperation with the national institutions both in administration and education sector. The creation of policy framework that involves national cultural and planning institutions as well as experts and stakeholders in order to create a sustainable protective environment is part of such an integrated planning approach.

5 CONCLUSION

The precision and high density of the laser scan measurements capture delicate details (original clay plaster and carved cliff surface) and facilitate the production of detailed 2D plans of the geometry of the niche (section, views) in almost all directions. Since our work is aimed to support the practical preservation and restoration works on site primary aim is to create a model serving as a means of communication that provides the general outline to all involved partners precise enough so that more specific observations and findings can be incorporated easily at a later stage. Also it is precise enough to contribute to the discussion process on the future of the site in the sense of work in progress without pre-assuming a final state that has to be achieved.
While the extension of such an object as the Bamiyan site and the complexity of its management justifies the usage of high-precision techniques for the documentation process the questions and purposes dealing with reconstruction have to be addressed carefully. The methodological approach has to reflect both technological and epistemological questions and has to be aware of

its potentials and even more important of its limitations (Petzet, 2002, Petzet and Melzl, 2007). In the case of the Giant Buddha figures of Bamiyan ethical components also have to be considered since the general discussion on physical reconstruction is going on (UNESCO, 2006) and still far from being resolved decisively. Based on virtual models it is possible to study and to compare concepts for technical measures in the future in detail prior to their execution. Due to the enormous object size and the complexity of the niche it became clear that the original shape information of the destroyed Buddha figure is essential in order to make the spatial configuration of the monument readable and understandable again. In how far this shape has to be reconstructed in future interventions such as a full or partial anastylosis can now be evaluated comprehensively by making use of the CAVE at the Virtual Reality Laboratory situated at RWTH Aachen University.

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