

# THE FUSION OF LASER SCANNING AND CLOSE RANGE PHOTOGRAMMETRY IN BAM LASER-PHOTOGRAMMETRIC MAPPING OF BAM CITADEL (ARG-E-BAM)/IRAN

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## ABSTRACT

After the devastating earth quake (26.12.2003, 6.3 Richter Scale) in Bam city/ Iran, RIEGL LMS GmbH /Austria and their Iranian agent, NPR Co. performed the 3D-mapping of the greatest mud-brick and adobe complex of the world, the historical Citadel of Bam (Arg-E-Bam). Making use of the unique system integration of close range photogrammetry and laser scanning technology, it is possible to provide the true colour textured 3D as-built models. The impressive results of the scanning campaign prove this bi-technique a highly efficient method whose capacities have yet to be fully discovered and exploited.

## KURZFASSUNG

Nach dem verheerenden Erdbeben in Bam/Iran (26.12.2003; 6.3 Richter Skala) wurde das Gelände der weitgehend zerstörten historischen Zitadelle von Bam (Arg – E – Bam), der ältesten Lehmziegelanlage der Welt, von RIEGL LMS GmbH (Österreich) und ihrer iranischen Vertretung, NPR Co. vermessen. Dabei wurde eine einzigartige Systemintegration zum Einsatz gebracht, die durch die Verbindung von Nahbereichsphotogrammetrie und Laserscanning das Generieren von texturierten Echtfarbenmodellen in 3D ermöglicht. Die beeindruckenden Resultate des Projektes zeugen von der Effizienz der angewandten Technologie und deren vielversprechender, noch nicht vollständig ausgeloteter Kapazität.

## RÉSUMÉ

Après le tremblement de terre dévastateur à Bam en Iran (26.12. 2003 ; 6.3. sur l'échelle de Richter), les entreprises RIEGL LMS GmbH (Autriche) et leur représentant iranien, NPR Co. ont effectué un projet de scanning de la citadelle de Bam endommagée, un monument historique, le plus vieux et le plus grand bâtiment en terre glaise dans le monde. En utilisant un système intégratif des technologies de la photogrammétrie et du scanning laser, il est possible de fournir des modèles 3D texturés et en couleur naturelle. Les résultats impressionnants de cette application prouvent cette bi-technique une méthode bien efficace dont les capacités restent à être pleinement découvertes et exploitées.

## 1. INTRODUCTION

Arg-E-Bam can not only be considered as a former main economic factor but also as the symbol for the vitality of the region of Bam, and a means of identification for the inhabitants. Therefore, the authors hope for a quick and efficient reconstruction, maybe partly on the basis of the data gained through an exemplary surveying campaign performed in early February 2004. Experts from UNESCO and ICHO (Iranian Cultural Heritage Organisation) had addressed NPR Co. shortly after the catastrophe. The state of damage of the citadel – that is most likely to be added to the World Heritage in danger list – had to be documented. A volume model of the citadel, details of cracks in the eldest walls, and an overall

map of the grounds were demanded as first results as a basis for mapping out the procedure of cleaning the debris and start restoration and reconstruction works. These demands could be satisfied within the four days of scanning, thanks to the technology employed: Riegl's approach consists in a combination of two techniques formerly considered as competitive: photogrammetry, that has gained its expertise over the last hundred years, and the innovative laser scanning, developed in the last decade only. As producer of high-end laser scanners Riegl LMS GmbH decided to develop a bi-technique in order to optimise the multipurpose usability of scanning results and to accelerate the traditional photogrammetric procedure employed for this.



Figure 1: Bam Citadel before and after the earthquake

## 2. METHOD

### 2.1. Hardware

The measurement system used for the Bam Citadel project consisted of a *RIEGL LMS Z420i* Laser-Scanner equipped with a calibrated Nikon D100 6 Mega Pixel digital camera

mounted solidly on top of the scanner (figure 2). The mathematical relation between these two sensors is defined by a perfect hardware calibration (effectuated beforehand by RIEGL). In addition to the precise internal



Figure 2: RIEGL LMS Z420i in Bam Citadel

camera calibration, a mounting calibration guarantees a reliable correspondence of image and scan data. This mounting calibration can easily be checked automatically in the field. After the execution of a panorama scan (field of view 360° x 80°, operation time 4 minutes, 2 Mio measurement points) and fine scanning of the (automatically identified) reflectors and possible additional detail scans resp. detail sequences, a series of photos are taken that cover the corresponding field of view. Right after performing a scan on a new scan position, the resulting data is merged with the already existing scans in the project file. The accuracy of the single scan data can be increased by averaging the results of a multiple scanning process, called scan sequence.

## 2.2. Post-Processing

The acquisition software package RiScan Pro stores the data in a well organized, open and documented rsp (RiScan Pro) format for further post processing and archiving. The data is directly readable by various post processing software without friction losses, as described in the subsequent section for PHIDIAS, the software solution utilized in Bam. The many features provided in the operating software RiScan Pro apart from raw data acquisition – such as merging, registration, calibration, resampling, filtering – prepare the data ideally for a latter interpreter, who can therefore orientate himself easily within the data without knowing the site and without external maps. In order to respond to requirements of countless different applications, RIEGL recommends a selection of proven software packages and, by providing a command library, allows software developers to write their own post processing software.

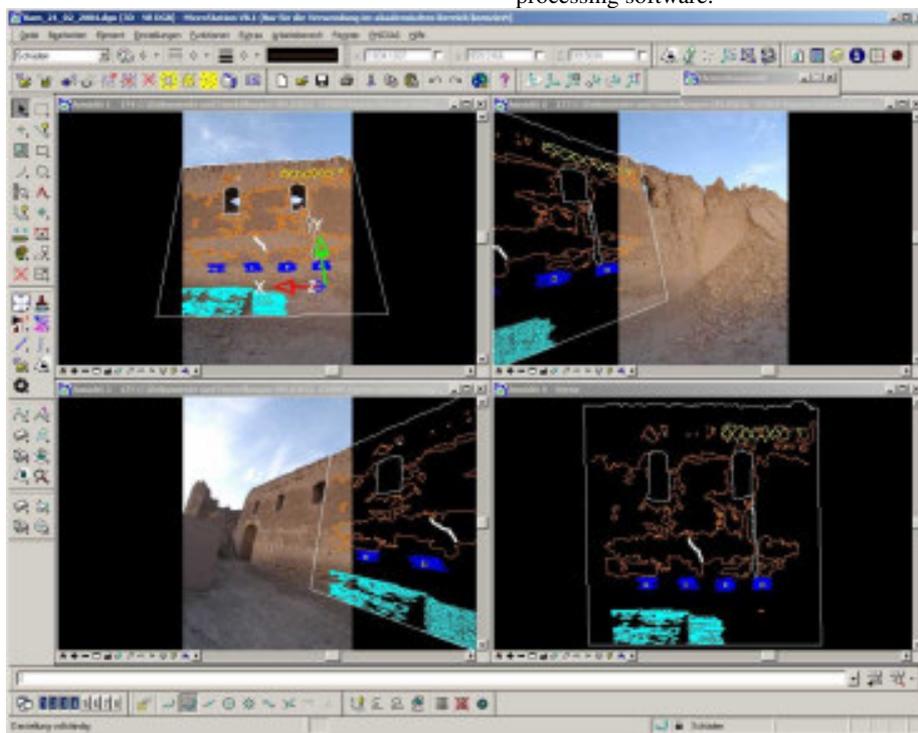


Figure 3: PHIDIAS mono plot post processing (point cloud, photograph and CAD drawing within one window)

## 2.3. Primary results

The immediate results of a scanning campaign show the versatility of the combined system and the different ways of data interpretation respective to the desired final result.

First of all, the operating software RiScan Pro delivers the data as point cloud that contains the RGB value for each pixel out of the corresponding photograph. This coloured point cloud serves as a visualisation of the scenery, for checking the data acquired and deciding upon the necessity of additional scan positions. The raw data can be resampled so as to keep even point clouds containing a large amount of single scans lightweight and thus manageable by the operation notebook in the field.

The second result consists of a decimated data mesh with a high resolution texture. The few post processing tasks necessary to achieve this are carried out directly in the same operating software. The high quality of the mesh is guaranteed through the Delaunay triangulation method. The mesh is to be cleaned and smoothed before the image data is applied in its entire pixel resolution. The gained mesh shows the respective advantages of laser scanning and photogrammetry: While the strength of laser scanning lies in the fast and reliable rendering of surfaces, the advantage of photogrammetry is the recognition of edges and details. By mapping the high resolution undistorted photographs on the scan data, it is possible to profit from both the high overall accuracy of the 360° scanner as

well as the detail identification capacity of photogrammetry. Consequently, the mesh is decimated in a way to maintain a large number of triangles on edges and to reduce the number of triangles on flat surfaces.

Out of this mesh and the undistorted pictures that cover the area of interest one can now easily generate orthophotos, in a far quicker way than by traditional methods. The so called Z-orthophoto (zop-format) as a 2,5D interpretation of the data – each point contains depth information – is ready for exportation into different CAD programs, e.g. [www.ScanDig3D.com](http://www.ScanDig3D.com), for further post processing.

A full exploitation of the 3D information of the data set is the mono plot procedure, possible through PHIDIAS, a software plugin programmed for MicroStation. This evaluation system

provides all the necessary photogrammetric tools for the combined evaluation, while being able to display the photograph and the scanned data point cloud simultaneously, one on top of the other. The basis of a combined evaluation of both records is the perspective representation of the scan data. Therefore, users can profit from all features of a 3D - CAD system when performing an evaluation without having to renounce classical photogrammetry. The single frames can be co - oriented without consideration of the angles of convergence between the pictures. After the definition of a drawing surface out of the scan data as plane or triangulated mesh, the object can be digitised in the high resolution photograph. Figure 4 shows how the drawing of single bricks happens immediately in global 3D coordinates, in three formats (point cloud, photo and CAD) at once.

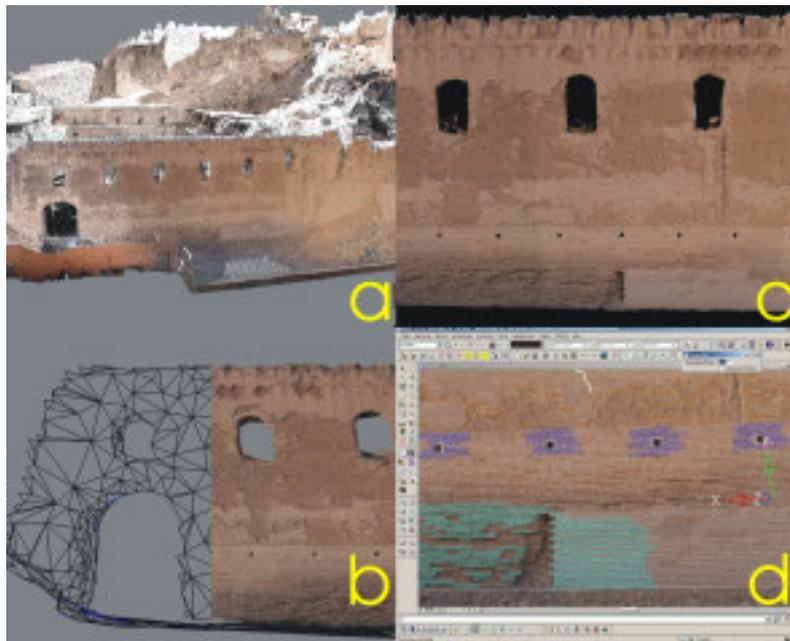


Figure 4 a) coloured point cloud b) decimated mesh with high resolution texture c) orthophoto d) mono-plot post processing

### 3. IMPLEMENTATION

The crew was split into a scanning-team, a surveying-team, and a post processing team working simultaneously in the field.

More than 80 retro-reflecting signals were positioned onto strategically important points in and around the protruding part of the citadel, the governing place. As these reflectors served as tie-points for merging the data of different scan positions, their locations were chosen such as to guarantee optimal visibility. The description of these points, and consequently every measured point, in global UTM coordinates was made possible by the results of the surveying team who measured the reflectors by dual frequency GPS receivers and total station. The signals are automatically extracted out of the scan data and fine scanned in a next step. Then, by comparing a minimum of six reflectors found in the

scan data with the pre-established list of global coordinates, an automatic matching of the data is carried out, and the scan position is thus registered in the project. All the data is used for the hybrid multi station adjustment of the operating software RiSCANPRO.

The merging accuracy is displayed instantaneously after the automatic finding of the corresponding tie points. The feedback of at least six used reflectors with typ. 4 – 7mm standard deviation means that the merging process has been carried out successfully. The simultaneous display of the registered, resampled and merged point clouds of all scan positions allows the operator to decide upon following scan positions in order to reduce the scan shadows of the final scan data to the largest extent.

A total of 24 adjacent scan positions around the governing place - that had been considered as the object of main interest and highest priority by ICHO experts - and one

supplementary position from the opposite outer wall of Arg-E-Bam were chosen.

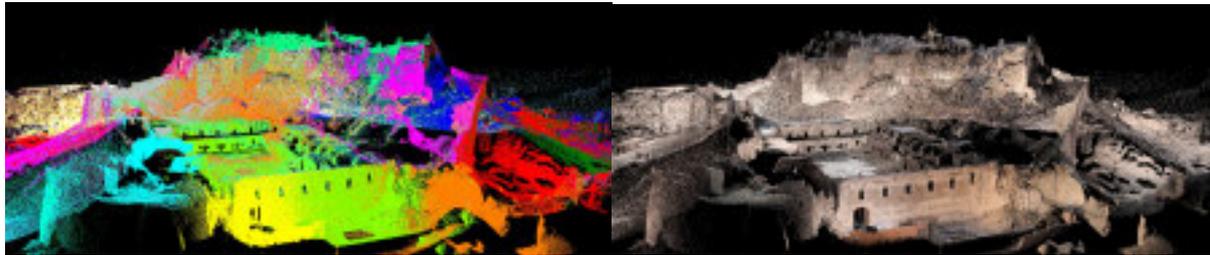


Figure 5: Merged point cloud of different scan positions within RiSCAN PRO, left: colour encoded, right: true coloured

### 3. CONCLUSION

The characteristics of the most powerful instrument of the RIEGL LMS scanner series, the LMS-Z420i, are: its narrow beam divergence (0.2 mrad only), its operating range (up to 800m), and its single-shot accuracy (10 mm, which can be improved up to 5mm by scan sequences). As a consequence, the raw scan data provide a precious basis for different post processing activities. The time-of-flight laser measurement technique employed, allowing long range performance and reliable data acquisition even for locations difficult to access,

is perfectly completed by the photogrammetric method (high pixel density, hence definition and vectorisation of edges and high accuracy of details.). Thus, the versatile hybrid instrument corresponds ideally to architectural, topographic and archaeological requirements. The high speed of operation allows a quick data acquisition, and it is therefore possible to build up an archive of historical sites and monuments for multipurpose post-processing, not only under such tragic circumstances like the catastrophic earth-quake in Bam.

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