CIPA HERITAGE DOCUMENTATION · BEST PRACTICES AND APPLICATIONS · Series 1, 2007 & 2009

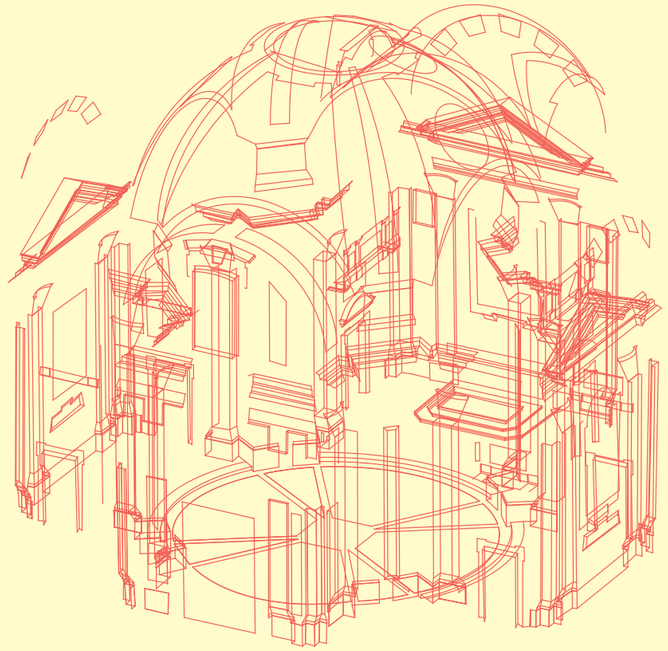
The ICOMOS & ISPRS Committee for
Documentation of Cultural Heritage

The ISPRS International Archives of the
Photogrammetry, Remote Sensing and Spatial Information Sciences
Volume XXXVIII-5/C19 • ISSN 1682-1750

CIPA HERITAGE DOCUMENTATION

BEST PRACTICES AND APPLICATIONS

Series 1, 2007 & 2009



Editors: Efstratios Stylianidis, Petros Patias, Mario Santana Quintero

ICOMOS

isprs
information from imagery

The ICOMOS & ISPRS Committee for
Documentation of Cultural Heritage

CIPA HERITAGE DOCUMENTATION

BEST PRACTICES AND APPLICATIONS

Series 1, 2007 & 2009

XXI International Symposium – CIPA 2007, Athens

XXII International Symposium – CIPA 2009, Kyoto

Published by CIPA

Editors: Efstratios Stylianidis, Petros Patias, Mario Santana Quintero

THE INTERNATIONAL ARCHIVES OF PHOTOGRAMMETRY, REMOTE SENSING AND SPATIAL INFORMATION SCIENCES
INTERNATIONALES ARCHIV FÜR PHOTOGRAMMETRIE, FERNERKUNDUNG UND RAUMBEZOGENE INFORMATIONS WISSENSCHAFTEN
ARCHIVES INTERNATIONAL DES SCIENCES DE LA PHOTOGRAMMÈTRIE, DE LA TÈLÈDÈTECTION ET DE L'INFORMATION SPATIALE

Volume XXXVIII-5/C19 • ISSN 1682-1750

Copies of this volume are available from:

UNESCO – ICOMOS Documentation Centre
49-51 rue de la Federation
F - 75015 Paris (France)
Tel: +33 (0) 1 45 67 67 70
Fax: +33 (0) 1 45 66 06 02
E-mail: centre-doc-icomos@unesco.org

GITC bv
P.O. Box 112
NL – 8530 AC Lemmer (Netherlands)
Tel: +31 514 561854
Fax: +31 514 563898
E-mail: mailbox@gitc.nl

CIPA Treasurer
Prof. José Luis Lerma García
Universidad Politéchica De Valencia (UPV)
Departamento de Ingeniería Cartográfica, Geodesia y Fotogrametría
Camino de Vera s/n. Edificio 7i. 46022 Valencia, Spain
Tel: +34 96387707
Fax: +34 963877559
E-mail: jllerma@cgf.upv.es

ISSN: 1682-1777
Printed in Greece by Ziti Publications

CIPA's Sustaining Members

ARCHEOTECH SA
Chemin des Croisettes 23
CH 1066 Epalinges, Switzerland
www.archeotech.ch

The Getty Conservation Institute
1200 Getty Center Drive, Suite 700
Los Angeles, CA 90049-1684, USA
www.getty.edu/conservation/institute

ART GRAPHIQUE et PATRIMOINE
15, Avenue Jean Jaurès
94340 Joinville-le-Pont, France
www.artgp.fr

English Heritage
37 Tanner Row
York, YO1 6WP, UK
www.english-heritage.org.uk

Josef LINSINGER ZT-Gmbh
Hauptstr. 31
A 5600 St. Johann / Pg, Austria
www.linsinger.at

ArcTron GmbH
Ringstraße 8
D-93177 Altenthann, Germany
www.arctron.com

TPLM3D
132 avenue Franklin Roosevelt
69500 BRON, France
www.tplm-3d.fr

Riegl Laser Measurement Systems GmbH
Riedenburgstr. 48
A-3580 Horn, Austria
www.riegl.com

Metria Digital, S.L.
New Techniques for Heritage Documentation
Parque Tecnologico de Asturias, CEEI Building
33428 Llanera – Principality of Asturias, Spain
www.metria.es

Preface

The ICOMOS Scientific Committee, *CIPA Heritage Documentation*, is proud to present this first in a series of publications presenting state-of-the-art research and applications in the discipline of Cultural Heritage documentation.

The intention of this publication is to record and archive the progress in documentation techniques and products during the two-year cycle of the CIPA symposia. In addition, the CIPA-HD Board would like to acknowledge the important contributions made during these symposia which, besides their theoretical and technical rigor, also provide examples of good practice or important applications in Cultural Heritage documentation.

The publication starts with an introduction to heritage documentation by presenting the state-of-the-art, the different approaches and the tools engaged in heritage documentation procedures.

The first section includes papers presented in the 2007 CIPA Symposium in Athens, Greece. All papers have been selected by a special jury and awarded Best Paper awards in various categories at the Symposium. The six (6) selected papers concern Best Practices and Applications. All the papers present different aspects, applications, technical problems and novel approaches to CH documentation.

The second section is dedicated to papers presented in the 2009 CIPA Symposium in Kyoto, Japan. As in the case of Athens, all papers have been selected by a special jury. The seven (7) selected papers concern Best Practices and Applications. All selected papers present different aspects, applications, technical problems and novel approaches to CH documentation, mainly in Asia.

The publication concludes with a brief description on the future trends in heritage documentation.

It is our belief that this publication will prove useful for those working in Cultural Heritage documentation and we wish again to congratulate the authors for their contribution.

We would also like to acknowledge the contributions of the Sustaining Members of CIPA-HD, whose financial support has made this publication possible.

C. Ogleby, *CIPA President*

E. Stylianidis, P. Patias, M. Santana, *Editorial committee*

Table of Contents

1 Introduction to Heritage Documentation

P. Patias[1], M. Santana[2]

1. *Aristotle University of Thessaloniki, Department of Cadastre, Photogrammetry and Cartography, Univ. Box 473, GR-54124 Thessaloniki, patias@auth.gr*
2. *Department of Architecture, Urban and Regional Planning - R.Lemaire International Center for Conservation - University of Leuven (KU Leuven), president@cipa.icomos.org*

1.1 State-of-the-Art

Cultural documentation is a complicated process, and includes a wide suite of activities that include surveying, testing and monitoring and gathering textual and other information. "The geometry of the object is not the only parameter to be recorded. All specificities making the object unique are meaningful; all potential values – architectural, artistic, historical, scientific and social – are parameters to consider", (D'Ayala and Smars, 2003).

The guiding concepts of cultural heritage documentation have been detailed by D'Ayala and Smars (2003) (Patias, 2007) as:

- **Objectivity**: "… an objective basis is a guarantee to having a firm ground on which to debate the conservation choices…" and "…the use of any specific set of data necessarily influences any decision-making process. The manner in which a survey is executed significantly influences further actions".
- **Values**: "The recorder's choices are critical…… What is seen today as uninteresting may appear tomorrow as extremely valuable. The importance of thorough recording is emphasised by the common loss of minor details which may disappear at the moment of new conservation work, leading to loss of integrity or of historical evidence."
- **Learning process**.
- **Continuity**: "… Documentation should not be seen as an activity confined within a set time…. Therefore, a basic requirement is that the results of documentation should be available for future use."
- **Fabric**: "Documentation should not stop at the surface.... Integration with other documentation techniques is necessary."
- **Documentation sets**: "Information gathered during documentation may be large and manifold…. thus it is critical to organise the available information, for which the metric survey is a natural support. Sets of thematic drawings (geometry, materials, pathologies etc.) can be prepared. A specific set prepared by one specialist can bring insight to other specialists who are working on other sets."
- **Redundancy**: "… Every piece of information is associated with uncertainty. Documentation data should be supplemented by information about the quality of the data. Control procedures offer a way to assess quality."

These concepts lead to increasing needs for recording and documentation of CH, which put briefly are:

- recording of a vast amount of four dimensional (i.e. 3-D plus time) multisource, multi-format and multi-content information, with stated levels of accuracy and detail;
- digital inventories in 3-D and, as far as available, dated historical images;
- management of the 4-D information in a secure and rational way, making it available for sharing and distribution to other users; and
- visualization and presentation of the information in a user-friendly way, so that different kinds of users can actually retrieve the data and acquire useful information, using Internet and visualization techniques.

CIPA's main objective is to provide an international focal point for efforts in the improvement of all methods for surveying of cultural monuments and sites. The combination of all aspects of photogrammetry with other surveying methods is regarded as an important contribution to recording and monitoring cultural heritage, to the preservation and restoration of any valuable architectural or other cultural monument, object or site, and to provide support to architectural, archaeological and other art-historical research.

In contrast to most conventional photogrammetric applications, cultural heritage documentation is much more challenging, due specifically to the varying size of the objects to be documented as well as the different quality and resolution requirements. Choosing the appropriate technology (sensor, hardware, software), the appropriate procedures, designing the production workflow and assuring that the final output is in accordance with the set technical specifications is a challenging matter in cultural heritage documentation (Patias, 2004, Patias 2007). For this, the leading parameters are the size and the complexity of the object and the level of accuracy required. These two are the major factors, which crucially influence the procedure to be followed and, sometimes, even the viability of photogrammetry itself. Other secondary factors, which may have an impact (and are sometimes crucial) are speed/time limitations for the documentation and budget limitations. The reason that these factors are secondary in nature is that they do not influence the viability of photogrammetry as the techniques to be followed (since photogrammetry already has a distinct advantage over other techniques concerning the above factors) but they may influence the technicalities of the procedure which should be followed.

These strict and of varying type requirements gave rise to a palette of techniques and instrumentation for CH applications. Nowadays image acquisition systems are almost exclusively based on digital sensors. Even non-standard imaging principles such as panoramic cameras, fisheye systems, rotating cameras and other vision techniques are used. Beside this, archives with thousands of analogue images demand the need of precise digitization of film, photo prints or even glass plates for further digital photogrammetric workflow (Patias, et. al., 2008).

In addition to digital image based sensors (satellite, aerial and close range), different kinds of range based sensors like 3-D scanners (airborne, mid and close range), IR-sensors, thermal systems, geophysical sensors and many more are used to collect a whole spectrum of information on cultural heritage objects and sites.

1.2 Training Approaches

Heritage places are a unique and irreplaceable source of information. The process of acquiring heritage information serves for the identification of heritage places with significance at the local, national and/or international community.

The documentation of cultural heritage requires a multidisciplinary approach, ensuring that recording and documentation tools. As well as, the preparation of information systems provides appropriate and timely information enabling to understand the significance and to detect and monitor the integrity of heritage places.

1.2.1 The training objectives and contents

Information collected by recording and documentation for conservation projects play an essential role in safeguarding our cultural heritage, it permits:

- Understanding of significant and integrity of heritage places;
- Transmission of this understanding thus increasing public awareness;
- Informing decisions for conservation;
- Creating records for posterity in case of destruction;
- Providing timely and sufficient information for preventive maintenance

The teaching strategy should involve an innovative role-playing technique, which empowers students and instructors to:

- Develop an understanding of the role of information in conservation, addressing national and international standards;
- Review the potential limitations of recording and documentation techniques, including simple and advanced tools, and the financial constraints.
- Develop a practical approach to the use of these tools and documentation techniques in order to capture information from cultural heritage resources;
- Include the use of information systems in cultural heritage resources management;
- Design reports for presenting information to stakeholders and decision makers.

A training programme should consider explaining:

- Key definitions in cultural heritage documentation;
- Type of cultural heritage documentation assessments;
- Definition of a the heritage place baseline documentation;
- Definition of scope and level of detail;
- Cultural heritage Conservation workflow;
- Selection of recording tools;
- Explanation of heritage recording tools;
- Preparation of a 'documentation dossier or site atlas' of the heritage place using recording tools.

1.2.2 What is a baseline record of heritage places?

A training approach should identify and define the parameters relevant in particular heritage assessment. The chart in Figure 1 depicts the components of a baseline record.

This baseline, additionally, could be use as starting point for designing and implementing plan monitoring strategy, allowing detecting changes affecting the statement of significance of the heritage place. A baseline is defined by both a site report and a dossier of measured representations that could include a site plan, emplacement plan, plans of features, sections, elevations, three-dimensional models, etc.

The following checklist can be used as guideline to adequate requirements of information required defining the baseline and training purposes:

- Identify site location (centroid, boundaries, elements and buffer zone);

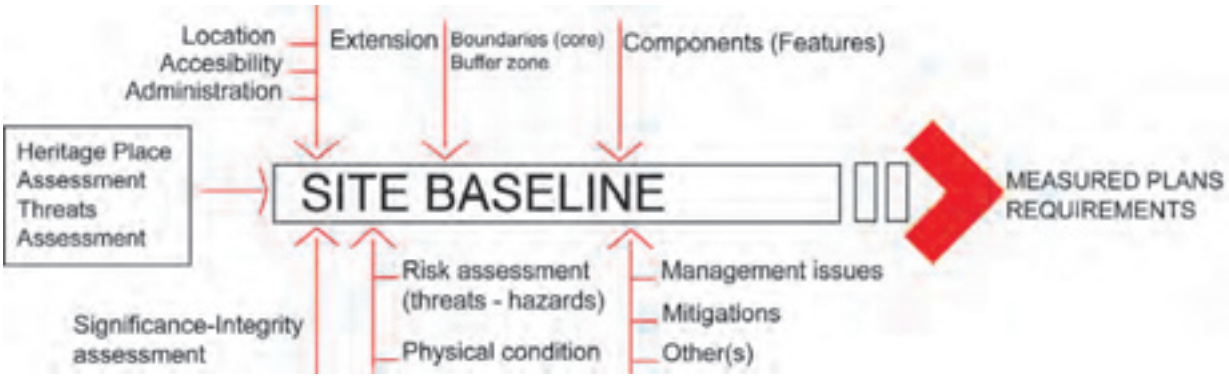


Figure 1: Defining a baseline, author.

- Identify and map evidences of criteria;
- Significance and integrity assessment;
- Risk assessment: threats and hazards associated to indicators;
- Administrative and management issues (current and passed mitigations);
- Other assessments.

1.2.3 Practical issues when recording heritage places

A good understanding of the recording heritage places requires the development of skills that recognize the following issues:

- Nothing is straight, square or horizontal, heritage places are affected by weathering and their design might not be regular;
- One should record from the wide to the small (fault theory);
- Records should be referenced, it is advisable to link and establish a Basis and Control system;
- The site baseline means that the heritage recording is to collect information of 'as-built condition', one should record only what is visible, although assumptions deduced from "logical" way of fabric should be mentioned;
- Define an appropriate level of detail of the information to be provided;
- All records should provide provenance information.

1.2.3.1 Defining scope: levels of detail

The following levels, developed by Letellier0 are presented here to provide an essential guide to define the amount of heritage information required for a specific objective in understanding heritage places. Each training course to be developed should specify, which of these levels are been taught. The levels are:

- Reconnaissance;
- Preliminary;
- Detailed.

1.2.3.2 The Reconnaissance Record

Usually, the reconnaissance record is an overview photo survey that will allow conservationists to visualize, in their entirety, a site and its related buildings and features in sufficient detail to understand the site's overall general characteristics. It should permit rapid identification of significant features and problem areas. The quantity of photos taken will vary with the size of the site and related structures and features, and the client's requirements. For a building, a reconnaissance record would normally include elevations together with significant details. More complex sites such as cultural landscapes or archaeological excavations will require general views from all compass points and at various height elevations (that is heights of land), supplemented, as needs dictate, by representative details.

1.2.3.3 The Preliminary Record

Preliminary recording will complement the reconnaissance record by providing more complete information pertaining to the most significant elements of a site. The purpose of this record is to produce a record of the resource's major features. Additionally, the preliminary record could include data necessary for preliminary analysis, and define areas for further investigation and future 'detailed recording'. The accuracy of data is approximately ± 10 cm for plans, elevations, and cross sections, and ± 2 cm for structural and other structural details.

1.2.3.4 The Detailed Record

Detailed recording may take place prior to, during or after a conservation activity so as to record a site's physical configuration, condition and significant features. Detailed recording occurs when a highly significant resource becomes the subject of directed research and analysis, or intervention planning and conceptual design. To ensure cost-effective detailed recording, completeness should be tailored to the immediate needs of a conservation team. Detailed recording may be phased over a number of years depending on planning requirements and related budget. The accuracy of a detailed record can vary between approximately ±5 mm (for details) and ±25 mm (for building plans).

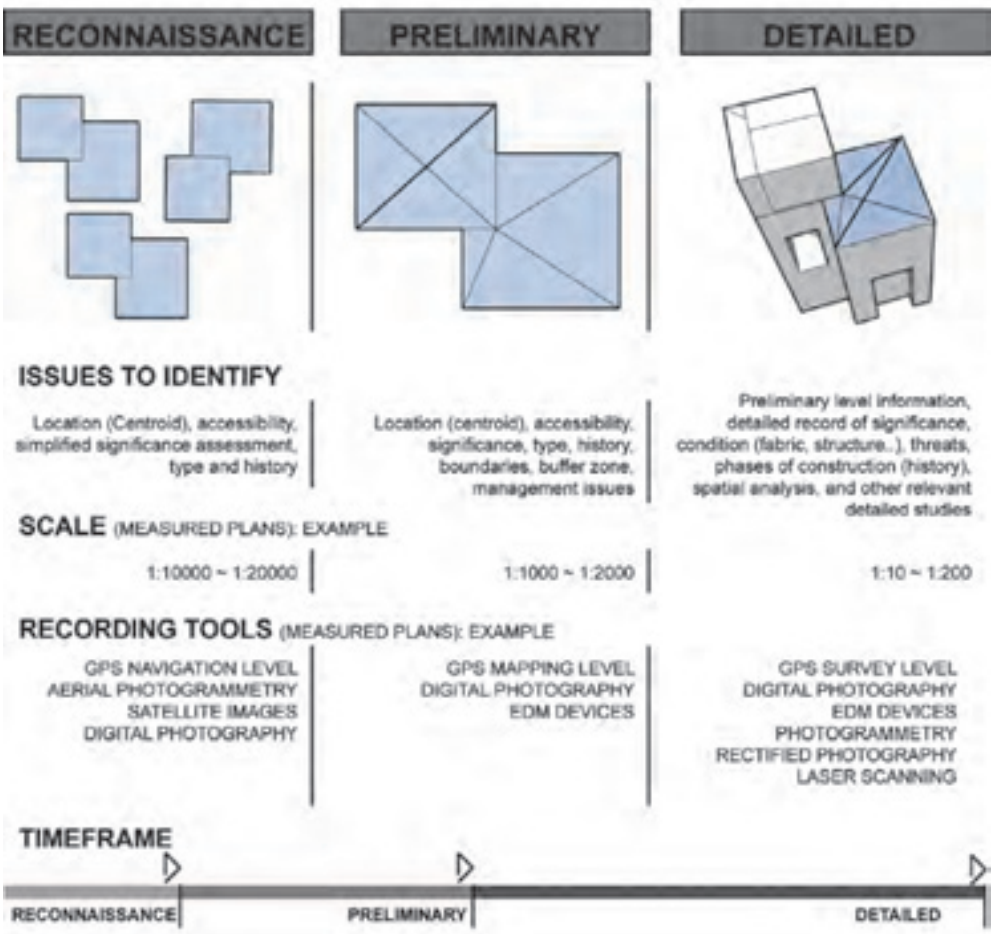


Figure 2: Heritage information's levels of detail for conservation (based on research by R. Letellier).

1.2.4 Tools: level of engaged with a heritage place

The use of tools for recording heritage places can be also classified according to the selection, time, skills and level of engagement required with the fabric to capture data from the site being studied.

Selection: deals with the type of geometry captured by the sensor, for instance using hand-survey we are capturing points, distances, profiles, etc, with laser scanning we are capturing three-dimensional shapes, points, and to some extend the colour of the fabric. Defining the type of information to be selected is of primarily importance when recording heritage places.

Time: relates to the time it takes to record features from the heritage place's fabric, for instance when using hand-survey the time required onsite will be considerably more than the at the office, while using photogrammetry, the onsite time is limited to taking photographs and defining a control system and the office time is larger to restitute the geometry and colour of the fabric.

Level of engagement: this relates to the time of control system necessary to be defined and the knowledge required of the site prior to record the heritage place. For instance with a GPS unit, the operator requires to select the points to define the boundaries of the site, while when using laser scanning, the 3D-shape of the object is fully recorded, although it is important to point out that knowledge of the site is always required, see reconnaissance as the first level of detail required when studying heritage places.

Skills: it relates to the expertise required to operate a capturing tool to record the fabric of heritage places. For instance to record the centroid of a site using GPS and transfer that to a database, is a simple task that does not required much training, while if using a GPS equipped with a mobile GIS application might required much more training but certainly the resulting survey will be more complete.

In addition, to the requirements defined to prepare a site baseline, these parameters should be fully studied when considering recording heritage places.

1.2.5 Documentation dossier or site atlas

The training approach should encourage to work around several case studies, in which the participants will prepare dossier that should contain an initial understanding of the building's current condition, history and baseline measured maps, several examples of theses dossiers exist already:

English Heritage 'Understanding Historic Buildings: A guide to good recording practice' (2006):

Part 1:
http://www.english-heritage.org.uk/upload/pdf/Understanding_Historic_Buildings_1.pdf
Part 2:
http://www.english-heritage.org.uk/upload/pdf/Understanding_Historic_Buildings_2.pdf
Part 3:
http://www.english-heritage.org.uk/upload/pdf/Understanding_Historic_Buildings_3.pdf

Guidelines for Local Surveys: A Basis for Preservation Planning bulletin (28 MB)
http://www.cr.nps.gov/nr/publications/bulletins/nrb24/nrb24.pdf (last visited 2/2/2007)

The Secretary of the Interior's Standards and Guidelines for Archaeology and Historic Preservation
http://www.nps.gov/history/local-law/arch_stnds_0.htm

The Secretary of the Interior's Standards and Guidelines for Preservation Planning
http://www.cr.nps.gov/hps/pad/PlngStds/guideintro.htm (last visited: 2/2/07)

The Secretary of the Interior's Standards for Architectural and Engineering Documentation
http://www.nps.gov/history/local-law/arch_stnds_6.htm

NPS-28: Cultural Resource Management Guideline
Chapter 8: Management of Historic and Prehistoric Structures
This chapter specifies contents of Historic Structure Reports
http://www.nps.gov/history/history/online_books/nps28/28chap8.htm

HABS/HAER Documentation Programs:
http://www.nps.gov/history/hdp/standards/habsguidelines.htm

Sample Projects:
http://www.nps.gov/hdp/samples/index.htm

References

D'Ayala, D. and Smars, P. 2003. Minimum requirement for metric use of non-metric photographic documentation, University of Bath Report. See http://www.english-heritage.org.uk/server/show/conWebDoc.4274.

Demas, M. 'Site unseen': the case for reburial of archaeological sites', Conservation and Management of Archaeological Sites (2004), Vol. 6, pages 137-154.

Eppich, E. Chabbi, A. ed. Illustrated Examples Recording, Documentation, and Information Management for the Conservation of Heritage Places, The Getty Conservation Institute, 2007 J. Paul Getty Trust.

ICOMOS 'Principles for the Recording of Monuments, Groups of Buildings and Sites' http://www.international.icomos.org/recording.htm (accessed: 15/11/2008).

ICOMOS 'Venice Charter', http://www.icomos.org/venice_charter.html (accessed: 15/11/2008).

Letellier, R. Schmid, W. LeBlanc, F. Guiding Principles Recording, Documentation, and Information Management for the Conservation of Heritage Places, Getty Conservation Institute, 2007 J. Paul Getty Trust.

Parks Canada Periodic Report on the Application of the World Heritage Convention http://www.pc.gc.ca/docs/pm-wh/rspm-whsr/sec3/sec3c_e.asp (Last reviewed 19/06/2008).

Patias, P. 2004, Overview of applications of close-range Photogrammetry and Vision techniques in Architecture and Archaeology, C. McGlone (ed), Manual of Photogrammetry, 5th edition, ISBN 1-57083-071-1, American Society of Photogrammetry Publ., Maryland, USA, chapter 14.5, pp 1044-1050.

Patias, P. 2007, "Cultural Heritage Documentation", Chapter 9 in "Applications of 3D measurement from images", J. Fryer, H. Mitchell, J. Chandler, editors, pp. 225-250, Whittle Publishing Co., ISBN 10: 1-870325-69-9, ISBN 13: 978-1-870325-69-1.

Patias, P., P. Grussenmeyer, K. Hanke, 2008, "Applications in cultural heritage documentation", in ISPRS Book series, Vol. 7, "Advances in Photogrammetry, Remote Sensing and Spatial Information Sciences; 2008 ISPRS Congress Book", Zhilin Li; Jun Chen; Emmanuel Baltsavias (Edts), Chapter 27, pp. 363-384, CRC Press, Taylor & Francis Group, ISBN: 978-0-415-47805-2 (hbk), ISBN: 978-0-203-88844-5 (ebook).

RecorDIM initiative, http://www.getty.edu/conservation/field_projects/recordim/index.html, http://www.getty.edu/conservation/publications/pdf_publications/recordim.html and http://cipa.icomos.org/index.php?id=395 (accessed: 15/11/2008).

Santana Quintero, M., The Use of Three-dimensional Documentation and Dissemination Techniques in Studying Built Heritage, R. Lemaire International Centre for Conservation (KU Leuven), Leuven, 2003.

UNESCO's World Heritage Convention, http://whc.unesco.org/en/conventiontext/ (accessed: 15/11/2008).

2 Best Practices and Applications (2007)

2.1 Introduction

The following six papers are presented as "Best Practises and Applications" in the next pages. The selection is based on the papers presented to the CIPA Symposium in Athens (2007).

1. Filling lacunas in terrestrial laser canning data:
   the "Cavallo ligneo" of the "Palazzo della Ragione" (Padua, Italy)
   (M. Fabris, V. Achilli, D. Bragagnolo, A. Menin, G. Salemi)
2. The multi-image spherical panoramasas a tool for architectural survey
   (Gabriele Fangi)
3. Architectural patrimony management in Yemen
   (R. Héno, Y. Egels)
4. 3D modelling of heritage objectsby fringe projectionand laser scanning systems
   (H.-J. Przybilla, J. Peipe)
5. Evaluation of structural damages from 3d laser scans
   (J.I. San José, J. Martínez, J.J. Fernández, J. Finat, J.D. Perez-Moneo)
6. Simple Tools for Architectural Photogrammetry
   (V. Tsioukas)

Filling lacunas in terrestrial laser canning data: the "Cavallo ligneo" of the "Palazzo della Ragione" (Padua, Italy)

M. Fabris, V. Achilli, D. Bragagnolo, A. Menin, G. Salemi

Università degli Studi di Padova, Dipartimento di Architettura, Urbanistica e Rilevamento, Laboratorio di Rilevamento e Geomatica, via Marzolo, 9, 35131 Padova, Italy, massimo.fabris@unipd.it

ABSTRACT

Laser scanning methodology allows to reconstruct the metric characteristics of objects at different LOD (Level Of Detail) providing spatially dense points clouds. In particular, the terrestrial applications carried out in the last years have demonstrated the potentialities of the methodology useful in many different sectors. This technique has been used also for the "Cavallo ligneo" of the "Palazzo della Ragione" (Padua, Italy) survey, providing useful data for the restoration of the wooden horse. Due to the morphologic complexity of the object, some lacunas were created during the points clouds acquisition phase: different procedures to filling lacunas were stressed out providing a complete 3D model of the wooden statue.

Introduction

Terrestrial laser scanner devices represent one of the most widely investigated instruments in many fields of architectural and archaeological surveying applications. In order to allow photo-realistic navigation and presentation of cultural heritage objects, 3D models with good geometric accuracy, large amount of details, different LOD (Level Of Detail) and high resolution textures are required (Boehler et al., 2001; Boehler et al., 2003; Schulz, Ingensand, 2004; Staiger, 2005). Since several years, laser scanning techniques are used for different purposes also in the framework of cultural heritage (Bitelli, 2002; Lichti, Gordon, 2004). Terrestrial laser data acquisition allows to collect a very huge amount of measurements with an accuracy in the range of centimetres or even millimetres, which produces dense, accurate and detailed models. On the other hand, for specific geometric conditions of survey or for the objects interposition during the acquisition, the point clouds could be not homogeneous and could have sub-areas with absence of data (holes or lacunas). In these cases, some interpolation algorithms can be applied to reconstruct the no-data areas and to define a more uniform support grid.

In this paper, the surveying operations related to data collection and data analysis of the "Cavallo ligneo" of "Palazzo della Ragione" in Padua (Italy) are described and discussed in order to generate a 3D complete model of the wooden horse for its restoration.

The Wooden Horse Surveying

Documents which have been preserved to the present day tell us that it was built in 1466 for a roundabout, commissioned by Conte Annibale Capodilista. It was erroneously attributed to Donatello, as the inscription on the base shows, but was in fact the work of an unknown artist. The construction is hollow inside and built like the hull of a ship, resting on the four sturdy legs which were made using a technique similar to today's segmented beams; i.e. the wooden boards are glued together on the long side to exploit the tractive force of the wood in full and minimise the warping typical of solid wood as much as possible (Fischer, 2004). The wooden horse is characterized by relevant dimension: 5.75 m height and 6.20 m circumference of the body *(Figure 1)*.

The object has been planned in order to go inside and to park in quite comfortably: a trap-door allows the access inside to the body of the horse, while from the mouth air and light enter.

The hinge of equilibrium for this complex structure seems to be the cast iron sphere with a radius of about 27 cm and weight of about 615 kg. This sphere is the principal point of anchorage of the horse to the wood basement (along about 6.42 m). In 2004 the structure seemed very degrated and a complete survey was necessary to plan and to perform restoration operations for the wood statue.

Figure 1: The "Cavallo ligneo" of the "Palazzo della Ragione" (Padua, Italy).

The surveys were performed by means of a Leica HDS (ex Cyrax) 2500 laser scanner which provides an accuracy of 6 mm (single point) for distance ranging from 1.5 to 50 m. The single scans were acquired from eight different stationing points (located in the four corners and in the medium points of the four sides) with a mean grid size of 1 cm. Also specific reflective targets (useful for the semi-automatic identification) were acquired and used as control points; the coordinates were measured in a local reference frame by a total station Leica TC2003. The targets (5 for each scan) were positioned outside the wooden horse surface but inside the window acquisition of the laser scanner to survey the whole object without artificial element which covers some portions.

Data Processing

The allignment of the point clouds were performed using the Cyclone v. 5.4 software (Leica Geosystems) to generate the 3D global model. The software allows to co-register different scans using three different procedures: cloud registration, target registration and survey registration. The first one needs a large overlapping percentage between two adjacent different scans in order to roto-traslate the point clouds in the same reference frame. The second one uses the targets as reference points in order to execute the allignment and, again, a large overlapping percentage between scans must be taken in account. In this case lower computational time is necessary and more accuracy is obtained; furthermore, more time is needed in the surveying in order to acquire also high resolution scans of the targets. The last one procedure needs integration between laser data and topographic measurements: each target must be acquired with a total station in order to obtain the coordinates in the same reference system.

So, no relevant overlapping percentage between adjacent scans is needed; nevertheless, minimum overlapping is required in order to guarantee the model continuity. In this approach, the measurement time is increased, but also the final accuracy is scaled up. This survey registration method has been used to align the "Cavallo ligneo" point clouds: each scan was roto-traslated in a local reference frame imposing the targets coordinates as control points. The final 3D model has been processed using RapidForm2004 software (INUS Technology): the data redudancy between subsequent scans has been reduced, performing data fusion and extracting a polygonal mesh without discontinuities. Therefore, the data was reduced of the 64% without information loss. The Figure 2 shows three different meshes obtained by point reduction of 60%, 40% and 10%.

Filling Holes

Due to the limited available space around the object, some portions of the wooden horse statue were not acquired. Some of these areas with data gaps have no relevant dimensions, while others (like the back and the top of the horse) need affordable algorithms to close the lacunas. The reconstruction of these areas is performed using different schemes based on different interpolation algorithms.

Using the Inverse Distance to a Power, Kriging, Radial Basis Function, Local Polynomial (linear), Natural Neighbor, Nearest Neighbor, Polynomial Regression (cubic surface) and Triangulation-linear interpolation algorithms, several tests were conducted on the scans of the lateral portion of the wooden horse. However, the application of this method for reconstructing the back and the top of the horse provides not so good results (Fabris et al., 2005).

Further analysis was conducted with the RapidForm2004 software; the lacunas filling can be performed with automat-

Figure 2: Three different meshes of the "Cavallo ligneo" head obtained reducing the point clouds: (a) 60%; (b) 40%; (c) 10%.

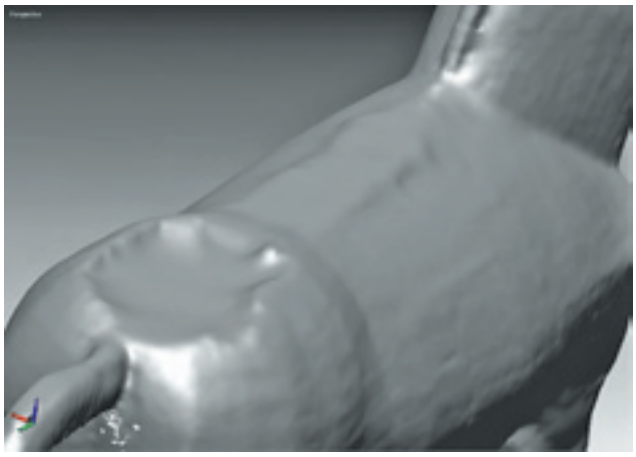


Figure 3: Results from automatic closing of large lacunas using the RapidForm2004 software.

ic, manual or combined procedures. The filling of simple and small dimensions holes were conducted automatically, while for the complex and large lacunas the procedure was performed with the semi-automatic modality. The automatic procedure, applied in correspondence of the back of the wooden horse, carried out unsatisfactory results *(Figure 3)*: the obtained surface is characterized by non adequate continuity with the adjacent surfaces and some topological anomalies are evident.

The semi-automatic procedure allows to close the large lacunas *(Figure 4a)* respecting the topology of the adiacent surfaces. At first, a carrying skeleton has been created *(Figure 4b)*, taking in account the curved closing of the lacuna and, subsequently, the holes with small dimensions have been closed automatically *(Figure 5)*.

Mesh and Nurbs Surfaces Generation

The lacunas filling have provided a global 3D model; the polygonal mesh has been simplified reducing the faces number and preserving the surface shape. In fact, the flat areas not need a large amount of data and allow to construct a lighter model with low computational effort.

Adopting a 10% mesh-reduction, an increased smoothing is observed; moreover, the comparison between the decimated mesh and the original mesh provides residuals lower of the instrumental precision. This mesh has been used to extract nurbs surfaces. The operation is needed because the mesh modification is a slow and laborious procedure which involves also thousands of triangular faces. Using nurbs surfaces, the procedure is easier dealing with single elements covering the object.

The nurbs surfaces extraction has been performed using an automatic procedure from the polygonal mesh; subsequently, the number and the control points' distribution have been adjusted *(Figure 6)*.

Cross Sections and Profiles Extraction

The polygonal mesh has been used to extract cross sections by means of the intersection between the 3D model with horizontal or vertical planes in the local reference system adopted (Figure 7). Moreover, the same approach allows to generate profiles, pro-

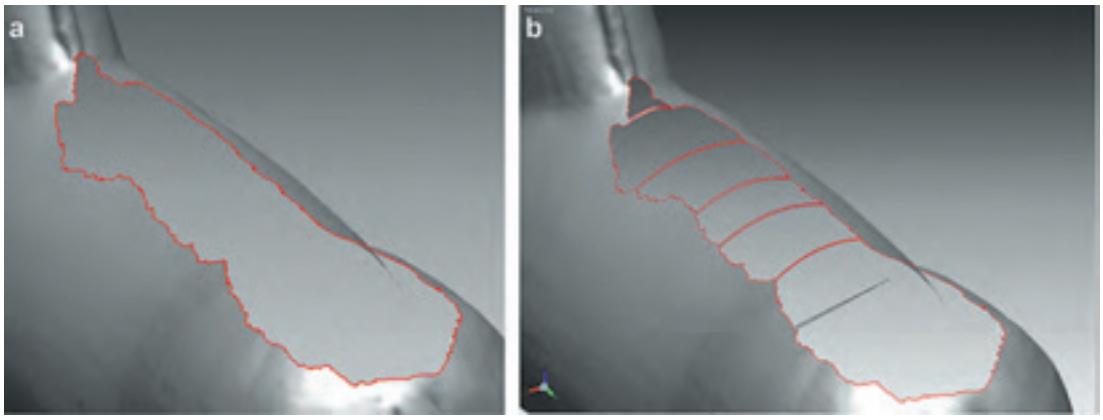


Figure 4: The big lacuna (a) on the back of the wooden horse was artificially subdivided in smaller lacunas (b) using a transversal skeleton structure.

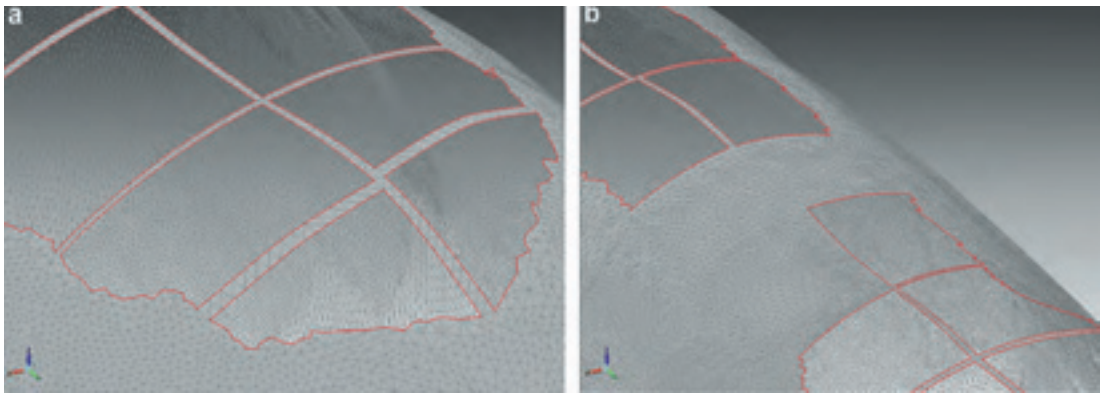


Figure 5: a) Construction of the longitudinal carrying skeleton; b) automatic reconstruction of the new lacunas (small dimension).

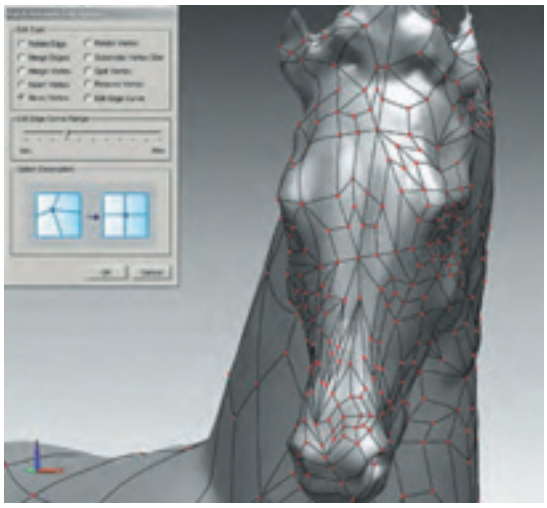


Figure 6: Control points management for Nurbs surfaces.

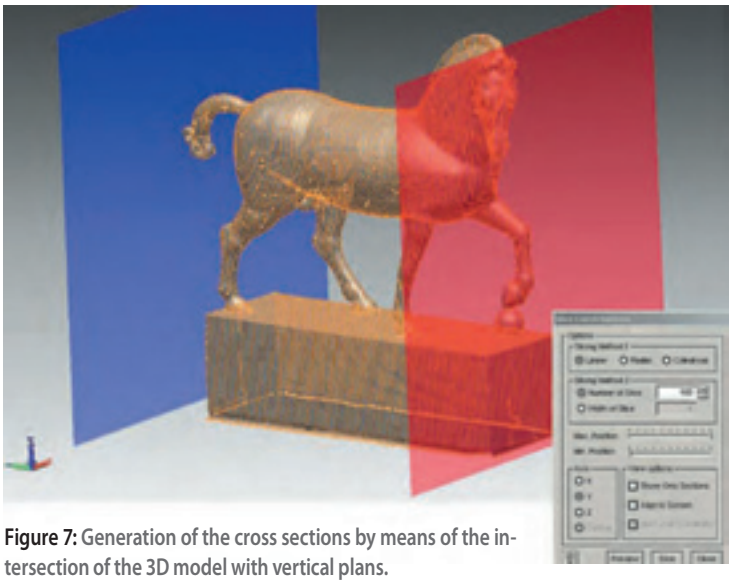


Figure 7: Generation of the cross sections by means of the intersection of the 3D model with vertical plans.

jecting the contours of the wooden horse respect to a reference plane. The cross sections and profiles allow to reconstruct the metric and the features of the wooden horse in AutoCAD software (Autodesk) for the restoration plan of this structure.

Conclusions

The application of the laser scanning methodology and its integration with the classical topographic procedures has allowed to generate a 3D model of the "Cavallo ligneo" of the "Palazzo della Ragione" in Padua; the wooden horse, built in 1466, characterized by relevant dimensions and morphological complexity, has a very degraded wood and restoration work has been planned. The laser scanner HDS 2500 have been used and the specific reflective targets were acquired in a local reference system and used as control points. Due to the limited available space around the object, some lacunas (no data areas) were located; the allignment has been obtained using the Cyclone software and the performances of some interpolation algorithms have been evaluated. Some of these methods have allowed to filling lacunas with precision comparable with the laser scanner accuracy (the improvement was obtained considering some points of the surveyed data inside the lacuna). However, the application of the kriging algorithm to reconstruct the back and the top of the horse in this case has not provided good results. These methods can be used with small lacunas, taking advantage by the automatic procedures. Using the RapidForm2004 software the lacuna on the back of the wooden horse was filled by means of a semi-automatic procedure: at first, has been create by the operator an carrying skeleton in respect to the curving and subsequently the holes have been filled automatically. On the final 3D model a decimated polygonal mesh has been generated preserving the laser scanner accuracy; subsequently nurbs surfaces, profiles and cross sections have been extracted to work as input data for further analysis in AutoCAD environment for the restoration of the wooden horse.

References

G. Bitelli, 2002. Moderne tecniche e strumentazioni per il rilievo dei beni culturali. Atti della 6a Conferenza Nazionale ASITA, 1, pp. IX-XXIV.

W. Boehler, M. Bordas Vicent, A. Marbs, 2003. Investigating laser scanner accuracy. Proceedings of the XIXth CIPA Symposium at Antalya, Turkey, 30 september – 4 october, 2003.

http://www.group.slac.stanford.edu/met/Align/Laser_Scanner/laser-scanner_accuracy.pdf (accessed 13 Mar. 2007).

W. Boehler, G. Heinz, A. Marbs, 2001. The potential of non-contact close range laser scanners for cultural heritage recording. Proceedings of the CIPA Symposium at Potsdam University, Germany, 18 – 21 september 2001.

http://cipa.icomos.org/fileadmin/papers/potsdam/2001-11-wb01.pdf (accessed 2 Mar. 2007).

M. Fabris, V. Achilli, D. Bragagnolo, A. Menin, G. Salemi, 2005. Interpolazione di nuvole di punti ad alta risoluzione da rilievi laser scanner: applicazione a beni culturali ed architettonici. Atti della 9° Conferenza Nazionale ASITA, 2, pp. 1037-1044.

Fischer, 2004. Il Cavallo ligneo. Palazzo della Ragione.

D. Lichti, J. Gordon, 2004. Error Propagation in Directly Georeferenced Terrestrial Laser Scanner Point Clouds for Cultural Heritage Recording. Proceedings of FIG Working Week 2004, Athens, Greece, May 22-27, 2004.

http://www.fig.net/pub/athens/papers/wsa2/WSA2_6_Lichti_Gordon.pdf (accessed 26 Apr. 2007).

T. Schulz, H. Ingensand, 2004. Influencing Variables, Precision and Accuracy of Terrestrial Laser Scanners. Proceedings of INGEO 2004 and FIG Regional Central and Eastern European Conference on Engineering Surveying, Bratislava, Slovakia, November 11-13, 2004.

http://www.group.slac.stanford.edu/met/Align/Laser_Scanner/SchulzT_TS2_Bratislava_2004.pdf (accessed 13 Mar. 2007).

R. Staiger, 2005. The Geometrical Quality of Terrestrial Laser Scanner (TLS). Proceedings of Pharaohs to Geoinformatics FIG Working Week 2005 and GSDI-8 Cairo, Egypt, April 16-21, 2005. http://www.fig.net/pub/cairo/abstracts/ts_38/ts38_05_staiger_abs.pdf (accessed 2 Mar. 2007).

The multi-image spherical panoramas as a tool for architectural survey

Gabriele Fangi

Polytechnical University of Marche, Ancona, Italy, g.fangi@univpm.it

ABSTRACT

The surveys of the interior of two churches in Italy, the Magdalene's church in Pesaro, and San Dominic church in Arezzo, are shown and described as examples of a new photogrammetric technique. The first church is one of the most noticeable baroque architecture in the Marche region and it has been designed by the famous architect Luigi Vanvitelli in 18th century, the second one is a large and simple church in Arezzo. The proposed technique is based on the multi-image spherical panoramas. For the formation of the plane image of the spherical panoramas the commercial software has been used. The spherical panorama can be regarded as the analogical recording of the angular observations of a theodolite having its center in the center of panorama. But to be set in operational conditions as a theodolite, the spherical panorama has to recover two rotation angles to set the verticality of its principal axis. The estimation of such rotation angles can be performed both in a preliminary phase prior to the plotting or in a unique phase in a block adjustment. Control points, control directions, geometric constraints such as verticality and horizontality of space lines, can be used. In these study-cases almost no one of such control information was necessary, but the only block adjustment was sufficient. The block adjustment finally furnishes the estimation of the unknown points coordinates together with the six orientation parameters per panorama, three translations and three rotations, by means of the known geodetic equations of the horizontal direction and the zenith angle, (modified to take into account the two horizontal correction angles), that are nothing else than the collinearity equations of the spherical panoramas. The technique of the spherical panoramas has previously been experimented and used for the survey of two of the most noticeable Italian squares, Piazza del Popolo in Ascoli Piceno and Piazza del Campo in Siena. By that time, to be able to use the panoramas, besides the angular corrections, further polynomial corrections were necessary, gotten from a dense network of control points (100-200), (Fangi, 2006). In the case under examination not only such corrections were not needed but also no control point was used. The procedure improvement can be explained with the shorter distances, with the good improvement of the Stitching software, (that thanks also to the ceiling texture, produced better panoramas), and finally with the improvement of the adjustment algorithms, via the block adjustment. The image distortion is automatically corrected by the software itself in the rendering phase, by merging the overlapping image frames. The interior orientation is skipped. For the time being, the final plotting accuracy is limited by the quality of the panoramas and by the resolution of the spherical images. In the shown examples the width was 10.000 and 15.000 pixels for all the panoramas, corresponding to an angular accuracy of 0.04-0.03 g, therefore very scarce. The 3d plotting was performed with monoscopic multi-image observations. In the first example the block adjustment supplied, besides the orientation parameters, the coordinates of about 600 points, observed in at least three panoramas. The achieved accuracy is in the order of few the centimetres say $\sigma x = \sigma y = \pm 0.02$ m and $\sigma z = \pm 0.03$m. The advantage of the spherical panorama in comparison to classical photogrammetry consists in the greater completeness of the information due to its 360° amplitude, giving a synoptic view of the whole environment. A single panorama can replace many image frames; a couple of panoramas can substitute many photogrammetric models. The spherical panoramas are very simple, fast and easy to realize, they are very economic, and they are a very useful and powerful tool for the documentation and survey of the cultural heritage.

***Key words**: Multi-image spherical panoramas, simulation, adjustment, simple systems.*

Introduction

Till now the only metric applications of images panning to 360°, were mainly those gotten with high resolution rotating cameras (5, Luhmann, Tecklenburg, 2004, 6, 7, Schneider, Maas, 2004). The technique here proposed uses on the con-

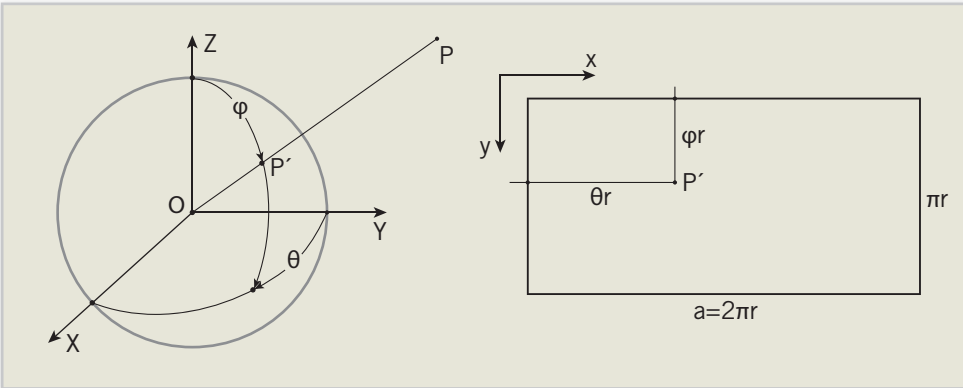


Figure 1. The latitude-longitude projection. Relationship between spherical coordinates and the image coordinate of a spherical image.

trary panoramas realized with images taken with normal digital cameras and then mosaicate with common commercial software. The projection sphere of the images is mapped in the cartographic plane with the so-called longitude-latitude representation from which the angular directions can be drawn that one would measure with a theodolite whose center coincides with the center of the sphere. The greatest difference consists in the fact that while the theodolite is set with its principal axis vertical, in the case of the sphere it is not possible to sufficiently make vertical the principal axis. One must estimate and apply two correction angles around the two horizontal axes (as it is done by a biaxial compensator in the theodolite). After the correction, the restitution of the object takes place with the normal topographical methods as intersection and resection. The parameters of orientation of a panorama are six, the three coordinates of the center and three angles, of which one, around the z axis, is the zero bearing, common to all the angular theodolite stations. Among the center of projection, the image point and the object point the collinearity equations are written, which are nothing but the traditional equations to the horizontal direction and the zenith angle, corrected to take into account of the missed verticality of the principal axis of the sphere. One can also write the coplanarity equations between two panoramas and estimate the five parameters of the relative orientation of one panorama to the other one and to proceed therefore to the computation of the model coordinates. In this approach the phase of interior orientation is completely omitted. The pattern of the errors has practically been observed in all the real panoramas as a consequence of the missing axis verticality. The survey with the spherical panoramas has been in fact experimented for the first time for two noticeable Italian squares, Plaza of the People to Ascoli Piceno and Piazza del Campo in Siena (3, Fangi, 2006). In the tests here proposed, realized for the survey of the interior of some churches, almost no control point was needed. The improvement of the technique can be explained with the particular geometry of the objects but above all with the block adjustment of the observations.

The Multi-Image Spherical Panoramas

The theory of the multi-image spherical panorama has been developed by Szelisky in 1994 for the Apple Computers (8, Szelisky, Shum, 1997). The whole extension to 360° around the taking point is covered by photos, all of them having the same center of taking, and partially overlapping. The ray connecting this center with the object point intersects the two adjacent photos in the corresponding image point. Such ray projects the image points on a sphere of arbitrary radius. The sphere is then mapped on the cartographic plane with the so-called latitude - longitude representation *(figure 1)*.

$$x = r \cdot \theta \quad e \quad y = r \cdot \varphi \qquad [1]$$

with the angles expressed in radiant. Such representation is not conform, nor equivalent. The poles of the sphere are represented by two segments of equal length to the circumference of the sphere, and therefore equator and poles have the same length. The height of the map is equal to the development of a meridian. From such representation the angles of direction of the projective line can be drawn. In fact, knowing the extension, the radius of the generating sphere is derived.

$$r = \frac{a}{2\pi} \qquad [2]$$

$$\theta = \frac{x}{r} \quad \varphi = \frac{y}{r} \qquad [3]$$

They are the same that would be measured with a theodolite. Two are the differences: the first one is the achievable precision, in fact maximum width is around the 20.000 pixels, and every pixel corresponds to 0.02 gon, therefore very inferior to the one of a theodolite. The second difference is that in the sphere, contrarily to what happens in the theodolite, the axis cannot be set vertical with sufficient accuracy. It is necessary therefore before derive the angular directions, to estimate and correct two rotation angles around the horizontal axes. Such operation is equivalent to a biaxial compensator of a theodolite. The estimation of such angles can be done with different methods (6, Fangi 2006) such as control directions, control points, geometric constraints such as horizontality and verticality and finally block adjustment.

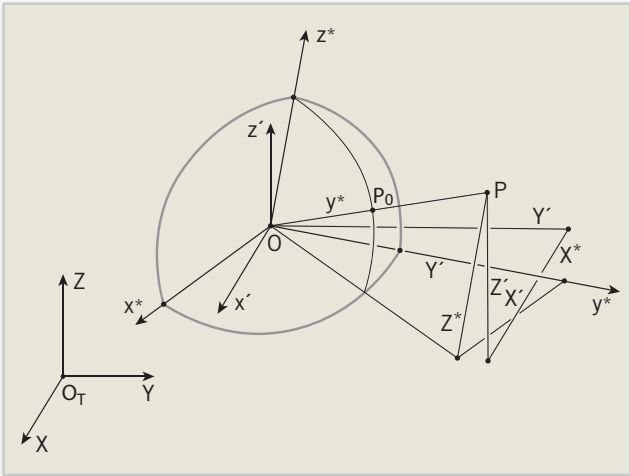


Figure 2. Relationship between object coordinates, spherical coordinates, before and after the correction of verticality.

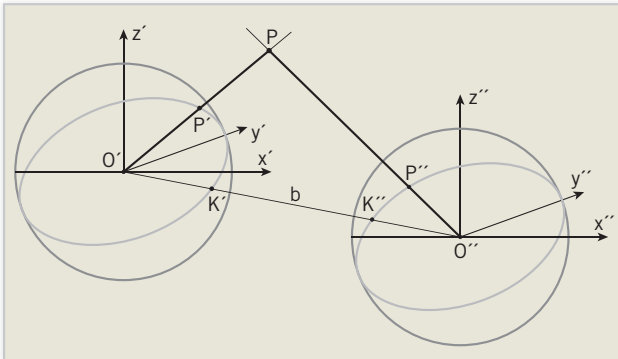


Figure 3. The coplanarity of two spherical panoramas.

The Collinearity Equations or the Corrected Equations of the Horizontal Direction and of the Vertical Angle

The point coordinates

Let's considerer three orthogonal reference systems *(figure 2)*:

a) a local terrain system $[O_T;X,Y,Z]$ with vertical Z axis *("terrain system")*;

b) an auxiliary system $[O;X',Y',Z']$ parallel to the terrain system with vertical Z axis, with origin in the centre $O(X_0,Y_0,Z_0)$ of the sphere, *("sphere system")*;

c) a system $[O;X^*,Y^*,Z^*]$ centred in the centre O of the sphere and oriented parallel to the panorama borders, with Z axis not vertical, from now on called "*panorama system*".

Given an arbitrary object point P(X,Y,Z), it is:

$$\begin{aligned} X' &= X - X_0 \\ Y' &= Y - Y_0 \\ Z' &= Z - Z_0 \end{aligned} \qquad [4]$$

The spherical coordinates of the point P in the panorama system, are *(figure 2)*:

$$\begin{aligned} X^* &= d \cdot \sin\varphi \cdot \sin\theta \\ Y^* &= d \cdot \sin\varphi \cdot \cos\theta \\ Z^* &= d \cdot \cos\varphi \end{aligned} \qquad [5]$$

The angular corrections

The corrected spherical coordinates (X',Y',Z') can be derived from X',Y',Z' of the sphere system, with a rotation matrix where the angular corrections, da_x, da_y around the two horizontal axes, are small enough:

$$\begin{bmatrix} X^* \\ Y^* \\ Z^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & -da_y \\ 0 & 1 & da_x \\ da_y & -da_x & 1 \end{bmatrix} \cdot \begin{bmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{bmatrix} = \begin{bmatrix} d \sin\theta \sin\varphi \\ d \cos\theta \sin\varphi \\ d \cos\varphi \end{bmatrix} \qquad [6]$$

By dividing the first by the second one we get:

$$\theta = \theta_0 + \frac{x}{r} = \operatorname{atg}\frac{X^*}{Y^*} = \operatorname{atg}\frac{r_1(X-X_0) + r_2(Y-Y_0) + r_3(Z-Z_0)}{r_4(X-X_0) + r_5(Y-Y_0) + r_6(Z-Z_0)} =$$

$$= \operatorname{atg}\frac{X' - da_y Z'}{Y' + da_x \cdot Z'} \qquad [7]$$

Where θ_0 is the zero bearing of the origine, R radius, x and y image coordinates of the panorama. As it is known, the zero bearing is the clokwise angle between the northern direction and the direction of the origine of the angles, the left border of the panorama in this case. We derive:

$$x = R \cdot \left(-\theta_0 + \operatorname{atg}\frac{X^*}{Y^*}\right) = R \cdot \left(-\theta_0 + \operatorname{atg}\frac{X' - da_y Z'}{Y' + da_x \cdot Z'}\right) \qquad [8]$$

From the third:

$$\varphi = \operatorname{a\,cos}\frac{Z'}{d} = \operatorname{a\,cos}\frac{r_3(X-X_0) + r_6(Y-Y_0) + r_9(Z-Z_0)}{d} =$$

$$= \operatorname{a\,cos}\frac{-da_y X' + da_x Y' + Z'}{d} \qquad [9]$$

where $d = \sqrt{X'^2 + Y'^2 + Z'^2} = \sqrt{X^{*2} + Y^{*2} + Z^{*2}}$

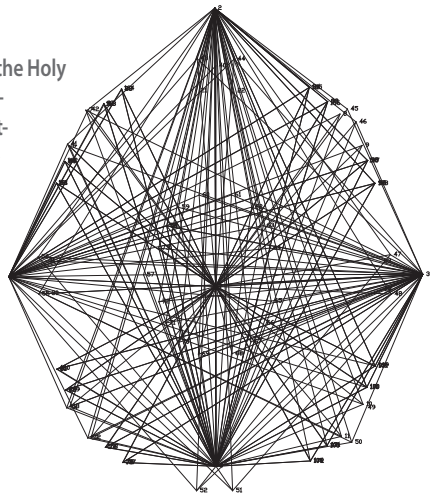
is the distance of the sphere center O from point P, invariant in the two reference systems.

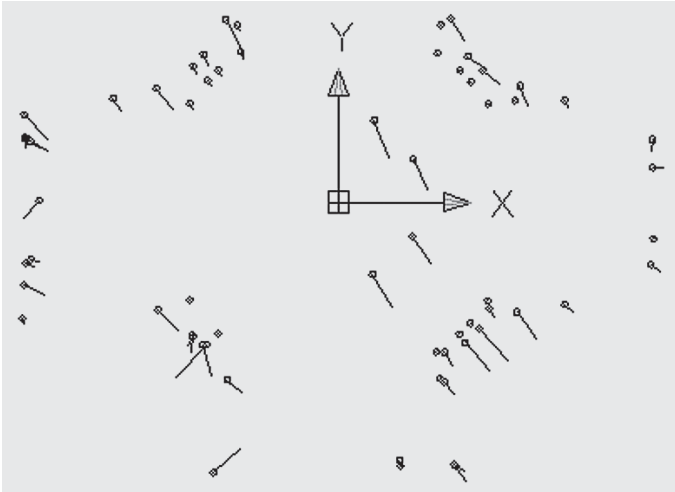
The preceding equations are the equations of collinearity for the spherical panoramas or the correct equations of the horizontal direction and the vertical angle corrected to take into account the missed verticality of the axis of the sphere. They must be linearized near approximate values of the parameters and coordinates and then adjusted in block, according to a surveying technique already set-up (2, Fangi, 2004). The restitution takes places by means of the eqns. [7] and [9]. The approximated values are supplied by a classical procedure where the initial values of the correction angles are set to zero, or by means of the relative orientation described in 4.

Figure 4. The central panorama of the Church of the Holy Magdalene in Pesaro, with the errors amplified 10 times.

Figure 5. Church of the Holy Magdalene, Pesaro - The observation network done from the five panoramas (left).

Figure 6. Distribution of the error vectors amplified 10 times. It is evident a systematic effect (right).





The Coplanarity Condition

The two corresponding image points P′(x′,y′,z′) and P″(x″,y″,z″) of the arbitrary object point P on the two spheres lay on the same epipolar plane O′PO″ and their coordinates satisfy the coplanarity condition:

$$g = x'^{T} R'^{T} b R'' x'' = 0 \qquad [10]$$

$$\begin{bmatrix} x' & y' & z' \end{bmatrix} R'^{T} \begin{bmatrix} 0 & -bz & by \\ bz & 0 & -bx \\ -by & bx & 0 \end{bmatrix} R'' \begin{bmatrix} x'' \\ y'' \\ z'' \end{bmatrix} = 0 \qquad [11]$$

where R′ and R″ are the rotation matrix of the two bundles, bx, by, bz, the components of the base b. Eqn. [10] is linearized and divided by the value of the two radii:

$$\begin{bmatrix} (\sin\varphi' \cdot \sin\theta') & (\sin\varphi' \cdot \cos\theta') & \cos f' \end{bmatrix} \begin{bmatrix} 1 & -\delta a'_z & -\delta a'_y \\ \delta a'_z & 1 & -\delta a'_x \\ -\delta a'_y & \delta a'_x & 1 \end{bmatrix} \cdot$$

$$\begin{bmatrix} 0 & -bz & by \\ bz & 0 & -bx \\ -by & bx & 0 \end{bmatrix} \cdot \begin{bmatrix} 1 & \delta a''_z & -\delta a''_y \\ -\delta a''_z & 1 & \delta a''_x \\ \delta a''_y & -\delta a''_x & 1 \end{bmatrix} \cdot \begin{bmatrix} (\sin\varphi'' \cdot \sin\theta'') \\ (\sin\varphi'' \cdot \cos\theta'') \\ \cos\varphi'' \end{bmatrix} = 0 \qquad [12]$$

The procedure is similar to the one set up for the theodolite stations that was called "blind traverse" (Fangi, 1,1998), with the sole difference that the unknown parameters increase from four to six and that the relative orientation is performed with five independent parameters among the 8 possible, as in traditional photogrammetry. The solution of [12] brings to the relative orientation of one bundle with respect to the other one. The relative orientation is useful to link stations not having reciprocal observations and therefore to supply the approximated values of the unknown coordinates to input in [7] and [9] for the block adjustment. Note that no control information neither interior orientation is needed.

The Church of the Holy Magdalene in Pesaro

Our first tests on the metric use of the spherical panoramas date from 2005. The experiments have been done in the campus of the faculty of Engineering in Ancona, in Piazza del Popolo in Ascoli Piceno, in Piazza del Campo in Siena. The results have not been satisfactory entirely (3, Fangi, 2006). The church of the Magdalene is in Pesaro has been designed by

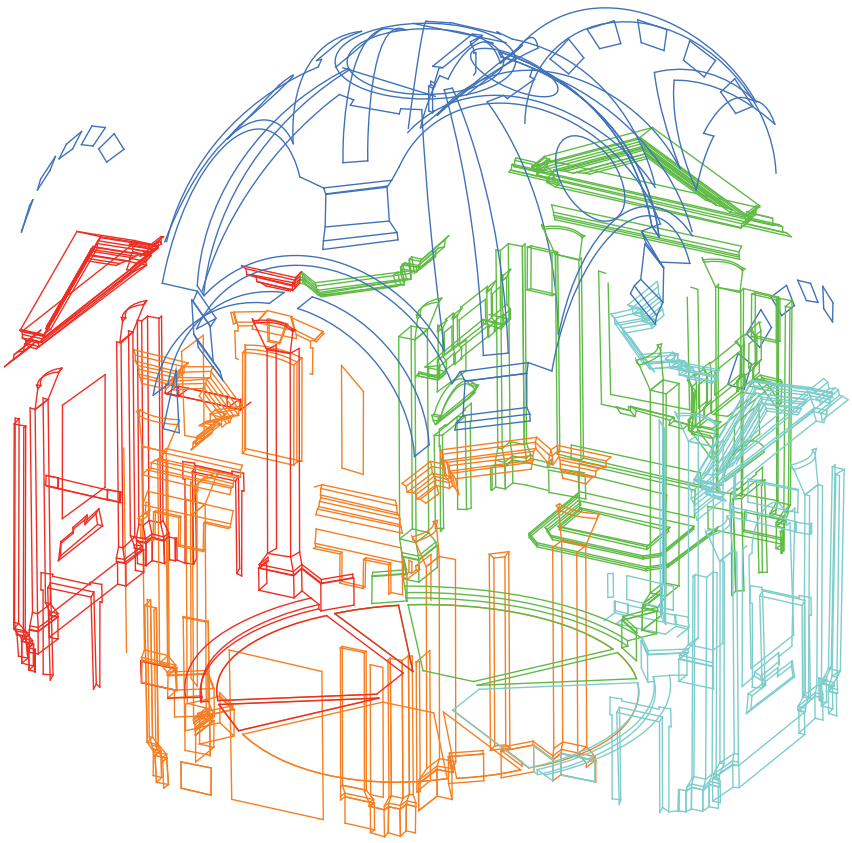


Figure 7. Church of the Holy Magdalene, Pesaro. The wire-frame of the model, axonometry.

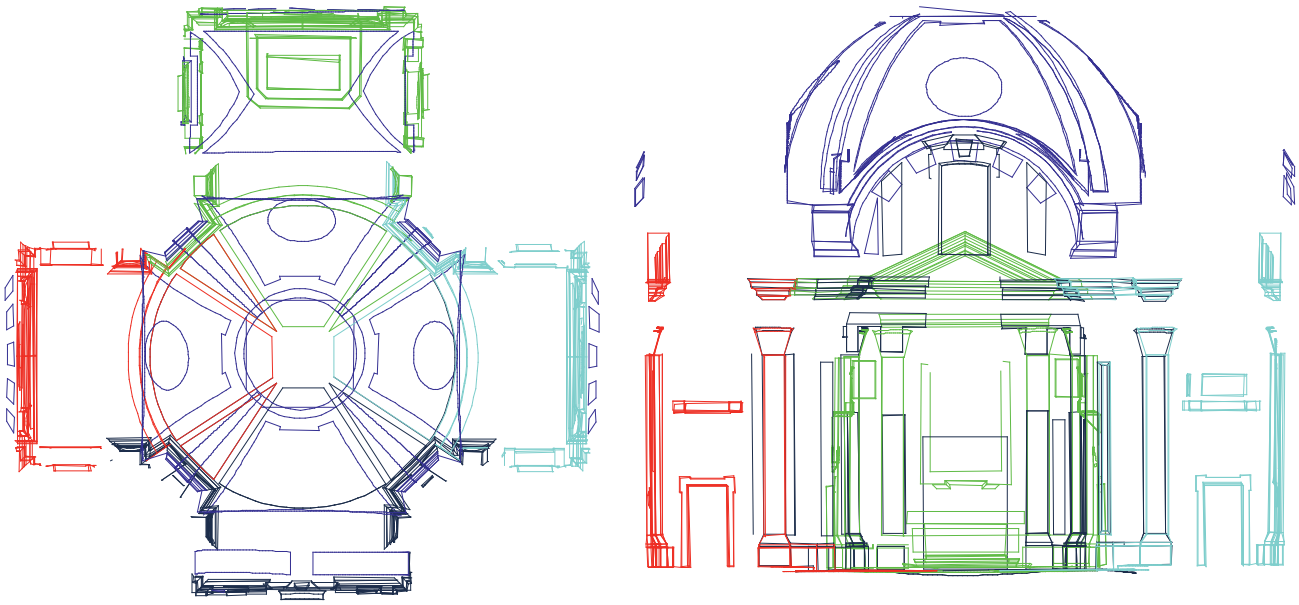


Figure 8. Church of the Magdalene – Plan and lateral view of the wire-frame.

the architect Luigi Vanvitelli and built between 1740 and 1745. It is a Baroque church of medium size *(figures 4, 7 and 8)*. Five panoramas have been taken one in the center and four according to the principal directions of the plan *(figure 5)*. Every panorama is composed by 25 frames taken with Panasonic Lumix TZ10 camera 35mm equivalent focal length, 5Mb. The software used for the formation of the panorama is Stitcher 5 Realviz, the width of every panorama is 10.000 pixels. With a theodolite the position of the five centers of the panoramas has been established. A block adjustment of the observations has been done, fixing the coordinates of three station points only, and the results are the following:

Magdalene Project, Pesaro September 2006	
Number of observations =	4640
Number of unknowns =	1764
Redundancy =	2876
Number of unknown points	583
sigma zero =.0018754 rad = 0.1194g = 3 pixel.	
Average of sd of the adjusted points sqmx = .029m, sqmy = .032m, sqmz = .043m	

After the restitution, 64 check points, taken with the reflectorless total station, have been compared with those taken with the photogrammetry, table 2.

In figures 4 and 6 the effects of a systematism are evident; therefore even if the average value of the module for the errors is 6 cms, when the systematic error is eliminated, a consistent reduction of such value will result. In the table 2 are shown the values of the correction angles. Note that their standard deviations are of one order inferior.

The Church of St. Dominic in Arezzo

Church of rectangular plan with narrow high gothic windows was built at the end of the 1200; it guards in the altar the famous painted Crucifix of Cimabue (XIII sec.). The inside, with one nave only with beamed ceiling, is decorated with frescos of the 13th and 14th centuries *(figure 9)*. On the right wall the Gothic chapel Dragondelli stands. Two panoramas with Lumix Panasonic FZ50 camera, 35 mm equivalent focal length, 10Mb, were taken by the A. only for tourist purposes. The panorama formation is by Autopano Pro, the width of every panorama is 15.000 pixels. Since no one measure nor control point were available, the plotting was carried out with the procedure of the relative orientation, described in 4, where an arbitrary value of 100 was given to the base. As can be seen, the building frame is oriented according to the relative symmetric system and it is not levelled. It was not possible to plot the abse, for the bad quality of the intersection and for the lack of photographic coverage. Obviously it is not possible to give some qualitative parameter of the restitution. The geometric congruence can serve as sole verification.

Table 1: *Average of RMS errors on check points (in m).*

Only 3 fixed Stations Points (64 check points)	3 SP+ 3 Control Points (58 check points)	Test 3 SP+ 10 CP (51 check points)
sx = 0.0234, sy = -0.0333, sz = 0.0044 mean module = 0.0639	sx = 0.0190, sy =-0.0197, sz =0.0081 mean module = 0.0470	sx = 0.0203, sy = -0.0246, sz=0.0065 mean module = 0.0537

Table 2: *Values of the correction angles and their standard deviations (gon).*

panorama	1	2	3	4	5
Alfax	-0.5323 ±0.0148	-0.2807 ±0.0104	0.1954±0.0096	-0.24620 ±0.0111	0.0560 ±0.0097
alfay	-0.3198±0.0148	-0.3877±0.0104	0.0332±0.0096	-0.42673±0.0111	-0.4414 ±0.0097

Figure 9. Church of St. Dominic, Arezzo, one of the two spherical panoramas utilized for the plotting.

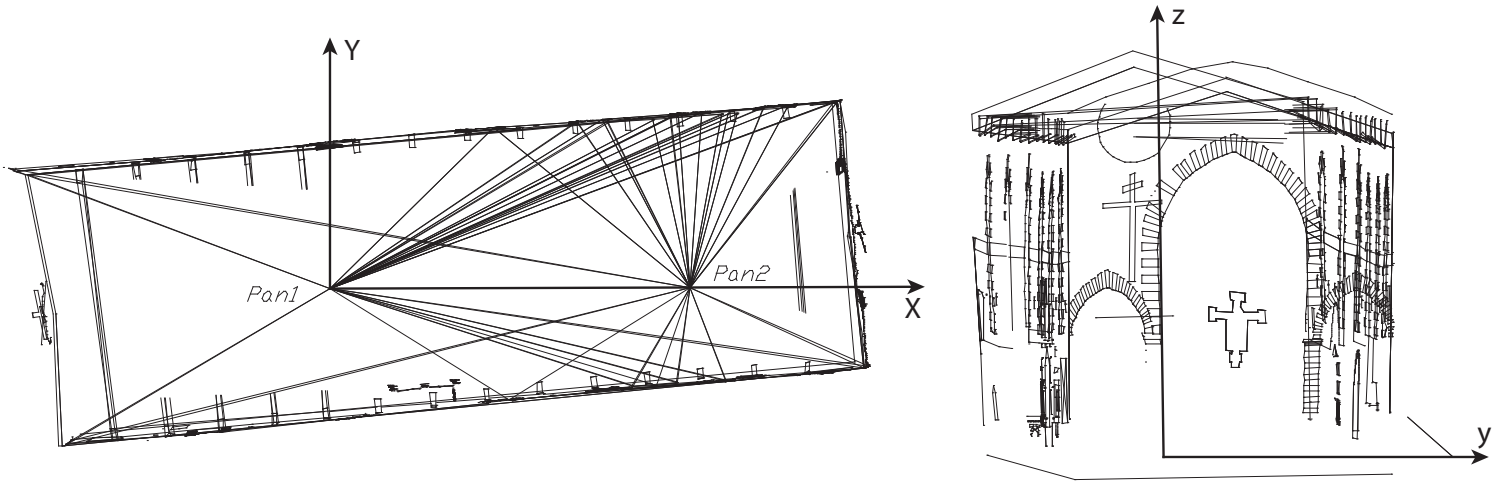


Figure 10. The network of observations of St. Dominic for the relative orientation, with the two panoramas Pan1s and Pan2 and the relative system.

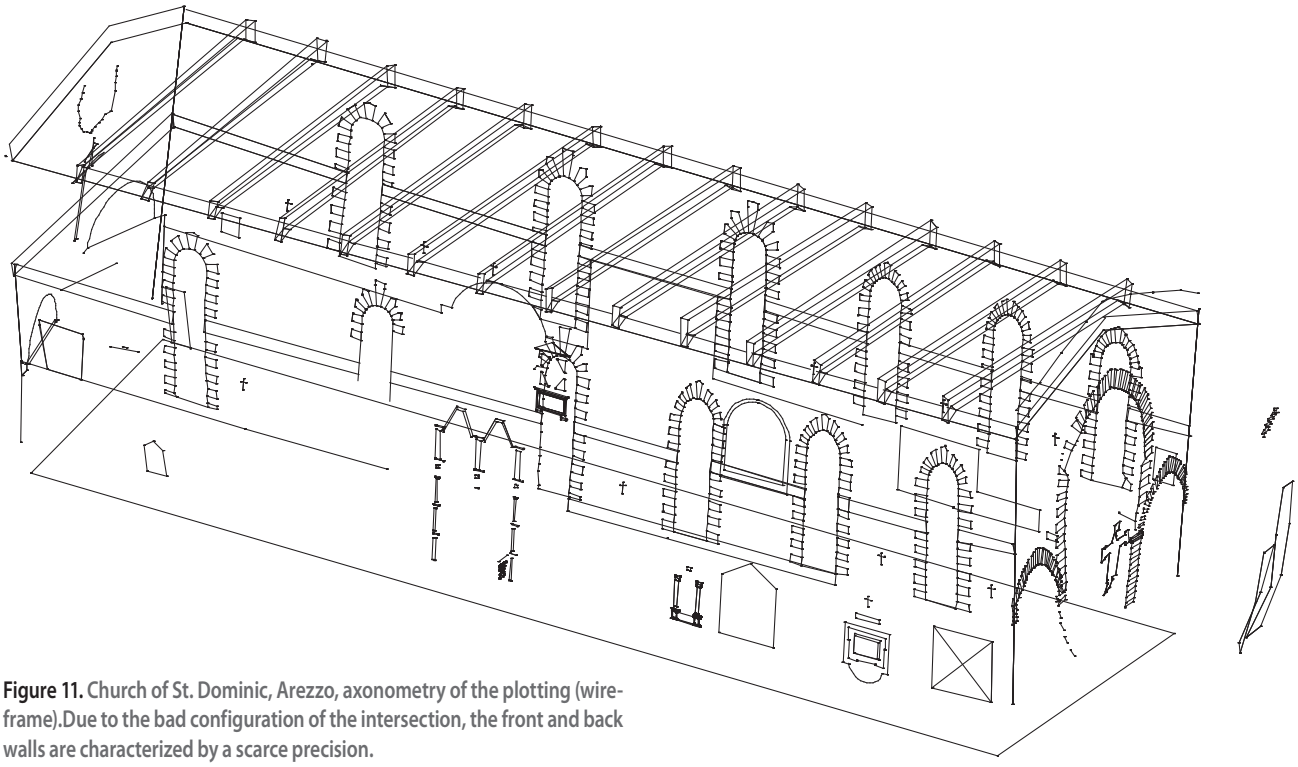


Figure 11. Church of St. Dominic, Arezzo, axonometry of the plotting (wire-frame).Due to the bad configuration of the intersection, the front and back walls are characterized by a scarce precision.

Conclusions

The accuracy of the here proposed photogrammetric procedure is the one typical of the monoscopic systems. The advantages are many: the great speed of execution, every couple of panorama includes or replaces many photogrammetric models, the completeness of documentation, every panorama constitutes the ideal image extending 360°. The possibility to skip the interior orientation, due to the spherical form of the equivalent sensor or pseudo-sensor, permits the direct plotting from relative orientation. Finally the great inexpensiveness of the system, being the equipment very economic and light. On the other side the limit is in the low spatial resolution and in the prevailing use for indoor environments, where the construction of the panorama is facilitated by the presence of the ceiling. All these advantages with the possibility to perform a plotting with very simple measurements only, like tape distances, make the procedure to be a very useful tool for recording and classification of cultural heritage, even for non expert people.

Besides the possibility not to employ expensive instrumentation as the theodolite and the capability to perform the plotting in relative orientation, the sizing and the levelling can be done afterwards by simple means, make the procedure a precious tool for the survey and the cataloguing cultural heritage in the developing countries.

Thanks

I am grateful to Giuseppe Di Carlo for the help in the plotting of the church of the Holy Magdalene, to Marco Giacinti for supplying the CreatePoints software for the image measurements.

References

1. *Fangi G. (1998)* The Coplanarity Condition For The Orientation In Surveying - ISPRS Arch. *WG VI/3.*
2. *G. Fangi (2004)* - Block bundle adjustment for theodolite stations in control networks - The case of the Guggenheim museum in Bilbao, - *ISPRS Archives vol. XXXV part B5, pg 372-376 – ISSN 1682 - 1750.*
3. *G.Fangi (2006)* - Investigation On The Suitability Of The Spherical Panoramas By Realviz Stitcher For Metric Purposes, *ISPRS Archive vol.XXXVI Part 5.*
4. *H.Haggrén, H. Hyyppä, O. Jokinen, A. Kukko, M. Nuikka, T. Pitkänen, P.Pöntinen, R. Rönnholm (2004)* – Photogrammetric Application of Spherical Imaging - *ISPRS Archives Vol. XXXIV, part 5/W16.*
5. *T.Luhmann, W. Tecklenburg (2004)* – 3-D Object Reconstruction from Multiple-Station Panorama Imagery - *ISPRS Archives Vol. XXXIV, part 5/W16.*
6. *D.Schneider, H.-G. Maas (2004)* – Application and Accuracy Potential of a Strict Geometric Model for rotating Lines Cameras –*ISPRS Archives Vol. XXXIV, part 5/W16.*
7. *D.Schneider, H.-G. Maas (2005)* – Combined Bundle Adjustment of Panoramic and Central Perspective Images –, – *ISPRS Archives Vol XXXVI-5/W8.*
8. *R. Szeliski and H. Shum. (1997)* Creating full view panoramic image mosaics and environment maps. *In Proc. of SIGGRAPH, pages 251-258.*

Architectural patrimony management in Yemen

R. Héno[1], Y. Egels[2]

1. *Ecole Nationale des Sciences Géographiques, Département d'Imagerie Aérienne et Spatiale, Cité Descartes, F-77455 Marne-la-Vallée CEDEX, France, raphaele.heno@ensg.ign.fr*
2. *Professeur, consultant, 99 rue de Charonne F-75011 Paris, France, yves.egels@free.fr*

ABSTRACT

On the initiative of Marylène Barret, archaeologist and art restorer working at the French embassy in Sana'a Yemen, and detached at the SFD (Social Fund for Development) of Yemen, professors of the French ENSG (Ecole Nationale des Sciences Géographiques), together with some of their students went twice to Yemen since October 2004 to survey five historic mosques on the point of being restored. The goal of both field operations and post-processing of the collected data was to provide a specific training and to enable a transfer of technology to a Yemeni team who should soon be in charge of organizing by themselves similar operations as part of a specific unit at the SFD. Today, according to an agreement between the ENSG and the SFD, trainings should go on to make that unit operational as soon as possible.

Introduction

Context

In the south of the Arabian Peninsula lies Yemen, formerly known as an important step on the Frankincense Road, well known today for its astonishing mountainous landscape, and much less so for its very rich architectural heritage. This richness is a result of the country's former prosperity, and needs to be transmitted to future generations. Any action of safeguarding this cultural heritage is of course valuable. The first step to preserving a monument is simply to produce a complete and precise documentation of it.

Partners

Marylène Barret, archaeologist and art restorer working at the French embassy in Sana'a (Barret, 2004), the capital of Yemen, and detached at the Social Fund for Development of Yemen (SFD), was the first to introduce the idea of creating in the country one team able to use traditional techniques of close-range photogrammetry to produce the documentation.

The SFD is an autonomous agency with financial and administrative independence, governed by a Board of Directors, representing the government, NGOs, and the private sector under the chairmanship of the Yemeni Prime Minister. The SFD seeks to reduce poverty by improving living conditions and providing income generating opportunities for the poor. It should be noted that it already has a department for Cultural Heritage.

Having read about the particular works previously done by French IGN (Institut Géographique National) on prestigious archeological sites, Marylène Barret invited its technical university, **the ENSG** (Ecole Nationale des Sciences Géographiques), to survey the first monument in order to convince the Yemeni authorities of its interest. In that context, four ENSG teachers,

Figure 1: Yemen in the Arabian Peninsula.

Great Mosque of Sana'a, size: 75×66m.

Mosque of Asnaf, recently restored, size: 9×8m.

The two mosques surveyed in Taez, Al Ahsrafieh (size: 35×30m) and Al Muzzafar (size: 54×54m).

Figure 2: The surveyed monuments.

together with six post-graduates (Photogrammetry, Positioning and Measures of Deformations), went to Yemen twice to do a photogrammetric survey of historic mosques on the point of being restored.

Sites of interest

Five mosques were completely surveyed: at first, in October 2004, the small mosque of Asnaf, the great mosques of Sana'a (7-8th/9th/12th century) and Shibam-Kawkaban (9th/10th century), then, in October 2005, the mosques of Al Ahsrafieh (13th century) and Al Muzzafar (13th century) in Taez.

Recording the Monuments

Field work using a combination of topometry, photogrammetry and lasergrammetry

Methodology

In order to obtain a reliable and accurate survey, being faithful to the shape and appearance of the monument, it has been decided to use topometry, photogrammetry and 3D laser scanning altogether.

Setting up a local topometric system

A local network of both flat and spherical targets has been set up and measured to ensure that images and laser scenes could be used later and combined into a common 3D coordinate system. Reference points were located inside (and even in a part of the underground floors) and outside the mosques, links between them being made through the doors (between inner and outer mosque, and also between the inner mosque and the courtyard) and the terrace. A basic network in 3D was thus formed on which all the measurements depend. The team used Trimble 5600 DR, Trimble 3600 DR, and LEICA TCR 803 (Direct Reflex) total stations for the control survey. The total stations' direct reflex capabilities also enabled the team to take measurements of distance without prisms and accurately determine the position of the spherical targets by direct measurement. In total, 450 control points were established at Sana'a, 200 at Shibam and around 200 also in the two mosques in Taez. The 3D coordinates of all the network points were computed with COMP3D, a software program for global bundle adjustment, for micro-geodesy, photogrammetry, and 3D scanning developed by Yves Egels, ENSG' professor. Results were validated on the site and the precision achieved was approx.

Figure 3: Extract of the wooden steep sided ceilings (real and schematic views) and cross-section.

Figure 4: Image shooting of the ceilings.

5-6 mm (0.2 in) on the Shibam site and approx. 1 cm (0.4 in) on the Sana'a site; these differences being mainly due to the size difference of the surveyed sites (a 75-m-long (246-ft) side for the Sana'a mosque, 35-m-long (115-ft) for Shibam).

Image shooting

Although a terrestrial 3D laser scanner was available (Trimble GS100), traditional photogrammetry was considered for at least two reasons. For one thing, some nicely decorated details obviously required high resolution images that the scanner could not ensure. Secondly, the configuration of the mosque itself, like the wooden steep sided ceilings *(Figure 3)*, was so complex that a complete 3D laser scanning would have been much more tedious than a regular stereoplotting.

Thus, traditional stereoscopic image coverage has been made on the ceilings, as well as the facade walls, and the particular details, such as the "mihrab". A Minolta Dimage previously calibrated at the ENSG, equipped with an outer flash was used, producing approximately 400 images on the site of Sana'a, and 200 in Shibam. In order to be as productive as possible, images have been taken from ground level, which resulted in an average ceilings pixel size of 3mm.

3D laser scanning

A Trimble 3D Scanner was used to survey the general architecture of the buildings (columns, arches, interior and exterior walls, and terraces) shaped without decoration but with lots of hidden parts. The measurement interval was approx. 15 mm (0.6 in). 3D scanning is well suited to the walls as well as terraces and pillars in which detail density is fairly low, enabling rapid scanning at a low resolution. In contrast to photogrammetry techniques, the scanner's acquisition time is proportional to the detail desired. However, it is also less sensitive to hidden areas (no need for stereoscopy, precision independent of distance). Its main advantage is its ability to rapidly supply large amounts of data without major processing. For instance, the team completed 100 hours of scanning over two weeks to acquire the necessary data for the mosques of Sana'a and Shibam.

Data processing in France

Vertigeo

A tacit agreement between the SFD and the ENSG first stipulated that five mosques be surveyed by ENSG' students, their expenses such as plane tickets and local accommodation being paid by SFD. Further data processing was subject to another contract signed in 2005 by Vertigeo, the ENSG company managed by students. Since that time, ENSG' students helped by their professors have worked in their free time to produce and deliver the expected results.

Products to deliver

The list of results to be produced was vague at the beginning, as the SFD as a sponsor knew little about the possible results of topometry, photogrammetry and lasergrammetry, and as the ENSG itself was making its first life-size field survey with a laser scanner. Traditional outputs of an architectural survey were

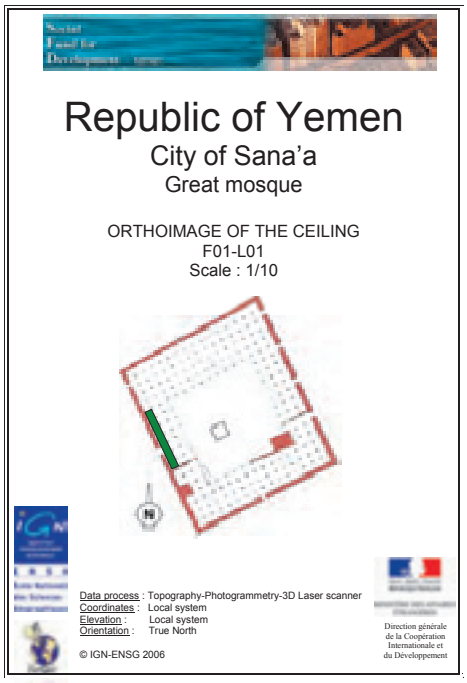


Figure 5: Box out of the graphical rules retained by Vertigeo.

however required: horizontal plane at ground level, vertical elevations, main cross-sections, and orthoimage for the wooden ceilings and for the façades. Results had to be delivered digitally and in hardcopy according to graphical rules that Vertigeo was free to design *(Figure 5)*.

Orthoimages were computed at the closest resolution to the ground resolution of raw images, that is to say 3mm for the ceilings of the mosques of Sana'a and Shibam, and 5mm for the façades. Ceilings were printed at the scale of 1/10 *(Figure 6)*, and façades at the scale of 1/50.

Figure 6: One row being printed at the scale of 1/10.

Photogrammetric tools

Aerotriangulation

An IGN software, Topaéro, normally designed to compute georeferencement of aerial images with the bundle adjustment method, has been successfully used for computing the aerotriangulation of the wooden ceilings and of the façades. Tie points had been previously measured in a semi-automatic way, using LPS.

Orthorectification

Automatic correlation was tested on the wooden ceilings to produce DSM, which is necessary to compute a true orthoimage. As a matter of fact, the ceilings look very much like a dense urban area, although it is seen from below rather from the top. But because of the repetitive aspect of the ceilings, both in shape and drawing, the correlation results were so poor that the interactive editing task would probably have been longer than direct manual stereoplotting! Nevertheless the volume of traditional stereoplotting would have lead to unacceptable delivery time. Thus, a simplified method was adopted : only the lowest wooden beams have been recorded into the DSM, while in Adobe Photoshop, the central area of the images were defined, limited at both extremities by the lowest beams, and saved into alpha layers (*Figure 7*), that the software later used to compute the orthoimage, was able to understand as such. Taking only the central part of the images easily allowed the orthoimage to look like a "true" one, while limiting the area of interest to the lowest beam avoided possible ghosting effects or any wrong edge matching artifacts.

This simplified methodology was only applied for the ceilings, because it was acceptable regarding the cost and the geometric accuracy, satisfying the architects at the same time. As a matter of fact, even if the delivered orthoimage

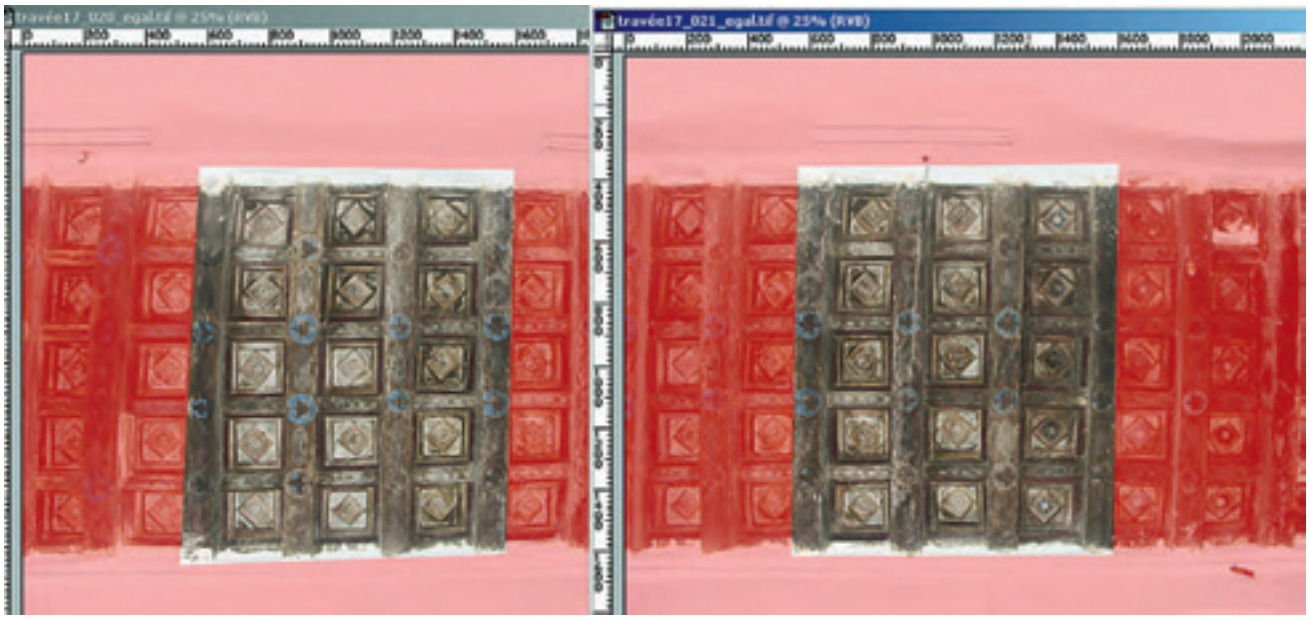


Figure 7: alpha layers

was not 1cm accurate as it was first expected, it gave the restorers a precious overview document, *(Figure 8)*. Of course for the façades and other more usual areas, rigorous orthorectification was normally used at a reasonable cost.

New products for architects and restorers

Cumulus

Furthermore, even if a huge potential of the dense laser scanning was assumed since the beginning, no efficient and user friendly tool was available yet on the market. Yves Egels, at that time head of the DIAS (photogrammetry department at the ENSG), already familiar with software development, decided to write a new one, mainly dedicated to terrestrial 3D laser data processing. Rapidly operational, Cumulus was able to visualize laser data using any color, or scanning intensity, or color from the scanner low resolution camera, or even color from outer high resolution images whenever georeferenced in the same topometric system as the laser data. Cumulus was also able to georeference laser scenes using the spherical target of the topometric network, to compute sections through the laser data in any specified direction, and also to compute true orthoimages, taking into account both occlusions in the laser data and in georeferenced outer images. Y. Egels made his software also usable for 3D data captured by traditional stereoplotting, which, as mentioned above was helpful in producing orthoimages on the wooden ceilings.

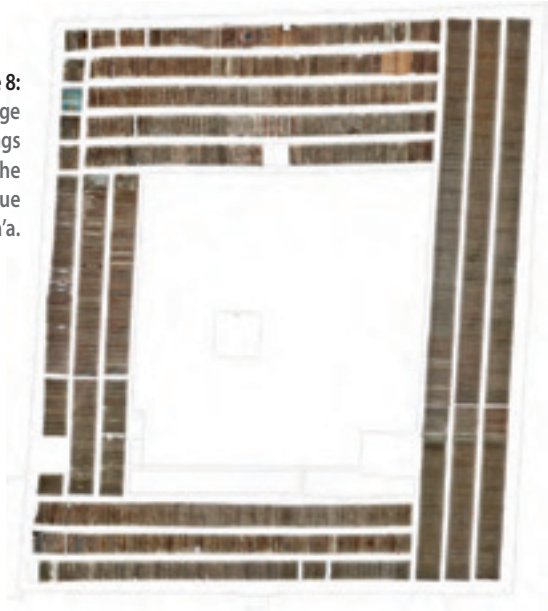


Figure 8: Orthoimage of the ceilings of the Great Mosque of Sana'a.

Graphical rendering of the data

Since it became, thanks to Cumulus, rather simple to produce, among other things, sections and orthoimages, which are the traditional results that architects and restorers ask for, some of the people in charge of the restoration operations asked for more than was initially required, like more cross-sections (fourteen cross-sections were asked for the Great Mosque of Sana'a), and horizontal planes at different levels (ground level of course, but also pillar capital level). The raw output from Cumulus is unfortunately a bit rough, because of the unexpected objects which have been scanned together with the intended objects (the mosques were usually full of bookshelves which were too cumbersome to move), and also because of the intrinsic noise of the scanning.

Moreover, there always remain occlusions that produce holes in the final products. All this makes it inevitable to clean the raw output from Cumulus, for use by most architects apparently not prepared to deal with such data. This step has been very little tried out so far at ENSG, mainly through lack of time and manpower. However, a student is expected to work on that specific subject at SFD during the summer 2007, to produce real cartographic data out of the raw output from Cumulus, and also to work out its methodology. However, one may expect that architects will slowly come to appreciate the very rich content of raw data, in spite of the above mentioned defects.

Transfer of technology

Yemeni pool of experts

Besides proving to Yemeni authorities the validity of 3D modelling techniques, Marylène Barret also intended to set up in

Figure 9: One raw cross-section in the Mosque of Sana'a.

Yemen, and first in SFD, a specific unit specialized in advanced documentation techniques for the historical architectural heritage of Yemen. For that purpose, ENSG teachers have identified four Yemeni experts from among various specialists (architects, surveyors, engineers) as being sensitive to the urgent need to produce complete and accurate documentation of the rich Yemeni architectural heritage and able to understand the methods to produce this documentation.

Training sessions

In order to have that team operational as soon as possible, training sessions have been organized. Trainees first attended the two week field operation in Taez, where each of them worked together with one French student. This organization, apart from leading to friendships, gave the opportunity to Yemeni trainees to efficiently learn the basics of a field survey and to French students to clarify the knowledge they had to teach. After that, two more training sessions were given in Sana'a by ENSG teachers, during which basic theory required to use the photogrammetric tools for the whole process where taught. Most of these tools, like Cumulus, were translated into Arabic for the occasion. Finally the trainees came to France for one month, where they surveyed almost alone a part of the Chartreuse of Villeneuve-Lez-Avignon. This included field survey and data processing.

Agreement of cooperation between the SFD and the ENSG

An agreement between the SFD and the ENSG should be signed very soon, making the already very good relationships between these two official institutions. Training sessions will be regularly given in Yemen for at least two years, by ENSG professors and professionals. Some engineers or high level students could take part in implementing the documentation unit in SFD in their ENSG practical training (possible duration from two to six months). For instance, two ENSG students make their practical training in SFD during the summer of 2007, one to help organize the newly funded unit, the other to redraw some rough cross-sections and to write its methodology.

SFD unit specialized in advanced documentation techniques for the historical architectural heritage of Yemen

Although the documentation unit was first set up in SFD, it may well be transferred later on to other organizations. This will of course require the current Yemeni trainees to have a good knowledge of all steps in the production process, so that they can become trainers themselves. It seems to be safe to keep the documentation in SFD in its early stages, since SFD already invested in training sessions, and provided the first necessary basic equipment, that is to say, besides existing printers and computers, a semi-professional camera –Canon EOS 5D-, a total station –Leica TCR 803- and topometric accessories. Purchasing a 3D terrestrial laser scanner will be considered only when the documentation unit works smoothly.

Conclusion

Although the idea of creating in Yemen an autonomous documentation unit was first looked on with some doubt, Marylène Barret worked hard and finally succeeded in having SFD support this project actively. Today, thanks to the SFD's sincere involvement combined with great enthusiasm and long-term involvement of ENSG' professors to see that unit work, tangible results may already be seen: on the one hand documents essential for the preservation of a still little-known heritage have been produced, and authorities are beginning to see its importance. On the other hand, the Yemeni team has received most of the equipment, and is starting already to work properly. Once the documentation unit is fully operational, which is expected to happen within two years, the next stage will be to see that unit itself becoming expert in the field of 3D documentation for Yemen and for the neighboring Middle-Eastern countries.

References

Barret M., 2004: Aga Khan award for the restoration of the Abbas mosque in Asnaf http://www.akdn.org/agency/akaa/ninthcycle/page_02txt.htm

3D modelling of heritage objects by fringe projection and laser scanning systems

H.-J. Przybilla[1], J. Peipe[2]

1. *Lab. for Photogrammetry, Dept. of Surveying and Geoinformatics, Bochum University of Applied Sciences, Germany, heinz-juergen.przybilla@fh-bochum.de*
2. *Institute for Photogrammetry and Cartography, Bundeswehr University Munich, Germany, j-k.peipe@unibw-muenchen.de*

ABSTRACT

The treasure of the Essen cathedral in Germany is one of the few collections of medieval art completely preserved in the course of history, including approximately 250 objects such as crosses, crowns, swords, statues, manuscripts, and reliquaries. These precious works of art show a great variety in size, shape, material, and complexity. In the paper, ideas and concepts for recording the manifold objects of the treasure by optical methods such as photogrammetry, fringe projection and laser technique are reported on. The measurement systems used are described as well as calibration aspects, difficulties of data acquisition and processing are mentioned, and virtual models of the treasure are presented.

Introduction

The recording and modeling of cultural heritage objects for the purpose of conservation, structural investigation, restoration, visualization, documentation, and archiving is, by common consent, an important task. Mobile and flexible optical 3D measuring systems based on techniques such as photogrammetry, fringe projection, laser scanning, and combinations of these image-based or range-based systems can successfully be applied to the measurement and virtual reconstruction of objects in art and cultural heritage.

Recently, it was decided to establish a digital archive of the treasure of the Essen cathedral by means of optical 3D measurement methods. The treasure of the Essen cathedral is one of the most significant collections of ecclesiastical art in Germany. It originates from the former canoness convent's treasure which passed into the property of the parish after the secularisation in 1803. Since 1957 the diocese of Essen has been responsible for the treasure. Because only a few pieces have got lost in the course of history, the collection is exemplary due to its completeness. However, the treasure includes approximately 250 objects comprising some outstanding works, in particular from the Ottonian epoch *(Figs. 1 & 2)*. A great number of significant works of art var-

Figure 1: Otto-Mathilden-Cross, 10th century, different materials, 44.5 cm high, 29.5 cm wide (© Martin Engelbrecht).

Figure 2: Child's Crown, made for Otto III., 10th century, different materials, e.g. gold sheets, jewels, and pearls (© Martin Engelbrecht).

ying in size, shape, material, and complexity are to be measured. The artifacts provide more or less cooperative surfaces: a challenge for any measurement system. The 3D reconstruction is to be performed with high accuracy (0.1 to 1.0 mm, depending on the size of the object) at large scales (1:1 to 1:5).

The paper overviews both the main objects of interest being among the treasure and the measurement systems or techniques, respectively, to be used for the recording. A chapter dealing with difficulties and drawbacks when digitizing artefacts is included. Finally, the state of the project as up to now is reported on.

Measurement Systems

"We can safely say that at the moment, for all types of objects and sites, there is no single modeling technique able to satisfy all requirements, like high geometric accuracy, portability, full automation, photorealism, low costs as well as flexibility and efficiency." (Remondino & El-Hakim, 2006)

The authors of this paper entirely confirm the above statement from their own practical experience. Therefore, several measurement techniques are proposed for the project

- photogrammetry,
- fringe projection technique,
- laser scanning.

Active sensors using fringe projection or laser technique accomplish the very fast and precise digitization of an object surface resulting in a dense 3D point cloud. The combination of image-based and range-based methods is appropriate to all tasks where a single technique by itself fails. So the structure of an object can be measured by photogrammetry, complex details of the object surface with a range sensor. Texture information for generating a realistic 3D model is provided by high resolution digital colour images.

Subsequent to the point cloud generation, software is used for a topologically correct surface reconstruction, for texturing and visualization, in this case by means of the RapidForm and Geomagic software packages (Inus, 2007; Geomagic, 2007).

Fringe projection systems

For the data acquisition of the treasure of the Essen cathedral mainly fringe projection systems have been applied so far. At the beginning of the project, a Breuckmann optoTOP HE-600 was used to digitize the *Golden Madonna*, the oldest known statue of Virgin Mary dating from around the year 990 A.D. (Peipe & Przybilla, 2005). Since then a Breuckmann triTOS has been employed *(Fig. 3*; Breuckmann, 2007). The system consists of a mechanically stable base connecting a 1.3 megapixel camera and the fringe projection unit, and a high-end PC or notebook with the operating and object reconstruction software. The triangulation angle of the system amounts to 20 degree leading to a medium accuracy of about 0.2 mm when digitizing object surfaces. Base length and lenses can be changed to capture different fields of view. Calibration data and accuracy figures of the triTOS system were determined by test measurements published in a previous paper (Bange et al., 2007).

A series of scans has to be generated to cover the complex artefacts, including a lot of detailed views to acquire more or less hidden regions, too. The single views can be combined within the triTOS software by a best fit approach based on iterative closest point algorithm (ICP). Moreover, a network of reference points precisely determined by photogrammetric means may serve to merge all the scans of the object captured with the range-based system. Furthermore, a Nikon D2Xs digital SLR camera was used to take colour images for texturing the 3D model.

Laser scanning

In addition to the fringe projection system, a laserscanner will be applied for point cloud generation. Laserscanners have been very expensive, but newly developed devices may change this situation. For example, the MicroScan laser sensor is a powerful but affordable measuring tool (RSI, 2007; *Fig. 4*).

The scanner is connected to the MicroScribe measuring arm, i.e. it is attached to the stylus of the 6DOF MicroScribe. The portable MicroScribe + MicroScan combination provides an accuracy of approx. 0.2 mm within a reach of about 1.5 m. 28.000 3D points per second are registered while the laser line is navigated over the object. The camera of the MicroScan records the deformations of the scanning line caused by shape variations of the object surface. Point clouds originating from different scans can be merged by the system software.

In addition to the laserscanning, the MicroScribe measuring arm can also be utilized as a touch probe device for digitizing single 3D point positions.

First results of laserscanner calibrations (by means of tools included in the system) and measurements show a good accordance with the specifications given by the manufacturer of the system. Further investigations have to be performed concerning calibration procedures, especially those defined by the German VDI/VDE guideline 2634 (VDI/VDE, 2002). An example of object scanning with MicroScan in comparison to an image taken with the Nikon camera is shown in *Fig. 5*.

Figure 3: triTOS fringe projection system.

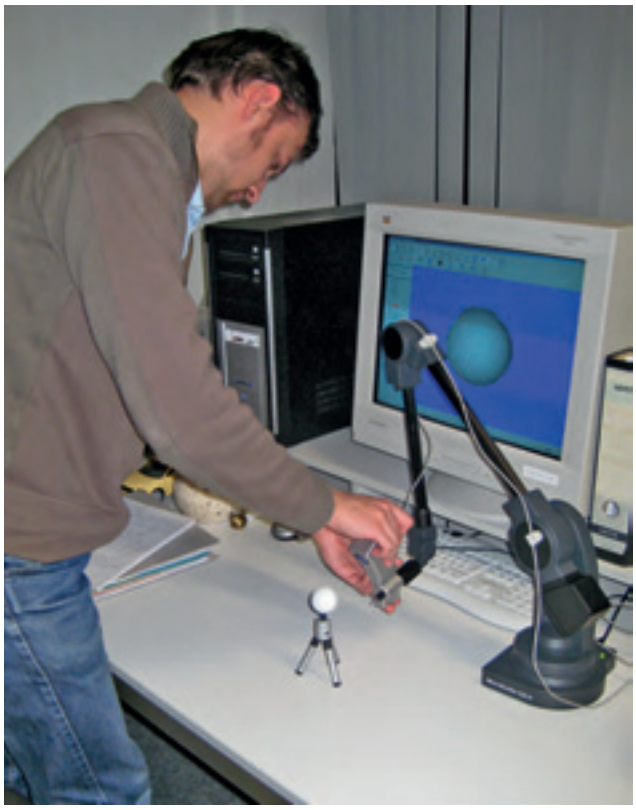


Figure 4: MicroScan + MicroScribe during calibration.

Figure 5: Scan (left) and digital image (right).

State of the Project

As mentioned in chapter 2, the *Golden Madonna* of the cathedral's treasure was digitized and modeled at first. In the meantime, some more works of art have been surveyed *(Figs. 6 & 7)*:

- the so-called Elfenbeinpyxis, an elliptical box (10.4 cm and 12.5 cm in diameter, 8.8 cm high), made of ivory, originating from the 5th/6th century,
- the Ludgeruskelch, i.e. a ceremonial cup (12.2 cm high, 7 cm diameter at the top), made of copper and gold, originating from the 10th century,
- the scabbard of a ceremonial sword (94 cm in length), made from wood and covered by golden plates, originating from the 10th century.

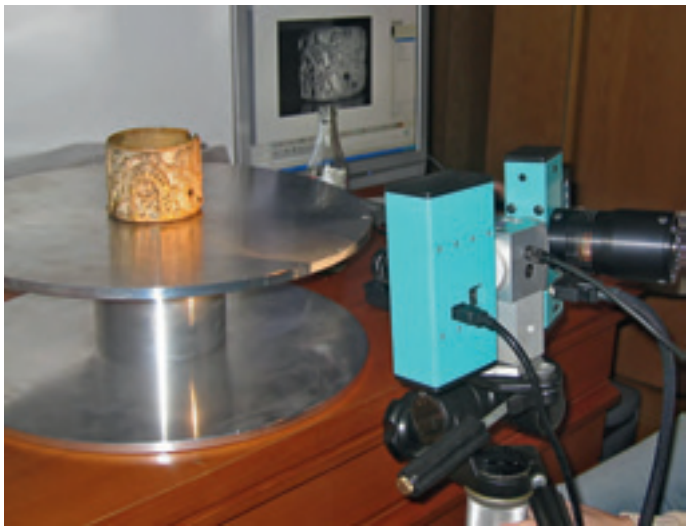


Figure 6: Digitizing the Elfenbeinpyxis.

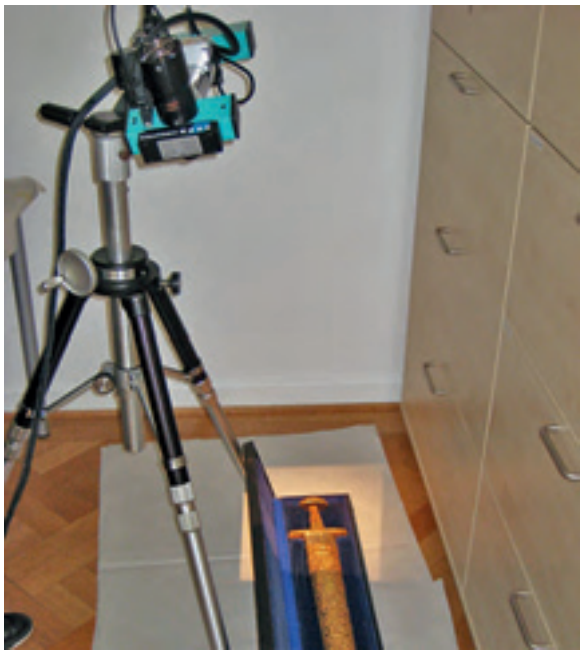


Figure 7: Digitizing the ceremonial sword

Table 1: *Specifications of data acquisition.*

	Elfenbeinpyxis	Ludgerus-Kelch	Ceremonial sword
Base length	50 mm	50 mm	300 mm
Measuring distance	400 mm	400 mm	1000 mm
Survey depth	90 mm	90 mm	180 mm
Fixed sensor, object on turntable	yes	yes	no
Number of scans	36	85	83
Measuring time	8 h	5 h	7 h
Fitting by ICP	during measurement	additional 5 h	additional 4 h

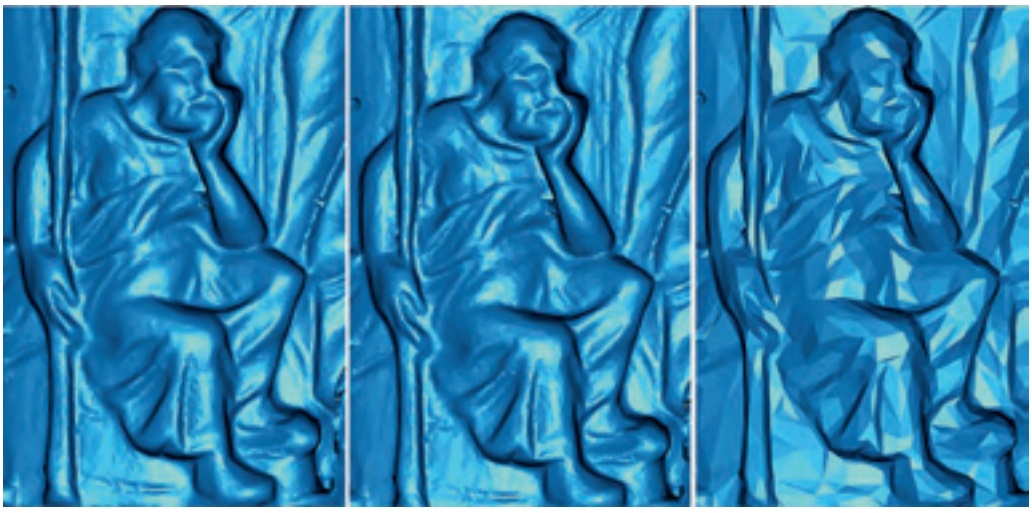


Figure 8: Detail of the Elfenbeinpyxis after reducing polygons.

These objects are very different in size, structure and material. Therefore, the digitizing is complicated and time-consuming. Some difficulties appear in case of

- reflections, especially when capturing glittering material (gold etc.)
- more or less transparent materials (gems etc.)
- complex surfaces providing hidden parts.

Specifications of the data acquisition can be found in Table 1.

Data Processing and Visualization

Visualization of complex object structures cannot be done by common computer aided design programs. Tools like those used for reverse engineering and rapid prototyping have to be applied to transform scan data into accurate digital models. Favourable results could be achieved with Geomagic Studio (Geomagic, 2007). This software package includes features such as

- point processing (data filtering, noise reduction),
- polygon building,
- curvature-based hole filling,
- automatic edge sharpening,
- surface smoothing,
- texture mapping,
- etc.

Figure 9: Textured detail of the Elfenbeinpyxis (left: 25%, right: 1.5% of original polygons).

A serious problem when digitizing and processing complex objects is the large amount of data, especially if the modeled artefact should be posted on the internet. Data reduction is an important issue. Fig. 8 presents a detail of the Elfenbeinpyxis, beginning (left) with the original resolution and, then, after reducing to 25% and 3% of the primary data volume. *Fig. 9* shows the same detail overlaid with photographic texture. Even a significant reduction of 3D

data is partly compensated by the overlaid texture.

These experiences can be confirmed with the results of other artefacts *(Fig. 10)*. Data processing using reverse engineering software seems to be suitable for modeling complex cultural objects (see Remondino & El-Hakim, 2006).

Concluding Remarks

3D data from different sources are suitable to establish a digital archive of the treasure of the Essen cathedral. Fringe projection systems have been successfully applied to generate 3D models of several important and valuable works of medieval art. In addition, the combination of a touch probe digitizer and a laserscanner provides an adequate accuracy and a favourable price/performance ratio, and seems very promising for quick data collection of complex objects.

Based on the geometrical reconstruction of the artefacts and additional information, multimedia processing is planned. In the near future, the data will be included in a 3D information system supporting any kind of art-historical activities and research, but also useful for the non-professional museum visitor interested in medieval art.

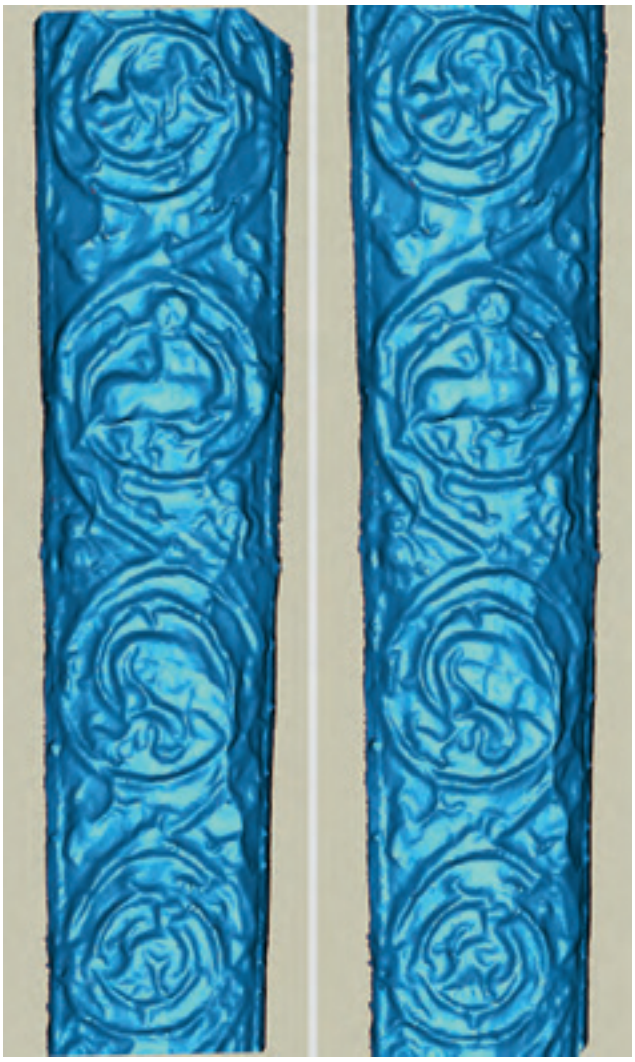


Figure 10. Detail of the ceremonial sword (left: 100%, right: 50% of original polygons).

References

Bange, L., Peipe, J., Przybilla, H.-J., 2007. Genauigkeitsmaße eines Streifenprojektionssystems zur 3D-Objekterfassung. In: Photogrammetrie - Laserscanning - Optische 3D-Messtechnik. Wichmann, Heidelberg, pp. 116-122.

Breuckmann, 2007. Product information optoTOP and triTOS. www.breuckmann.com (accessed 30 May 2007).

Geomagic, 2007. Product information Geomagic software. www.geomagic.com (accessed 30 May 2007).

Inus Technology, 2007. Product information RapidForm. www.rapidform.com (accessed 30 May 2007).

Peipe, J., Przybilla, H.-J., 2005. Modeling the Golden Madonna. In: Proceedings CIPA 2005 XX Int. Symposium, Turin, Italy, ISSN 1682-1777, pp. 934-936.

Remondino, F., El-Hakim, S., 2006. Image-based 3D modeling. Photogrammetric Record, Vol. 21 Issue 115, pp. 269-291.

RSI, 2007. Product information MicroScribe and MicroScan. www.rsi-gmbh.de (accessed 30 May 2007).

VDI/VDE, 2002. VDI/VDE Guideline 2634. Beuth, Berlin.

Evaluation of structural damages from 3d laser scans

J.I. San José[1], J. Martínez[1], J.J. Fernández[1], J. Finat[2], J.D. Perez-Moneo[2]

1. *University of Valladolid, Laboratory of Architectural Photogrammetry, School of Architecture, Av. De Salamanca s/n 47014 Valladolid. jmr@ega.uva.es*
2. *University of Valladolid, MoBiVAP research group, I+D building, lab2.2, Campus Miguel Delibes. 47011 Valladolid. jfinat@agt.uva.es, juandi@ega.uva.es*

ABSTRACT

There exists a very large number of damaged buildings in Cultural Heritage. Common damages are related with structural deformations (lack of verticality, crashes, e.g.) and the degradation of their support (deteriorated materials, e.g.). A dense information is needed for both of them. Non-intrusive methods based on laser scans provide 3D support with dense information with low human cost. In this work, special attention is paid to structural deformations.

The software platform UVACAD has been developed for solving visualisation issues relative to sub-clouds of points extracted from the global model. Interactive visualization concerns basic projective operations (sections and projections), cell decomposition and colour re-projection of the global 3D model. Slices with constant width and extracted by means of parallel planes have provided support for a semi-automatic drawing of sections drawn over the exported slices after their ortho-projection. Structural damages can then be visualised in a transparent way by overlapping the exported ortho-images. These results are illustrated with an example taken from the gothic church of Villamorón (Burgos, Spain). The performed 3D model has proven to be an accurate survey which has allowed the assessment for an urgent intervention policy to correct serious damages observed in this study.

Introduction

Due to the abandon of small villages and the lack of economic resources, the current state of Cultural Heritage buildings in rural zones show a poor state of conservation, which makes it very difficult to carry out any global intervention. Thus, sometimes it is only possible to make a detailed study of the structure to prevent further damages. Despite the fact that Castilla y León is one of the the European regions with the lowest density of population, it contains more than fifty per cent of the Spain's Cultural Heritage.

Unfortunately, the high number of damaged buildings and the limited budget makes it very difficult to design a global policy of conservation or restoration. Thus, before its collapse it is imperative to make a structural diagnosis and a thorough digitization of damaged buildings. Exchange of research experiences is crucial to compare and improve our current state of knowledge, and to try to coordinate a future development of restoration and conservation policies. Some recent developments can be read in [Dequal 2005].

Figure 1: One among hundreds of ruined CH goods in Castilla y León.

Figure 2: Scanning the Church of Santiago outdoors and indoors.

Common photogrammetric records are based on imagery and total stations. Planning of network for acquisition and data capture are time consuming; furthermore, post-processing work for image-based architectural surveying is tedious and requires a very high level of expertise. However, 3D laser scanners have proved to be more efficient in three-dimensional dense modelling. Although the local accuracy of measurements taken with robotized total stations is higher, laser-scanner surveys are often more appropriate for urgent interventions as they provide massive 3D volumetric information. Information processing provides metric data which are very useful to support conservation and restoration policies.

Since the 2001 edition of CIPA, there has been a very large number of works published, focusing on the laser scanner and its application to heritage recording subject. [Boehler (2002), Malinverni (2003)].

On the other hand, a large number of developments in Computer Graphics and Machine Vision for complex rendering of historical buildings have been performed along the last ten years. Modern scientific visualization offers the possibility to inspect and evaluate structural properties of buildings and other information relative to their environment. Thus, it is necessary to develop multi-resolution and hybrid approaches for architectural and environmental surveying (see e.g. El-Hakim et al, 2002). The development of interoperability tools between Surveying and Information Systems, including advanced visualization techniques models is the next challenge to face. Advanced Visualization must allow the exchange, processing and analysis of metric information with object-oriented data and metadata bases relative to the information with a 2D/3D support.

For dealing with such a massive data source, it is necessary to combine volumetric segmentation with 3D matching to different level-of-detail (LoD). This combination provides a semi-automatic identification of primitives appearing in buildings for each LoD. The coarsest level of the hierarchy involves the identification of geometric elements (dominant planes, quadrics, e.g.) whereas the finest level deals with complex primitives (ornamental details, pinnacles, ledges, sculptures, e.g.). The automatic identification of complex primitives from basic geometric primitives is still a challenge for semi-automatic 3D recognition and modelling with a large number of applications to CAD, Architectural or Archaeological Surveying, computer animation and simulation, including VR/AR, among others.

Currently, the LFA-MoBiVAP research group is developing information systems for Cultural Heritage Recording by means of advanced visualization systems. Post-processing of 3D information arising from sampling of huge clouds of points makes it possible to compare the current state of certain areas with their simple planar and quadratic primitives. Multi-resolution models have been applied in the visualization and virtual reconstruction of archaeological sites; examples of these are the analysis and ideal reconstruction of the roman theater of Clvnia (Burgos, Spain) as illustrated in [Finat et al 2005] and an extension for urban environments, in [Fernandez, 2006].

The main goal of this work is to contribute to the semi-automatic 3D modelling and design of architectural primitives corresponding to damaged buildings from range data files from scanning. To achieve this goal, simpler PL-models (piecewise linear) are generated from huge unorganized clouds of points captured with the laser scanner Ilris 3D (Optech). Sections of the point-clouds (understood as equispaced slices with constant width) and projections of selected ones onto reference planes are the result of the performed projective operations. These partial intermediate models are obtained with low computational cost and they are enough to identify coarse structural damages before urgent interventions.

Methodology

According to the methodology planned the steps performed in this and other precedent works is resumed as follows:

1. Data capture and construction of a global model by means of multiple scans alignining.
2. Global orientation of the model using ground control points. A high precision levelling traverse has been done.

3. Extraction of a regular sequence of longitudinal and transversal sections linked to point cloud slices small enough (in file size terms) to be exported to CAD models.
4. Re-projection of some selected of the sections on a common reference plane.
5. Interactive drawing of vector section onto 2D projected slices.
6. Inspection and dimension of elementary symmetries for longitudinal or transversal sections.
7. Quantification of deformations by comparison between actual and ideal sections.
8. Inspection and conclusions report.

All these steps are illustrated with examples extracted from the Gothic church of Villamorón (Burgos, Spain).

Current State

The church of Santiago shows some structural problems some of which are probably derived from interventions during the transition from Romanesque to early Gothic style. Indeed, the central nave may be too high compared to the side aisles; some certainly evident misalignments in columns along the transept produce strong alterations in the structure with visible crashes in the tower. This work is aimed at the identification of deviations with respect to vertical for walls and mis-

Figure 3: Two views from south-west and north showing severe damage.

Figure 4: Ashlars falling, vaults, archs and wall cracks, water flow…

alignments for columns, their quantification and the analysis of crashes and structural failures in the global 3D model.

The western facade shows an evident list, which is responsible for two large crashes across the wall, from roof to ground. In the eastern end of the temple, there appear severe crashes along windows which threaten the stability of its structure. Inside, the vaults are apparently full of cracks and a considerable number of ashlar blocks have fallen from the arches.

Crashes are also evident on the other end of the central nave, where lateral walls are literally detached from the roof. A large number of fractures also appear in the startings of arch nerves with the walls.

Data Capture and Global Model

In order to ensure a common general reference for the model, the scans are registered to a network of control points both in the exterior and interior of the church. Up

Figure 5: A crack from ground to roof in the bell tower.

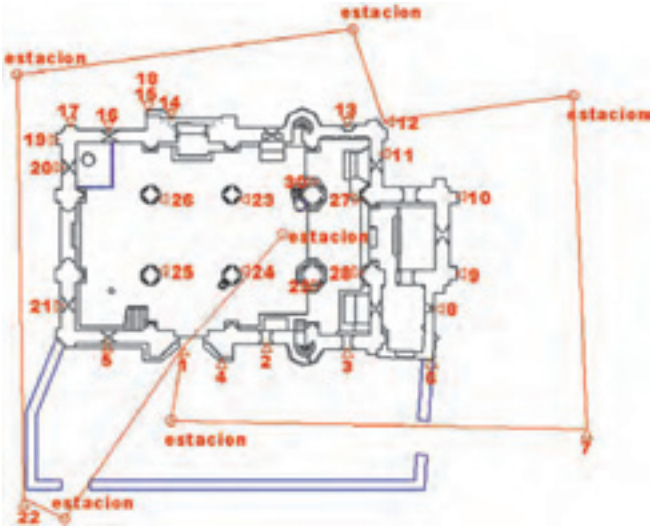


Figure 6: Levelling traverse and side shots.

Figure 7: Prof. San José as rodman.

to thirty level references have been surveyed with an automatic level Pentax AL320.

Not having the x,y coordinates of the reference points may seem to be quite imprecise but the points we took were on near flat surfaces which are easy to locate with the help of a sketch or picture. Some of them have been taken with the rod up-side-down because it is easier to identify those being above the scanner than other on the ground which was irregular and may be hidden by plants.

All of those levelled points were used for the absolute orientation of the model with the RMS of the being below 0.002m for the vertical adjustment.

The 145 scans covering the most of the inner and outer surfaces of the church where registered simultaneously with the help of a dedicated application Polyworks by Innovmetric which has demonstrated to be pretty capable for such as complex task. (by the time this work was done, the aligning algorithm was not yet implemented in our own developed software UVACAD).

More comprehensive data, where needed to record the temple's interior. They provide a global model of the vaults and roof. The relationship between the outer model and the inner one was possible thanks to the care taken while scanning the main entrance of the church from the outside. Some pillars and walls were captured from the exterior scans allowing to register the two models together.

A correct orientation and level allows the selection of a reference system given by a trihedral associated to ideal symmetric planes. The origin of this reference system has been placed at the intersection of the building axes at ground level. Thus it is possible to obtain three-parametric families of planes which are pair wise orthogonal between them.

Interestingly, during the process, we found that some modes of visualisation of the point cloud rendered as an extraordinary

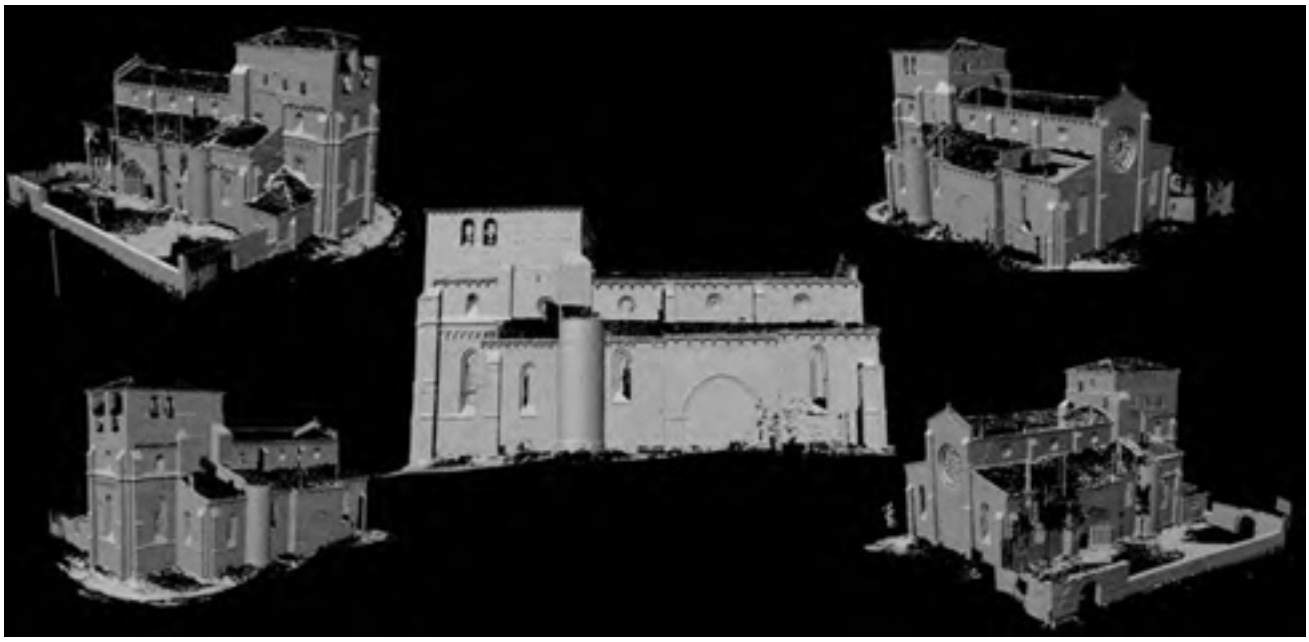


Figure 8: The final polygonal model of the outside skin.

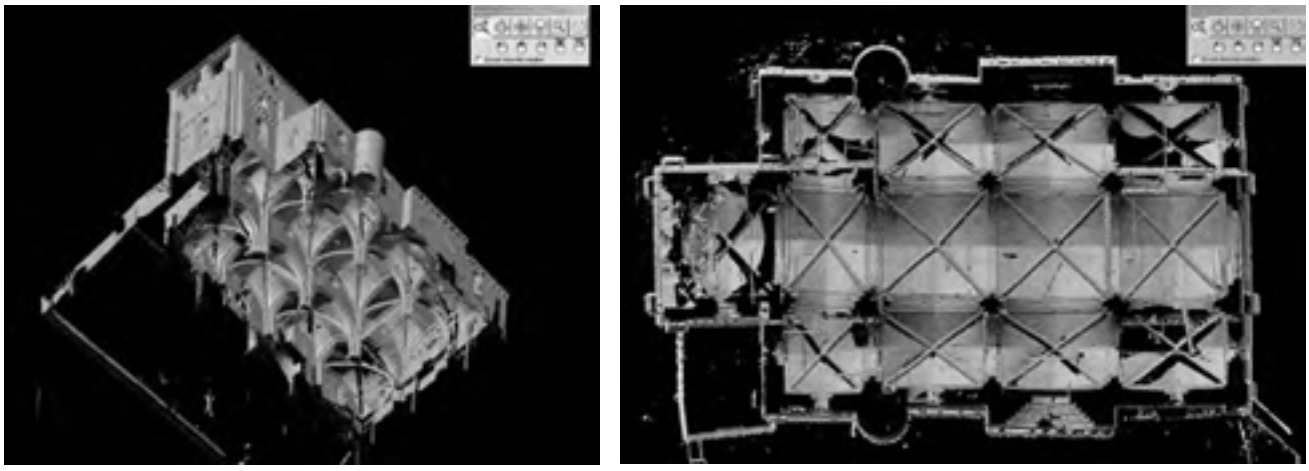


Figure 9: Vaults model registered to exterior.

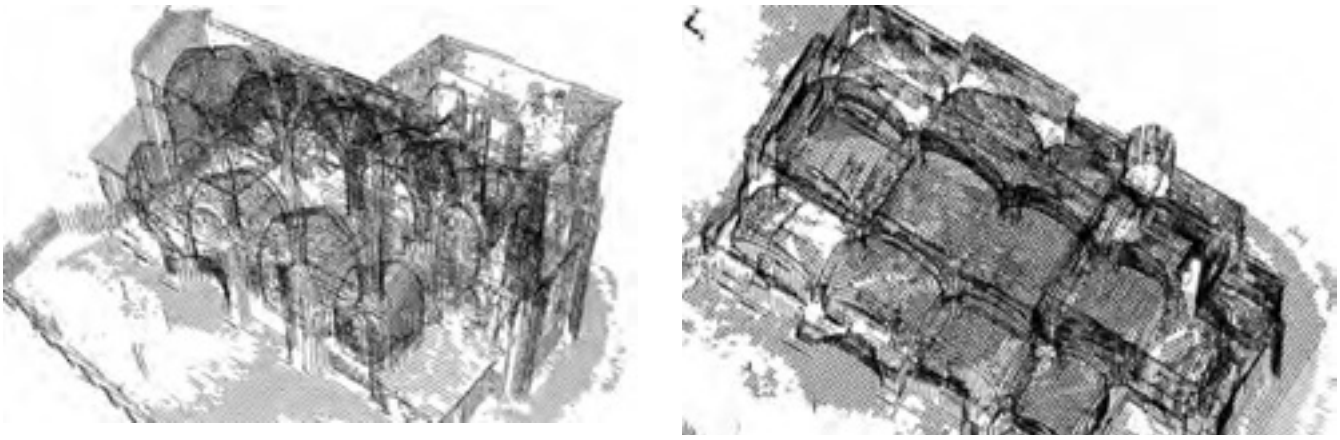


Figure 10: The two families of parallel sections are defined by building main axes.

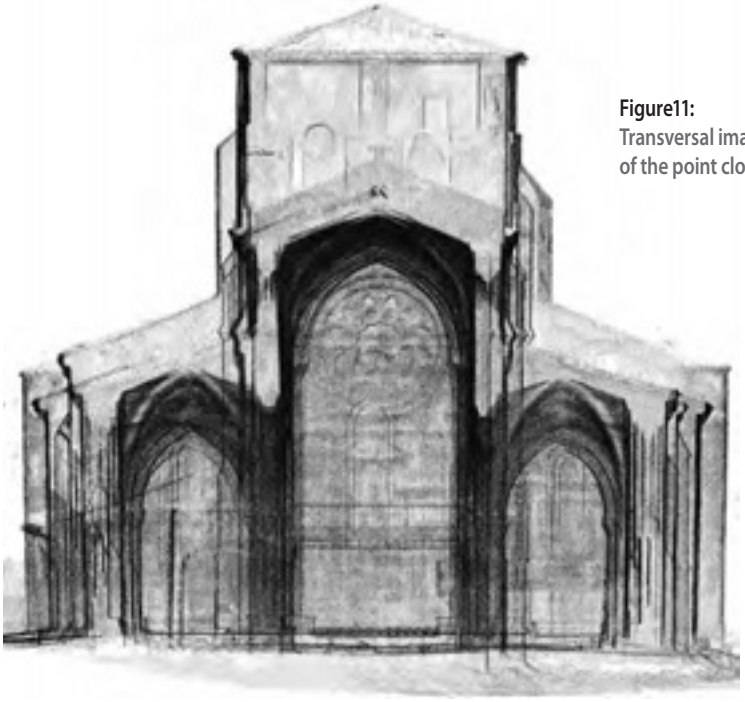


Figure11:
Transversal image
of the point cloud.

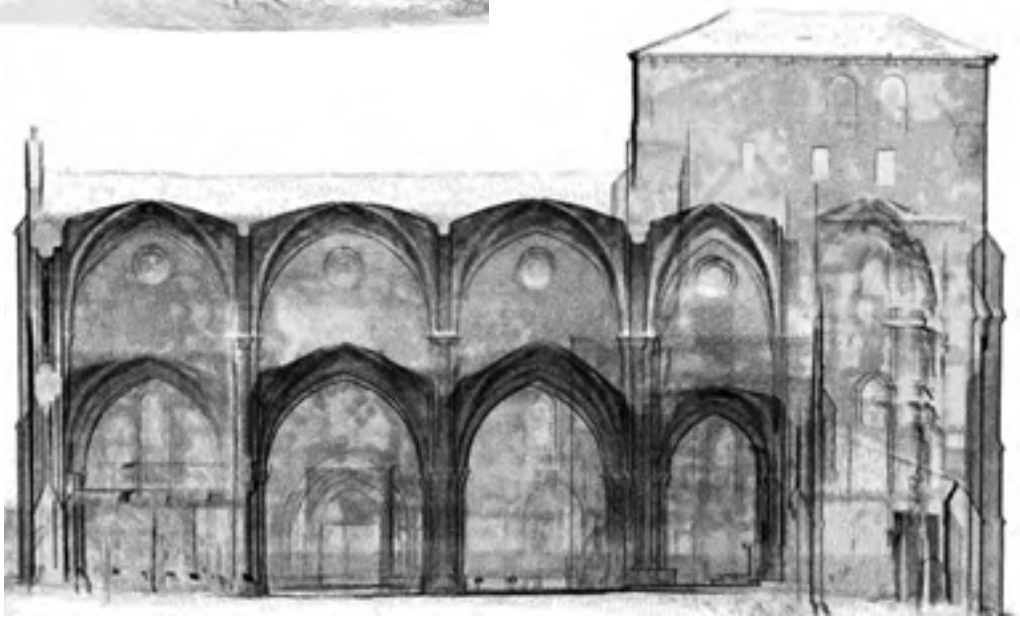


Figure 12:
Longitudinal view
of the church.

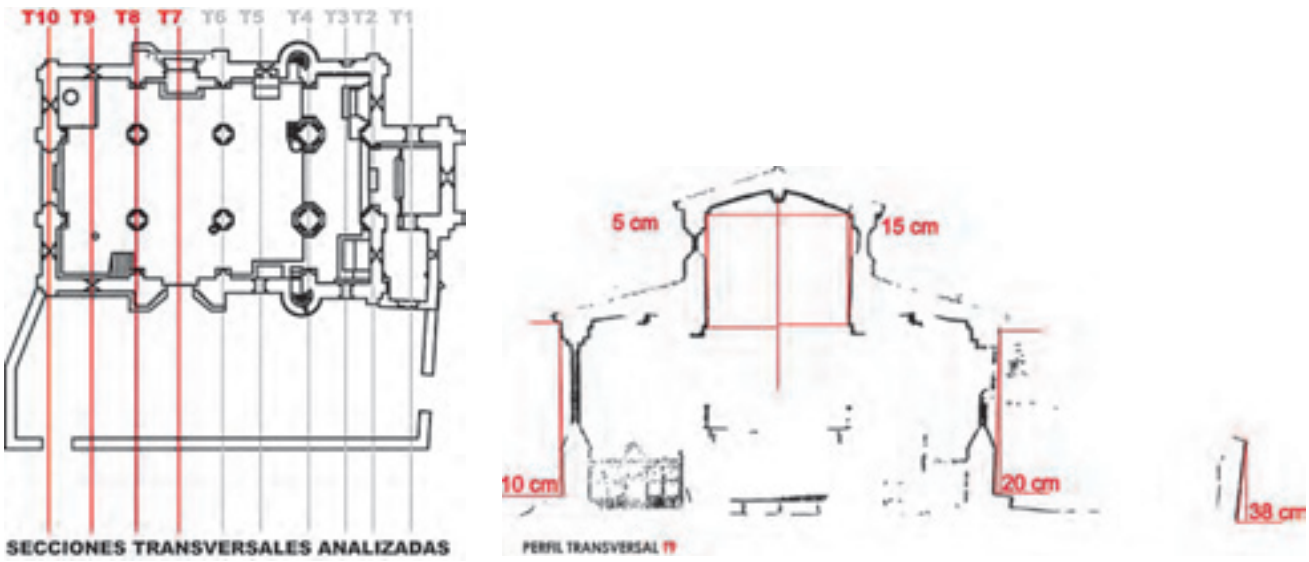


Figure 13: Inspection by cross sections. Dimensioning failures.

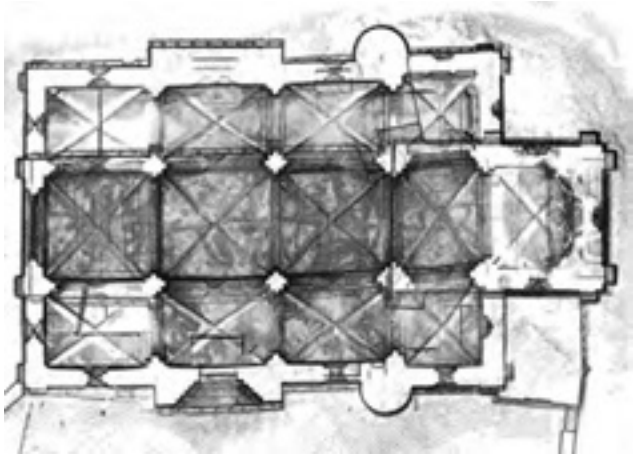


Figure 14: The floor plan appears plastic-like deformed.

way of highlighting some significant structural damages. In the next two images is showed how well 2D image files obtained by means of projection of the clouds and some further image processing give a short of radiography of the monument.

Structural Deformations

The main problems related to the identification and evaluation of structural deformations involves the principal directions for walls lean and the quantification of such a deviation. The absolute error bound is about 1 cm.. Independent analysis of transversal, longitudinal and horizontal sections has been performed.. The distribution of deviations with respect to the vertical is not equally distributed across the building.

Transversal sections

A sample of transversal sections, makes it possible to verify that the main lean, ranging from 1.3 to 1.8 degrees corresponds to the exterior south façade.

Longitudinal sections

As has been done with cross sections. The study of longitudinal sections shows that the maximum inclination is between 0.5 and 2.8 degrees and corresponds to the exterior west facade.

Horizontal sections

The axis of the south wall of the church eastern end does present a discontinuity with respect to the axis of columns of the principal nave with a difference of 25 cm. The error originated in the transformation of the building from Romanesque to early Gothic style. In particular, pillar bases do not compose an exact orthogonal network but are displayed in different positions with angles of about 88° instead.

Evaluation of structural deformations

From a technical point of view, the identification and the quantification for the wall's lean and misalignments presents two main orientations:

One shown by the longitudinal axis of the principal nave towards the south wall; in the south facade the lack of verticality is maximum, and this affects also the wall which opens to the atrium.

The other main gradient is showed by the wall which closes the feet of the temple

Furthermore, the longitudinal axis evidences lack of continuity, with displacements along intermediate components. Some pillars present displacements towards the south, which could be the origin of the largest cracks and the critical state of conservation of the building.

The most outstanding list affects some parts of the south wall where some vestiges of Roman cisternae have been identified. With the top side being 38 cm displaced from the vertical in 316 cm of height, resulting in a dangerous inclination of 6.72 degrees.

Contribution to the Heritage. Conservation and Protection. Conclusions and Future Work

As a resume, the whole structure is far from being stable. Indeed, recent corner ashlars falls and the fractures that are growing in the basement (possibly due to water filtration from an identified the Roman cisternae close to the church west) threaten to collapse the building totally or partially in the near future if there is no intervention. Fortunately, as a result of this work, some consolidation interventions have recently been executed.

In this work we have developed a hybrid image- and range-based methodology for an accurate evaluation of structural damages of buildings. This will surely be a positive contribution in the field of Cultural Heritage Conservation. The volumetric analysis performed clearly shows the effects and, consequently, helps to identify the causes of structural damages. Hence, it contributes in a decisive way to the assessment in the design and application of restoration policies. Still, there is much work to be done. Some of this, for which we are developing specific tools, such as 1) software aimed at facilitating the identification of damages to materials (i.e: state of walls, based in texture analysis), 2) the integration of basic geometric elements (piecewise dominant planes linked to walls and piecewise quadratic elements linked to vaults and dome), or 3) the identification of structural elements and software tools for Structural Analysis.

Acknowledgements

The authors acknowledge to the CICYT Project MAPA (Modelos y Algoritmos para el Patrimonio Arquitectónico) of the Ministry of Education and Culture for their partial financial support.

References

CIPA2001: Surveying and Documentation of Historical Buildings-Monuments-Sites. Traditional and Modern Methods, CIPA Intl workshop (Potsdam, Germany), 2001.

Dequal, S., 2003: "International Cooperation to Save the World's Cultural Heritage", The Intl. Archives of the Photogrammetry , remote sensing and spatial information sciences, Vol XXXVI, 5/C 34, 2003.

El-Hakim 2005, S, .Remondino, F., and Gonzo, L., eds: Virtual Reconstruction and Visualization of Complex Architectures, The Intl. Archives of the Photogrammetry , remote sensing and spatial information sciences, Vol.XXXVI, Part 5/W, 2005.

Fernández 2006, J.J. et al: "Extended Digital models for planning and management of interventions in buildings and complex urban models", 3rd Intl Conference on the Virtual City and the Territory, Bilbao (Spain), 2006.

Finat, 2005 et al: "The Roman Theater of Clvnia (Burgos, Spain): Hybrid Strategies for Applying Virtual Reality on Laser Scanning 3d files", The Intl. Archives of the Photogrammetry , remote sensing and spatial information sciences}, Vol.XXXVI, Part 5/W, 2005.

E. Malinverni, ed, 2003: "Vision Techniques for Digital Architectural and Archaeological Archives", The Intl. Archives of the Photogrammetry, Remote sensing and Spatial Information Sciences, Vol.XXXIV, 2003.

SanJosé, J.I. et al, 2006: "Risk Analysis and Diagnosis of Damaged Structures in Historical Buildings: Strategies for Assessment and Intervention", Proc. Intl Conf. and Brookerage event "Constructive Research Needs for the Heritage Protection", Cavtat (Croatia), 2006.

Simple Tools for Architectural Photogrammetry

V. Tsioukas

Department of Architectural Engineering, The Democritos University of Thrace, New Building of Central Library, Kimmeria 67100, Xanthi, Greece, vtsiouka@arch.duth.gr

ABSTRACT

In this paper a CAD application embedding photogrammetric procedures is described. Oleg Kolbaskin has originally created the CAD application and the photogrammetric procedures were implemented in the Department of Architectural Engineering of our Institute. The software can be used from both novice and experienced users in order to provide rectified images for cultural heritage documentation in the best quality using appropriate calibration and monoscopic image processing algorithms. Since it is based on a CAD environment further restitution and drafting can be followed in order to provide the 2D top view plans and facades' plans of sites and buildings. The original images are calibrated and corrected using an advanced image processing software procedure that provides the final images to be rectified. The rectified images may be then produced using either the classical digital rectification algorithms of the central projection solution or the perspective geometry solution (geometry correction based on the determination of vanishing points).

Problem Statement

One of the main tasks of the Architects' profession is in the field of Architectural Conservation and Restoration of Buildings and important Cultural Heritage Monuments (archaeological sites, excavation sites, traditional settlements, urban complexes of high historic value, etc).

The expertise, an Architectural Engineer should have in order to have the ability to accomplish the hard task of a restoration, should include special knowledge on modern recording techniques since they will help him to prepare a proper documentation. The results of the documentation project will lead to the final restoration study of the building. The appropriate techno-economical study will give the best profit result of the restoration.

A basic tool for the creation of the digital recording files of top-views, section and facade plans for the documentation of a building is a CAD software application. For the recording of flat vertical facades, the procedure of digital photogrammetric rectification has been applied with great success in several cases in the past (Dallas, 1996).

AutoCAD by AutoDesk, the well-known digital design and drafting application, is the most common software tool found in an Architect's office. It has been used with great success for the creation of 2D designs and 3D models of buildings. Although, the basic version is embedding some raster processing algorithms it does not include photogrammetric processing modules. For that reason, most of the owners of an AutoCAD software license are using an add-on module to create rectified images and mosaics of buildings' facades (Colorview GIS ImageRectifier by Peak Geo-Design, Inc.; ELCOVISION by PMS Photo-Mess-Systeme AG; PhoToPlan by kubit GmBh; SUPER/IMPOSITION by Datem). In other cases, the users prefer to use standalone raster processing applications to create the rectified images, which are later inserted in the AutoCAD environment to produce the final restitution designs.

Similar applications exist also as add-on modules for the Bentley's Microstation CAD application (Intergraph's IRAS/C and Bentley's Descartes). The Microstation application has been widely used from several recorders in the past.

In the past, some researchers have developed their own non-commercial applications in order to rectify digital images in architectural recording projects. Their aim was mainly to create the appropriate tools equipped with all the necessary features to accomplish their heavy research tasks and not to merchandize their applications.

Technological Approach

Photogrammetric rectification

The most of the applications that create rectified images, coming from either conventional or metric cameras, are using the projective transformation equations to define the relation between the film or digital sensor plane and the recording plane of a building's facade. In this case, the building's facade is considered flat and the low relief (if present) is assumed to produce negligible deformation on the final rectified image. The observation-measurements of at least four ground control points (predefined and topographically measured) on the image will lead to a solution of the unknown parameters that is connecting every point of the facade onto its digital image. The rectified image is finally generated through a resampling process.

The advantages of the method are:

- Quality control. By using more than the four minimum control points and through the statistical analysis it is possible to estimate the mean error and standard deviation of the produced rectified image. Adjustment is providing the optimal solution of the rectified image.
- The connection of every point on the rectified image to the local coordinate system is feasible. The local coordinate system is implemented with the use of a common Total Station used to define the control points' location on the building's facades.
- It is a fast and easy process.
- It is leading to a complete digitisation, if the rectified image is used properly in a CAD environment.

In the case where it is not possible to measure ground control points on the building's facade (due to the inability to access the building, or if the image has been created from an old photograph scanning) the definition of the vanishing points on the image, through the collection of parallel horizontal or vertical lines, can determine the position of the camera in relation to the building's facade locus (Karras, 1992). A similar product as the rectified image is generated. However, it lacks the quality control provided from the typical digital rectification process since no redundant control point measurements exist. No adjustment is applicable and only a couple of distance measurements can be used to calculate the final rectified product. The measurements that are used are horizontal and vertical distances that provide the correct scale of the rectified image (Karras, 1992; Fangi, 2001).

However, the advantages of the method are the same as in the previous case of a rectified image using ground control point measurements. Additionally:

- No complicated measuring devices and topographic networks are necessary.
- They provide a rectified image product in a very short time. However, the users of this photogrammetric procedure might not or do not want to have any knowledge of photogrammetric theory.

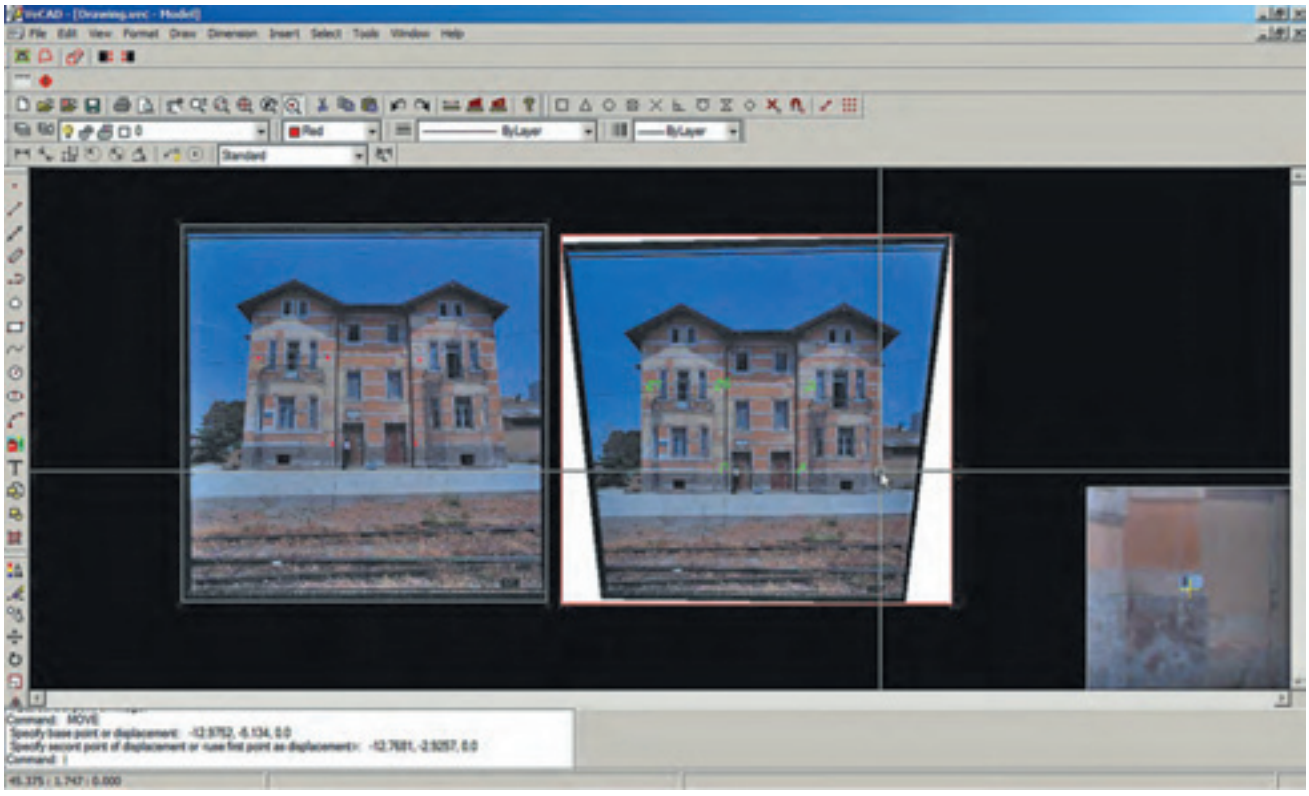


Figure 1: The rectified image was produced using control points measurements. In the lower right corner of the drawing space a magnifier window is displaying, in zoom, the region aground the cursor.

Our approach

In the teaching process of courses concerning digitization, recording and restitution of buildings' facades using surveying techniques and Photogrammetry, common commercial CAD applications have been used in our Department. The computers in the laboratories of our Department are equipped with the appropriate commercial applications to produce rectified images and are able to provide digital 2D designs of buildings' facades. However, the software licenses in the laboratories do not cover the elaboration of recording projects away from the university facilities. The students have the need to execute the photogrammetric and CAD applications on their personal computers at home. This need has lead the author to develop a software application that will have the ability to provide digital rectified images using both the previously mentioned techniques and is free of charge to be used by anyone (student or not) for non-commercial applications and projects (educational and research purposes).

The software has been based on the source code of VeCAD, provided by Oleg Kolbaskin and is comprising of a full CAD application. The contribution of the author was to embed all the photogrammetric processes to produce the rectification of a central projection image, using ground control point measurements *(figure 1)* or vanishing point geometry correction *(figure 2)*. Many of the features of the CAD environment are very similar to the ones of the common commercial applications.

Another application has been developed by the author to contribute in the best possible way to the creation of the most appropriate photogrammetric results. Since, the images that are processed are mainly coming from typical commercial digital cameras (i.e. student cameras) the low quality of their lenses are generating great radial distortion errors *(figure 3a)*. The image calibration application, that has been developed, is used to calculate the radial distortion parameters according to the Beyer model (Beyer, 1992). Prior to the use of the camera the user is taking a snapshot of an A4 printed targets page (of circular shape) that are automatically identified and defined accurately on the image using a best fitting ellipse algorithm. Additionally, commercial software applications such as Photomodeler can be used to provide the camera calibration parameters that will be used to create the corrected images (http://www.photomodeler.com/index.htm). Using a resampling and filtering image processing procedure, every image generated through the specific camera is then corrected *(figure 3b)* (Sechidis, 1999).

Potential Use

The proposed software application can be used free of charge from any Cultural Heritage Recorder that wish to provide for non commercial purposes, rectified images and digitised drawings of buildings facades and other planar surfaces. The program is not a commercial application and thus no fee is charged for its use. It can be downloaded from the personal website of the author http://utopia.duth.gr/~vtsiouka/VeCAD-Photogrammetry/. Inside the downloadable zipped file,

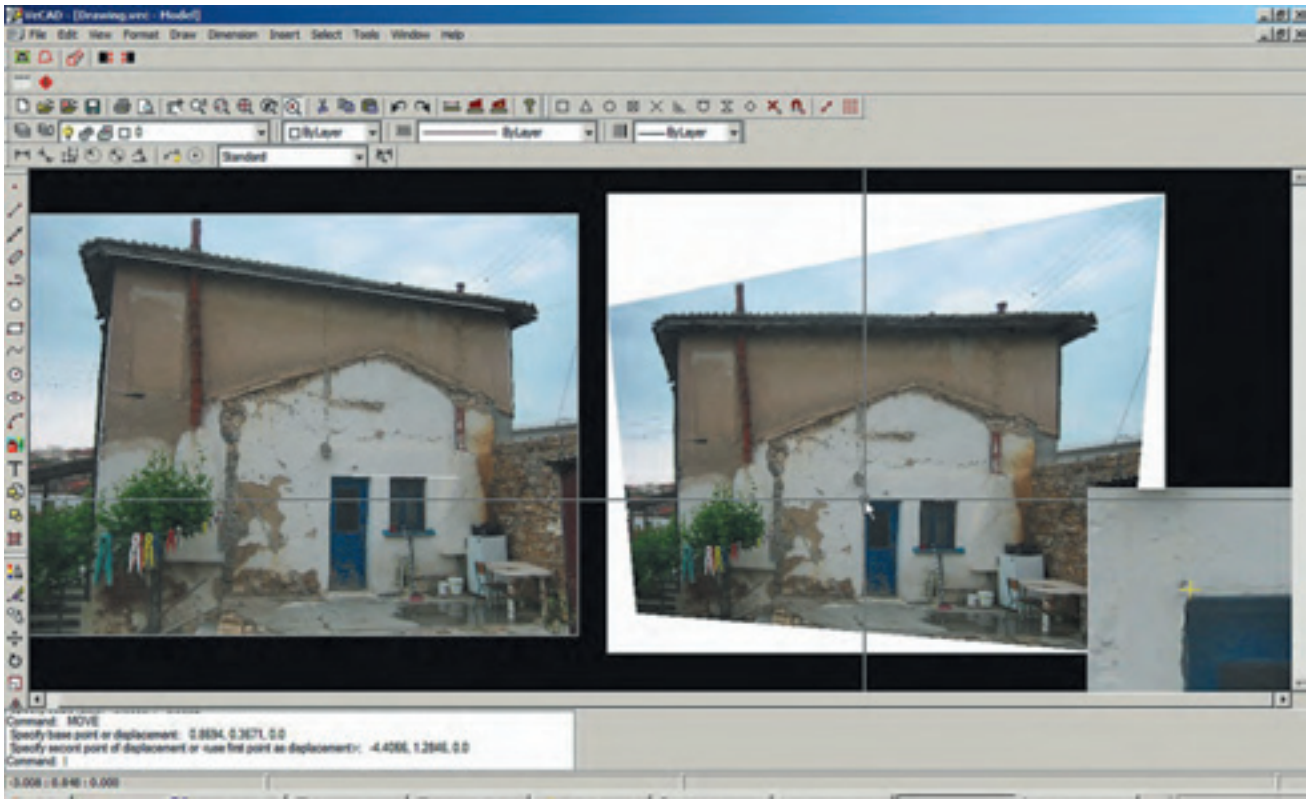
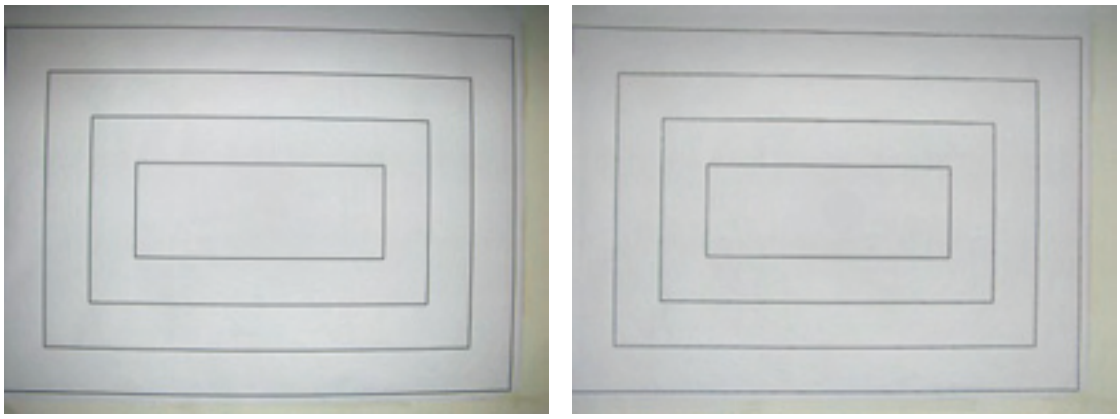


Figure 2: Original (left) and rectified (right) images processed in the CAD Environment. The rectified image was produced using vanishing points geometry.



Figures 3a and 3b: Radial distorted and corrected control images.

- the software application executables and the necessary setting files,
- instruction's manuals in Greek and English language,
- sample images and surveying data and
- demonstration videos

are included.

This information will give a first guide and demonstrate the use of the program to any potential user.

Contribution to the Heritage Conservation and Protection

The author has developed a software module and a calibration software application to support the teaching and research activities in the Department of Architectural Engineering of the Democritos University of Thrace. The application is able to provide rectified images using typical photogrammetric processes in a CAD environment featuring:

- No cost (but only for non-commercial applications)
- Low hardware demands
- Ease of use for an experienced CAD user.

The main aim of this research activity was the wide spreading of photogrammetric image processing practice especially for the recording purposes of buildings and sites, by an Architect, an Archaeologist or a Surveying Engineer.

References

Beyer, H., 1992, Ph.D. Thesis: "Geometric and Radiometric Analysis of a CCD-Camera Based Photogrammetric Close-Range System"

Dallas, R.W.A., 1996, Architectural and archaeological photogrammetry. In Close Range Photogrammetry and Machine Vision, K. B. Atkinson (ed.), Wittles Publishing, Caithness, pp. 283-302

Fangi, G., Gagliardini, G., Malinverni, E.,S., 2001, Photointerpretation and Small Scale Stereoplotting with Digitally Rectified Photographs With Geometrical Constraints, Cipa 2001 XVIII International Symposium, Potsdam, Germany

Nickerson, S., Chapiro, A., 2005, ASRix : A Simple Digital Image Rectifier, CIPA 2005 XX International Symposium, Torino, Italy

Karras, K., Petsa, E., 1992, The use of perspective in uncalibrated images for the documentation of the facades of historic buildings without control. Terrestrial Photogrammetry and Spatial Information Systems for the Documentation of Cultural Heritage. Ziti Editions, Thessaloniki, Greece, pp. 199-212 (in Greek).

Sechidis, L., Georgiadis, C., Patias, P., 1999, Transformations for "Calibrated image" creation using camera reports and distortion models. ISPRS Vol XXII Part 5W11, Workshop "Photogrammetric measurement, object modeling and documentation in architecture and industry", Thessaloniki, Greece, 7-9 July, 1999. pp 215-219.

Streilein, A., 1991, Development of a Digital System for Architectural Photogrammetry.

3 Best Practices and Applications (2009)

5.1 Introduction

The following seven papers are presented as "Best Practices and Applications" in the next pages. The selection is based on the papers presented to the CIPA Symposium in Kyoto (2009).

1. Application of a low cost laser scannerfor archaelogy in Japan
   (Akihiro Kaneda)
2. *A study on the gps tracking analysis for information management on heritage site*
   (S. Kim, J. Kim)
3. Multispectral image analysis for bas-relif at the inner gallery of bayon temple
   (T. Morimoto, M. Chiba, Y. Katayama, K. Ikeuchi)
4. Introducing EDM survey for recording vernacular heritage and sites in Pakistan
   (Salman Muhammad)
5. 3D model of gedongsongo templeand topography using terrestrial laser scanner technology
   (Adi J. Mustafa, Fahmi Amhar)
6. Digital Construction for Spatial Documentation of Beijing Old City
   (Ruoming Shi, Guang Zhu, Ling Zhu, Ruiying Wang, Yuqing Mu)
7. Laser scan documentation and virtual reconstruction of the Buddha figures and the archaeological remains (Bamiyan)
   (G. Toubekis, I. Mayer, M. Döring-Williams, K. Maeda, K. Yamauchi, Y. Taniguchi, S. Morimoto, M. Petzet, M. Jarke, M. Jansen)

Application of a low cost laser scanner for archaelogy in Japan

Akihiro Kaneda

Independent Administrative Institution, National Institutes for Cultural Heritage, Nara National Research Institute for Cultural Properties. 2-9-1 Nijyo-cho, Nara-shi, JAPAN. akaneda@nabunken.go.jp

ABSTRACT

In order to use three-dimension data collection in archaeological studies, it is necessary to establish realistic and feasible methods. This report presents our recent trial in Japanese archaeology. Three-dimensional documentation methods have begun to be used in Japanese archaeology. However, these methods are generally expensive. Three-dimensional documentation for archeological studies needs not so much use a highly technical or expensive technology as a realistic and feasible method for documenting artefacts. Therefore, we have experimented in low-cost three-dimension documentation methods for archaeology. Several photogrammetric and laser-scanning tools were tested. The NextEngine Desktop 3D Scanner Model 2020i (NextEngine, Inc.) yielded particularly good results for pottery and roof-tile artefacts. Point clouds data are able to transform and delete easily. These data export a three dimensional drawing with a traditional information. These works show several effects and problems with scanning archaeological artefacts. Most archaeologists in Japan are unable to use three-dimensional data effectively. We have to grope for how to use such data to classify and analyze artefacts. Furthermore, three-dimensional models of archaeological artefacts should be made accessible to the public on-line, and in museums.

Key words: Low cost laser scanning, NextEngine, Traditional drawing, Heijyo Capital Site, Nara.

Introduction

Aim of this report

The purpose of this report is to demonstrate a low-cost three-dimensional documentation method in Japanese archaeological studies.

Japanese archaeologists have conducted several archaeological excavations in recent years.

Most of these excavations are rescue excavations and according to the Agency for Cultural Affairs, more than 9500 such excavations were conducted in 2006.

Due to the nature of rescue excavations, however, the resulting archaeological records are difficult to use effectively. In addition, the budget for such excavations is limited.

A great deal of time and resources (both budgetary and human) are spent on making traditional drawings of the uncovered artefacts in the present situation.

Recently, three-dimensional documentation methods have begun to be used in Japanese archaeology.

However, these methods are generally expensive. It has not yet been possible to utilize the advantages of this new technology for archaeological studies.

Undoubtedly, Japanese archaeologists are eager to achieve a solution to the current problem – that is, to have access to more-economical and accessible tools.

Three-dimensional documentation for archeological studies needs not so much use a highly technical or expensive technology as a realistic and feasible method for documenting artefacts.

It is important to compare the new methods with the old, such as hand drawing, photography, and rubbing (which is a traditional recording method used in Asian countries). For example, we must ensure that the employment of new methods for documenting artefacts does not result in the loss of essential information that has been captured in the past using old methods.

Nabunken (Independent Administrative Institution, National Institutes for Cultural Heritage, Nara National Research Institute for Cultural Properties) has experimented in low-cost three-dimension documentation methods for archaeology.

Related Work

Recently, low-cost three-dimensional documentation methods for historical heritage have been in the spotlight.

Low-cost scanning equipment was examined for effectiveness in documenting archaeological artefacts (Lesk, 2007; Shear, 2008). The NextEngine scanner was reviewed by archaeologists (Abernathy, 2007). DAVID Laser scanner supplies a simple scanning tool for public use (http://www.david-laserscanner.com).

UCSD CISA3 project prosecute Digital Pottery Informatics with low-cost laser scanner (CISA3, 2009). They archive the digital Iron Age ceramics' data using NextEngine scanner.

Useful Open Source Software has been developed, such as Meshlab (http://meshlab.sourceforge.net/), Blender (http://www.blender.org/), and AutoQ3D (http://autoq3d.ecuadra.com/).

The ARC 3D Web service provides an online three-dimensional modelling tool (http://homes.esat.kuleuven.be/~konijn/3d/).

Methods and Results

Methods

Several photogrammetric and laser-scanning tools were tested. The NextEngine Desktop 3D Scanner Model 2020i (NextEngine, Inc.) yielded particularly good results for pottery and roof-tile artefacts. (These types of artefacts are common in Japanese archaeological sites.) The NextEngine Scanner is a low-cost laser scanner costing less than $3,000, including turntable and software *(figure 1)*.

First, pottery fragments and roof tiles excavated at the Heijyo Capital site (one of the ancient capitals of Japan) were scanned using this scanner. All artefacts were scanned in wide mode (dimensional accuracy is ±0.381 cm/±0.015 inch).

Each piece of scanned data was trimmed, and unified using Align and Fuse command at the ScanstudioHD with RGB texture.

Point clouds data were exported to .STL and .OBJ formats. These data were converted to PDF (PDF-E) file format by Acrobat3D ver.8.0 (Adobe Systems, Inc.).

It is possible to display this PDF file as an orthography projection or a perspective projection under various kinds of lighting conditions.

In addition, to create a bridge between the traditional approach to documentation and the new methods, it is necessary to include a traditional drawing of the artefact in a three dimensional documentation. For example, a pottery surface was drawn on the left side and the profile and inner area was drawn on the right side (This is the traditional way of presenting such information in Japanese archaeology, *figure 2*).

Point clouds data are able to transform and delete easily. To output a three dimensional drawing with a traditional information, Point clouds data cut out quarter of a pottery by Meshlab *(figure 3)*. This data was converted to a PDF file displayed in the shading illustration mode offered by Acrobat Reader9 (Adobe Systems, Inc.).

Figure 1. Laser Scanning by the Low-cost scanner.

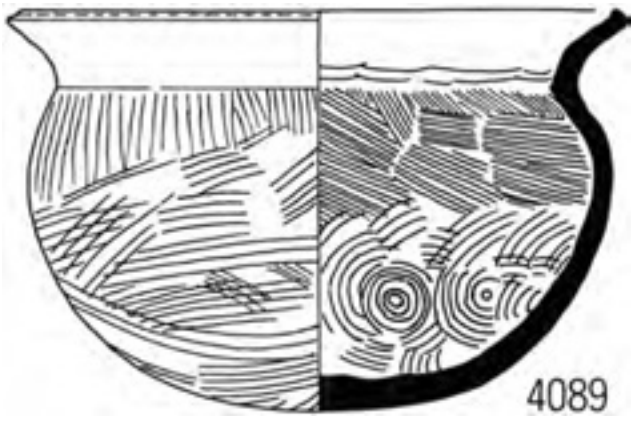


Figure 2. The traditional drawing (Haji ware).

Results

Many methods and types of low-cost equipment capable of capturing three-dimensional data are presently available. This capability is oftentimes more efficient than two-dimensional archaeological drawing.

For decorative artefacts, in particular, our trial demonstrated that it is possible to document artefacts faster using

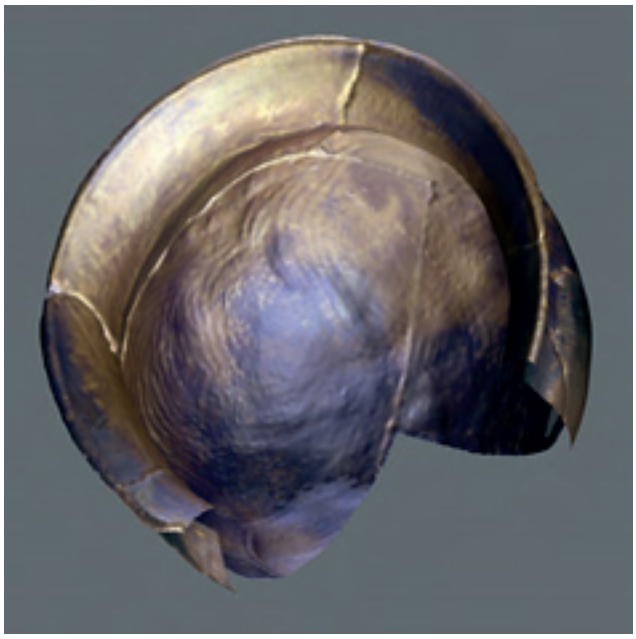


Figure 3. Cutting out the model with texture.

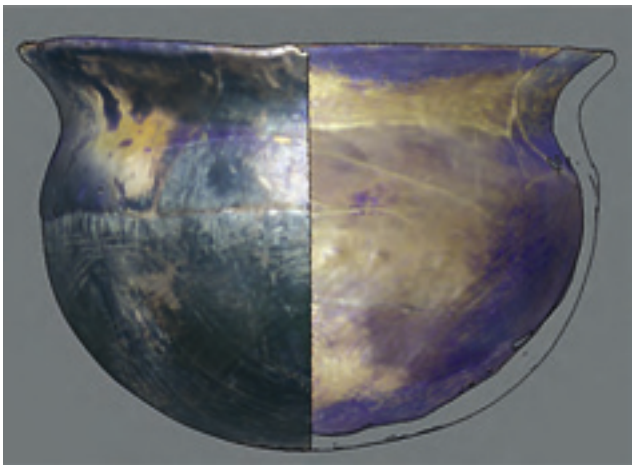


Figure 4. Shading illustration model from low-cost laserscanner.

three-dimensional methods, than it is using traditional methods. However, documenting artefacts such as dishes and cups is relatively easy using the traditional methods, but more difficult to document using three-dimensional methods due to the difficulty of aligning scans (as a result of the absence of match points). For example, the rims of pottery are often too narrow to allow for the lining up of match points. I will attempt to find a way to resolve this problem. Possible solutions include the appropriate positioning of artefacts and scanner, the selection of suitable targets, etc.

Conclusion

In order to use three-dimension data collection in archaeological studies, it is necessary to establish realistic and feasible methods. This report presents our recent trial in Japanese archaeology.

Most archaeologists in Japan (including the author) are unable to use three-dimensional data effectively. It is important, therefore, that archaeologists learn how to use such data to classify and analyze artefacts. For example, pottery and clay figures can be classified by the Fourier descriptor (Iwata and Ukai 2002) under way.

Furthermore, three-dimensional models of archaeological artefacts should be made accessible to the public on-line, and in museums. Our laboratory currently collaborates with archaeologists at local-government level and in foreign countries (such as China) on such projects. For example, PDF-X data generated from Ikoma Kiln sites (8th century A.D.) was presented at an annual exhibition about the excavations by the Ikoma City Board of Education.

Our laboratory will continue to further develop the utilization of three-dimensional data for use in Japanese archaeological studies.

References

Abernathy, D., 2007. Review: The NextEngine Desktop 3D Scanner. CSA Newsletter Vol.XX, No.1.

CISA3, 2009. Research Projects Digital Pottery Informatics. http://cisa3.calit2.net/arch/research/digitalpotery.php

Iwata, H. and Y. Ukai (2002) SHAPE: A computer program package for quantitative evaluation of biological shapes based on elliptic Fourier descriptors. Journal of Heredity 93: 384-385.

Lesk, M., 2007. 3-D scanning. Electronics in the Visual Arts conference 2007.

Shear, G., 2008. 3D Scanning for Profile Acquisition and Reconstruction of Mayan Ceramics. http://www.thepersistentbeat.com/Tech-Ceramics_files/3D%20Sherd%20Paper.pdf

A study on the gps tracking analysis for information management on heritage site

S. Kim, J. Kim

a Graduate School of Culture Technology, KAIST, 373-1 Guseong-dong, Yuseong-gu Daejeon, 305-701, Republic of Korea, sunny1015@kaist.ac.kr, jwkim21@kaist.ac.kr.

ABSTRACT

Depending on the concept of 'heritage interpretation', the significance of visitors and their behaviors on heritage site has been emphasized in recent days. The role of visitors should be redefined not only for immediate management issues of heritage site but also for long-term conservation of heritage site. This paper investigates visitors' behaviors on Gyeongbokgung Palace using GPS to record accurate data of their spatial pattern. During the process of research, GPS logger was used to track the spatial data of 100 visitor groups. As a result, 4 typical spatial patterns (Axis, Circulation, Hybrid, Front) of visitors were derived from GPS data. By statistical analysis, visiting time and spatial pattern have no relationship with destination familiarity of the visitor, composition of travelling party, or purposes of visit. Because of the spatial characteristics of the heritage site, visitors are easily confronted with 'ants-trail'. On the contrary, the spatial pattern of visitors can be explained by the level of provided information about buildings in Gyeongbokgung. The results of research will be applied to actual process of information management on the heritage sites. In conclusion, the structure and content of information about heritage site are the most important factors which can affect the visitor's spatial pattern and experience. This paper suggests information system in purpose of providing contextual information to visitors and providing more meaningful experiences to each visitor.

Key Words: Heritage Interpretation, Heritage management, Information management, Visitor behavior, GPS, Gyeongbokgung Palace.

Introduction

Definition of Heritage and Heritage Site

Heritage is one of the most controversial concepts since heritage revealed itself as a various functioning role in our society; identity of citizens, history of region, as well as important destination of tourism industry, means of community development. These versatile, such as social, historical, touristic and economical perspectives toward heritage sites hinder defining what heritage is and what it should mean to the public. Under these circumstances, many heritage practitioners simply leave the definition as broad and malleable as possible. (Harvey, 2001) Concurrently, Larkham defines heritage as "all thing to all people". (Larkham, 1995) Lowenthal sees that "heritage is today all but defies definition". (Lowenthal, 1998) Lastly UNESCO World Heritage Program defines heritage as "our legacy from the past, what we live with today and what we pass on to future generations". In addition heritage site is "the works of man or the combined works of nature and man, and areas including archaeological sites which are of outstanding universal value from historical, aesthetic, ethnological or anthropological point of view". Heritage is not substantial object which can be classified by the absolute rules irrespective of time change, but on the other hand, it is essentially accompanied with communicative process within stakeholders in society. So, Heritage refers to "value-loaded concept", and the value is always changing within social changes. (Hardy, 1988)

The definition of heritage is simple but still ambiguous. Heritage studies nevertheless should imply any actual, concrete conceptual background which can be used for heritage practitioners for the purpose of management. If we only emphasize unsystemized and heterogeneous side of heritage definition, heritage studies would be confronted with "morass of case studies". (Harvey, 2001)

Heritage Interpretation as Communication

ICOMOS Charters give practical guidelines to preserve, conserve, research on heritage sites. In the Charter of Venice (1964), "It is essential that the principles guiding the reservation and restoration of ancient buildings should be agreed and

be laid down on an international basis, with each country being responsible for applying the plan within the framework of its own culture and traditions." Consecutive ICOMOS charters emphasize the significance of public communication to heritage, including interpretation and presentation process. Interpretation particularly refers to the full range of potential activities intended to heighten public awareness and enhance understanding of cultural heritage site. Tilden insisted that heritage interpretation is more than to interchange of information between interpretation provider and receiver. It rather inspires and provokes the receivers of information, like citizens, foreign tourists, and potential visitors. The scope of interpretation is complex, but Tilden suggests six fundamental principles of interpretation. (Tilden, 1977)

- Any interpretation that does not somehow relate to what is being displayed or described to something within the personality or experience of the visitor will be sterile.
- Information, as such, is not interpretation. Interpretation is revelation based upon information, but they are entirely different things. However, all interpretations include information.
- Interpretation is an art, which combines many arts, whether the materials presented are scientific, historical or architectural.
- The chief aim of interpretation is not instruction, but provocation.
- Interpretation should aim to present a whole rather than a part, and must address itself to the whole man rather than any phase.
- Interpretation addressed to different visitor segments should follow a fundamentally different approach.

Antecedents

The concept of heritage interpretation implies that heritage site needs such information system which is based on visitor's behaviors and experience. This information system should give a new phase of personal experience and emotional provocation to visitors.

The advent of new technology has given an opportunity to researchers to model new media for visitor's information system, like PDA, Cellular Phone, etc. However, convergence between information technology and tourism industry often neglect the side of information users. There have been so many technological inventions for information system, but detailed knowledge of the basis of actual visitor behavior is lacking in designing the information system. (Nielsen, 2004) It impedes the system to be successful. Therefore, practical visitor studies need to be executed for establishing user-centric methodological framework in heritage information system.

Recent visitor studies were based on consumer behavior theory in the field of management, and attempted to explain visitor behavior by visitor behavior model. Visitor behavior is affected by situational influences, product characteristics, and individual differences. Situational influences of visitor is determined by nature of decision making, or composition of travelling party; family, friend or lovers. Product Characteristics are determined by purpose of trip and mode of travel. Family life cycle and socio-economic status influence individual difference. (Fodness and Murray, 1999) The satisfaction process of visitor also could be measured by theoretical model that explains the interrelationships between attitudes, prior beliefs, post-experience assessments. (del Bosque and Martin, 2008) The number of visiting sites also affects visitor behavior model. (Tideswell and Faulkner, 1999) However, limitation of theoretical behavior model lies in its methodology. The data which were derived from survey or questionnaire data, easily fail to describe the actual, spatial features of visitor behavior and these models remain at only theoretical level. (Mazanec, 2007)

Gareth Shaw insisted that research on spatial pattern of visitors has been neglected, though spatial concentration of visitors is the phenomena in tourism recently. (Shaw and Williams, 2002) Depending on the new technology, visitor behavior could be observed and analyzed. In national park, managers are confronted to organize the flux of visitors. They used ALGE system, which is used for athletic sports, to track the spatial pattern of visitors. (O'Connor and Zerger and Itami, 2005) In Akko, heritage site in Israel, 3 methods (GPS, Cellular Phone, Land Based TDOA) were experimented in tracking visitors. (Shoval, 2007) Engineers also developed computer algorithm that extract route of visitors from GPS data, and cluster groups by similar spatial pattern automatically. (Asakura and Iryo, 2007) VR and personal image, mental maps are combined to GIS recently. (Bishop and Gimblett, 2000) This kind of research is interdisciplinary approach of heritage studies.

Aim of Study

- To record spatial data of visitor on heritage site
- To analyze characteristics of visitor behavior in heritage site compared to other tour sites.
- To set guidelines for building interpretation system on heritage site based on visitor's experience.

Methods

Gyeongbokgung Palace

Gyeongbokgung, built in 1395 (the fourth year of King Taejo), is the historical site No.117 of Korea, and was the main palace of the Joseon Dynasty. It is the foremost palace of the five royal residences in Seoul, the capital of the Joseon Dynasty; Gyeongbokgung, Changdeokgung, Changgyeonggung, Gyeonghuigung and Deoksugung. The restoration project of Gyeongbokgung is in progress. As a result, the scenery of Gyeongbokgung will look differently from what it is at the current moment. However, there has been no research to observe the visitor's spatial pattern and analyze their experience on Gyeongbokgung. The results of study must be applied to new information system of Gyeongbokgung, as it will be restored for the next few years.

Methods

We used 2 methods to track the visitors in Gyeongbokgung; first, non-participatory tracking by trained researcher to record behavior of visitors, second, GPS tracking by GPS Logger to record more quantitative data of visitor's spatial pattern. These 2 methods function reciprocally. Finding only geometrical pattern from GPS data is hard to give implications about visitor's experience. The geometrical pattern itself does not tell why visitor has stopped at specific point and what visitor did at that moment. In contrast, non-participatory tracking depends on subjective decision of researchers. Therefore, a large amount of data must be recorded by GPS logger in objective way. Non-participatory tracking is process to examine "Spatial Behavior", and GPS tracking is process to examine "Behavior in Space". (Werlen, 2000)

We executed non-participatory tracking for 7 days, and 19 groups of visitor were analyzed. GPS tracking was carried out for 7 days, and 100 groups of visitor were analyzed. We used GPS740 Model (http://www.ascen.co.kr) for tracking visitors.

To supplement GPS data, we also executed 2 times of survey; before visiting and after visiting Gyeongbokgung. In prior survey, questions were 'purpose of visit', 'composition of travelling party', 'first visit or prior visit experience'. In posterior survey, 'impressive spot', 'used information source (brochure, signage, personal guide, none)' were asked to visitors. To control the environmental features, we carried out GPS tracking only on weekends during pm 12:00 ~ pm 4:00. For the same reason, the cloudy or rainy days were excluded.

Figure 1. GPS Logger.

Figure 2. Process of GPS Tracking.

Data Analysis

To analyze raw data from GPS Logger, we developed 2 algorithms. One is called Zone analysis. In Gyeongbokgung, there are 20 Zones to visit, including King's Garden, Pavilion, Hall, and Queen's room, etc. The outer rectangle in figure 3 shows area for the Throne hall compound. The inner rectangle shows Geunjeongjeon hall. Point A was recorded at 2009/03/28 13:08:19 and Point B was recorded at 2009/03/28 13:33:39. The differences between A and B refer to time of the visitors staying in the Throne hall compound. The developed algorithm calculated the visiting time of 100 groups in 20 zones automatically.

Figure 3. Zone Analysis.

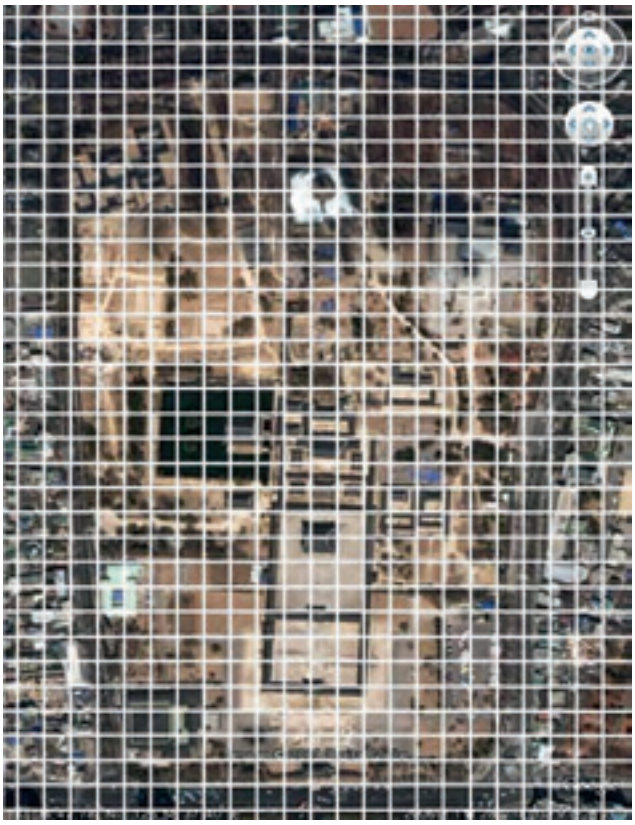


Figure 4. Grid Analysis.

Zone analysis is useful only for observing behavior in zones, but Grid analysis is useful for observing the whole area of Gyeongbokgung irrespective of zones. We separated Gyeongbokgung by 5183 grids. And the developed algorithm extracts the grid where visitors stayed more than 5 minutes.

Figure 5. 4 Patterns Mapping on Goole Earth. From left Axis, Circulation, Front, Hybrid.

By Grid analysis, we found the spot where visitors spent the most of time.

Result

The spatial pattern of visitors in Gyeongbokgung could be classified under 4 patterns; Axis, Circulation, Front, Hybrid. Axis pattern is for visitor who walked straight from entrance and only visited buildings which are on axis line. Visitors who walk in Circulation pattern doesn't move by axis line. They rather walk about Gyeongbokgung in clockwise or counter-clockwise rotation. Front pattern is for visitors who only stayed in front of Gyeongbokgung. They usually visited only 3 or 4 buildings. Hybrid pattern is the combination of Axis pattern and Circulation pattern.

Table 1. *Spatial Patterns*

	N	%
Axis	29	29.0
Circulation	22	22.0
Hybrid	33	33.0
Front	16	16.0
Total	100	100.0

By cross-tabulation analysis, 'information source' which media visitor used in Gyeongbokgung has correlation with the spatial pattern. Each information source, like brochure, personal guide, and signage, offers particular ways for visiting the site. And also 'desire of information' makes difference in visiting time. Visitors who want more information about heritage site or want to access information system tend to stay longer. Otherwise 'purpose of visit', 'composition of travelling party', and 'first visit or prior visit experience' do not indicate any statistical relationships with the spatial pattern or the total visiting time.

Spatial pattern of visitors is not only affected by the visitors themselves but also by the Supply-side. Supply-side includes the information system which heritage managers offer, and proximity of buildings. (Tideswell and Faulkner, 1999 and Shoval and Isaacson, 2007) As a result, we illustrated by GPS data which zone is the most frequently visited and which zone is not.

The figure 6 shows that visitors tend to stay more in the zone near the entrance. Point A refers to the main entrance of Gyeongbokgung. Previous studies have shown that a site in a close distance to others will be more attractive to visitors as it offers more opportunities. (Fotheringham, 1985) This is called the 'law of proximity'.

Table 2. *Hypothesis Verification*

H1. Purpose of Visit	Different Purpose of Visit makes different pattern.	Rejected
H2. Prior Visit Experience	Number of Prior Visit makes different pattern.	Rejected
H3. Composition of Travelling Party	Different Travelling Party(Friend, Family, etc) makes different pattern.	Rejected
H4. Information Source	Different Information Source makes different pattern.	Accepted
H5. Destination Familiarity	Repeat visitors will spend more time in site	Rejected
H6. Heterogeneity of preferences	The larger the travel party size, the more time will be spent	Rejected
H7. Risk and Uncertainty reduction	The further the visitors' city of origin, the more time will be spent	Rejected
H8. Desire of Information	Desire of Information will make difference in visiting time	Accepted

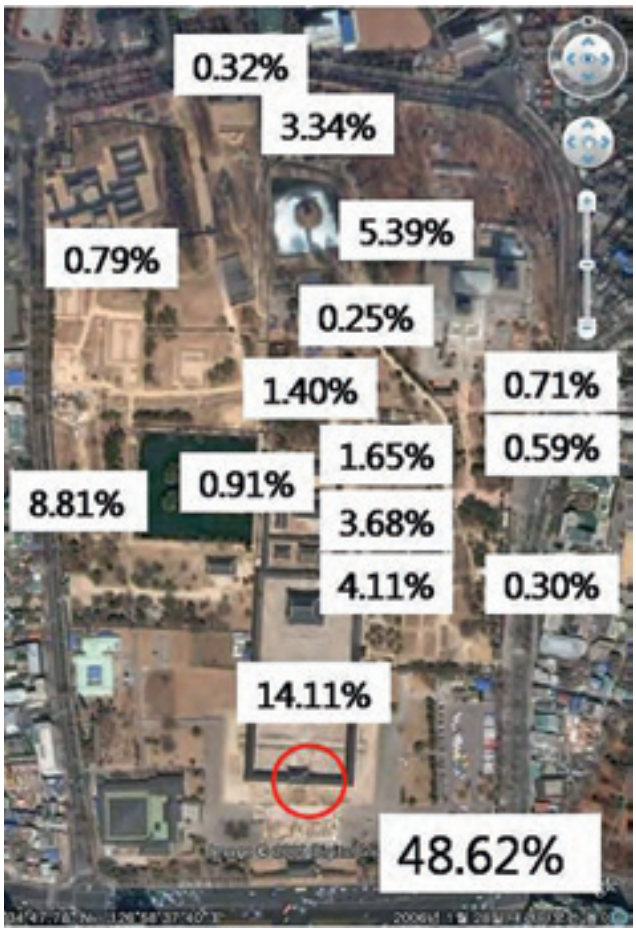


Figure 6. Time Spent in Each Zone.

There are two findings from spatial analysis of Gyeongbokgung. First is the exception of 'law of proximity'. Geoncheonggung Residence locates in northern side of Gyeongbokgung, but 3.34% of total visiting time is recorded. This number is quite high compared to nearby buildings. The reason is that Geoncheonggung has implicit information. Queen Myeongsung, King Gojong's wife, was assassinated here by Japanese. Even though Geoncheonggung is far from entrance, this famous historical event functions as vital information to visitors. The Second one is that visitors tend to stay much time out of zone. 48.62% of total visiting time is being spent out of zone. Heritage managers usually presume that visitors stay in the zone. Moreover, managers concentrated to develop information about zones. However, the fact shows that information about heritage site must contain pathway, resting place, trees, as well as a void space.

Discussion

The results indicate that visitors' behavior on heritage site are affected by the information system rather than their own features, such as purpose of visit, composition of travelling party. Previous studies showed the same results. Visitor behavior model has concentrated on the visitor's experience in macro level, like 2 or 3 days visiting. In micro level, like visiting only one place, visitors are confronted with 'ants-trail'. Individual Preference, purpose of visit play a vital role before visitors arrive at heritage site. But during the visit, they move in same pattern like ants. (Keul and Kuehbergerl, 1997) Therefore, the interpretation system should be designed carefully, since the information affect the visitor's experience directly. To deduct management issues from 'one' heritage site, behavior model and assumptions must be modified depending on particular situation that heritage site faces.

Visitors depend on the information which heritage manager offers. Visitors on heritage site are different from visitors at other tourism site or leisure site. Previous studies have shown that visitors on heritage site have a desire for leisure experience. (Prentice, 1993) And they also want to do window shopping, rather to get knowledge about heritage. (Markwell, Bennett, and Ravenscroft, 1997) But the result of previous studies was simply deducted, because heritage managers have offered only information for elite. (Bramwell, and Lane, 1993) This kind of heritage information is useless for giving more meaningful experience to visitors. Visitors need experience that is only possible on heritage site, even though they do not need 'to study' about heritage. Visitors have desires to participate, to walk around, to experience. Therefore, heritage interpretation is more human than researcher assumes. (Mitshce, and et al., 2008)

Contextual information system which emphasizes on the situation of visitors starts with archiving. Tracking data is also a kind of archive. Digital technology could be helpful for archiving. The most important point in archiving is to decide what has to be archived about heritage. Photos, footpath, articles, and mental maps could be examples. The target of archiving is extended from past to present days, and from historical, architectural fact to visitor's memory. Second step is to design the structure of system. The issues derived from the results must be reflected in the structure of system. There is no perfect structure, but there are storytelling methods that functions as a reference for designing structure. (Miller, 2004) Afterwards, information manager establishes strategy for each

Figure 9. Contextual Information System.

media; PDA, Kiosk, Web, and also analogue media like paper brochure. The service of media is segmented for various types of visitor.

Conclusions

Contextual information system will be evolving as socio-technical environment changes. It contains not only explicit information but also implicit information such as ideas, experience of people, and events. The information system must be comprehensible by a present visitor as well as a future visitor. (Cameron, and Kenderdine, 2007) Building heritage information system is a lively controversy. At least, information system must be designed according to visitor's desire and their experience. The definition of visitor must be enlarged to people who never visited the heritage site or people of future generation. For such purpose, visitor's need and experience should be observed by studying visitor behavior constantly. This research is the first step for building sustainable heritage interpretation system.

Relationships between nationality and visitor behavior, and differences among heritage sites are neglected on this research. Alongside, actual process of building information system could be the next research area. These all must be the tasks of future work.

Acknowledgements

The research was executed under authorization of Cultural Heritage Administration of Korea and Gyeongbokgung Office for access to Gyeongbokgung Palace.

References

Asakura, Y. and Iryo, T., 2007. Analysis of tourist behavior based on the tracking data collected using a mobile communication instrument. Transportation Research Part A, 41(7), pp. 684-690.

Bishop, I. D. and Gimblett, H. R., 2000. Management of recreational areas: GIS, autonomous agents, and virtual reality. Environment and Planning B, 27(3), pp. 423-436.

del Bosque, I. R. and Mart, H. S., 2008. Tourist satisfaction a cognitive-affective model. Annals of Tourism Research,35(2), pp. 551-573.

Bramwell, B. and Lane, B., 1993. Interpretation and sustainable tourism: The potential and the pitfalls. Journal of Sustainable Tourism, 1(2), pp. 20-27.

Cameron, F. and Kenderdine, S. 2007. Theorizing Digital Cultural Heritage: A Critical Discourse (Media in Transition). The MIT Press.

Fodness, D. and Murray, B., 1999. A model of tourist information search behavior. Journal of Travel Research, 37(3), pp. 220-230.

Fotheringham, A. S., 1985. Spatial competition and agglomeration in urban modeling. Environment and Planning A, 17(2), pp. 213-230.

Hardy, D., 1988. Historical geography and heritage studies. Area, 20(4), pp. 333-338.

Harvey, D. C., 2001. Heritage pasts and heritage presents: temporality, meaning and the scope of heritage studies. International Journal of Heritage Studies, 7(4), pp. 319-338.

Keul, A. and Kuehbergerl, A., 1997. Tracking the Salzburg tourist. Annals of Tourism Research, 24(4), pp. 1008-1012.

Larkham, P. J., 1995. 'Heritage as planned and conserved', in D.T. Herbert (ed.) Heritage, Tourism and Society. London: Mansell, pp. 85.

Lowenthal, D., 1998. The Heritage Crusade and the Spoils of History. Cambridge: CUP, pp. 94.

Markwell, S. and Bennett, M. and Ravenscroft, N., 1997. The changing market for heritage tourism: A case study of visits to historic houses in England. International Journal of Heritage Studies, 3(2), pp. 95-108.

Mazanec, J. A., 2007. New Frontiers in Tourist Behavior Research: Steps toward Causal Inference from Non-experimental Data. Asia Pacific Journal of Tourism Research, 12(3), pp. 223-235.

Miller, C. H., 2004. Digital Storytelling, A Creator's Guide to Interactive Entertainment. Focal Press, pp. 165-176.

Mitsche, N., and Reino, S., et al., 2008. Enhancing Cultural Tourism e-Services through Heritage Interpretation. Information and Communication Technologies in Tourism Proceedings of the International Conference in Innsbruck, pp. 418-429.

Nielsen, L. B., 2004. Post Disney experience paradigm?: some implications for the development of content to mobile tourist services, ACM International Conference Proceeding Series, 60.

O'Connor, A. and Zerger, A., et al., 2005. Geo-temporal tracking and analysis of tourist movement. Mathematics and Computers in Simulation, 69(1-2), pp. 135-150.

Prentice, R., 1993. Heritage: A key sector of the 'new' tourism. Progress in Tourism, Recreation and Hospitality, 5, pp. 309-324.

Shaw, G. and Williams, A. M., 2002. Critical Issues in Tourism: A Geographical Perspective, Blackwell, Oxford, pp. 135.

Shoval, N., 2008. Tracking technologies and urban analysis. Cities, 23(1), pp. 21.

Shoval, N. and Isaacson, M., 2007. Tracking tourists in the digital age. Annals of Tourism Research, 34(1), pp. 141-159.

Tideswell, C. and Faulkner, B., 1999. Multidestination travel patterns of international visitors to Queensland. Journal of Travel Research, 37(4), pp. 364-374.

Tilden, F., 1977. Interpreting our heritage. University of North Carolina Press.

Werlen, B., 2000. Sozialgeographie. UTB, Stuttgart, pp. 135.

Multispectral image analysis for bas-relif at the inner gallery of bayon temple

T. Morimoto[1], M. Chiba[2], Y. Katayama[3], K. Ikeuchi[1]

1. Institute of Industrial Science, The university of Tokyo, Japan - (tetsu23,ki)@cvl.iis.u-tokyo.ac.jp*

2. Graduated School of the Science & Engineering, Waseda University, Japan - mayukochib@fuji.waseda.jp

3. Tokyo University Agriculture and Technology, Japan - katayama@cc.tuat.ac.jp

Commission VI, WG VI/4

ABSTRACT

At the Bayon temple in Cambodia constructed by sandstone, a study on bio-deterioration is one of key tasks of conservation measures for it. Especially, the progress of the deterioration seen in the bas-relief of the inner gallery which was carved the myth world of Hinduism by outstanding description is remarkable. The purpose of this study is to investigate the kind, distribution, and reproductive cycle of biological colonization to discern the relationship with the environment attribute to deterioration and find an effective method to remove them. We assume that some of the microorganisms can be discriminated by detecting the absorbance spectra of photosynthetic pigments in them. We developed a new multispectral imaging system to analyze the spectral information of different microorganisms on the wall's surface. Our system has a wide field of view, low noise, negligible distortion and high resolution enable us to measure the bas-relief in situ. We also developed a segmentation method in order to the spectral image allow to discriminate kind and distribution of microorganisms. Our classification results show the difference in each microorganism's distribution between rainy and dry seasons.

Key words: Microorganisms, Bio-deterioration, Multispectral image, Normalized cuts.

Introduction

Spectral reflectance is inherent in the nature of objects. Different materials have different spectral reflectance. Object analysis based on this fact has been conducted in many fields, such as medical imaging, agriculture, remote sensing, and archaeology, to name a few.

Our Digital Bayon Project (Ikeuchi and Miyazaki, 2007), which have digitized the shape and surface reflectance of the Bayon Temple in the Angkor ruin for preservation and deterioration prevention, needs to determine what kind of microorganisms are present and how widely they exist over the structural surfaces. This involves the analysis of spectral reflection distribution of microorganisms living on the bas-relief of the Bayon Temple.

The microorganisms are one cause of deterioration in the inner gallery of Bayon Temple. Due to deterioration, the detailed bas- reliefs on the walls are losing their shapes. We examine the kind, distribution, and reproductive cycle of the microorganisms to find an effective method to remove them. We assume that some of them can be discriminated by detecting the absorbance spectra of photosynthetic pigments in them, and we find we can calculate absorbance from reflectance.

For the efficient analysis of spectral distribution over an object surface, a two-dimensional spectral image acquisition system is desirable. Traditional spectral cameras provide spectral data only from a limited area, often from a spot. It is difficult, if not impossible, to cover the entire surface of the bas-relief, whose size is 800m × 4m, located in the inner corridor of the temple. This is one of the motivations for us to develop an efficient, handy, and yet high-resolution spectral imaging system. The requirements of the system are: 1) to cover a wide area for efficient measurement to be able to determine distribution of microorganisms, 2) to be able to ignore variations of illumination conditions in dramatic weather changes from bright sunshine to dark squall, and 3) to design a handy system that can be transported to a deep jungle.

We developed a new multispectral imaging system using a Liquid Crystal Tunable Filter (LCTF) (Tominaga and Okajima, 2000), mounted on an automatic pan/tilt platform. Compared to conventional systems, our system has not only high image quality with sufficient spectral resolution but also a wide capturing angle for efficient sampling.

Preservation of cultural assets involves challenges to spectrum measurement. Cultural assets are often in severe outdoor environments, such as the environments of the pyramids

in Egyptian desert or the Angkor ruin in Cambodian jungle. In an outdoor environment, wide alterations in the illumination environment often occur quickly. Fixed exposure of a system causes saturation and underexposure. To tackle these problems, we developed a measuring method that can estimate optimum exposures based on noise analysis of the system.

Preservation of cultural assets also needs to determine not only the kinds of microorganisms that exist but also how widely they are spread and how much they mix with each other. This requires us to segment the multispectral images into spatial segments corresponding to the distribution of these microorganisms.

We propose an effective dimension reduction method by using Normalized Cuts (NCuts) (Shi and Malik, 2000), a class of non- linear dimensional reducers. NCuts methods are widely used as segmentation methods for RGB images in computer vision, but they are not used for multispectral image segmentation in general. NCuts methods are convenient in reducing dimension in a nonlinear manner, and simultaneously segmenting the data. One difficulty in applying NCuts method to our problem is the necessity of a huge memory space ($N \times N$) for creating an affinity matrix. We solve this issue by applying a local linear approximation (Bishop, 2008), by assuming local linearity on the tangential space of a global manifold space in the high dimension.

The specific contributions of our work are to propose a multispectral image acquisition technique for obtaining panoramic multispectral images, to develop a segmentation method to handle global nonlinear dimensional reduction, and to apply our method to the microorganism analysis of bas-relief of Bayon temple actually.

The structure of this paper is as follows. Section 2 describes our hardware design for panoramic multispectral imaging and capturing techniques of data acquisition for cultural assets. Section 3 derives a nonlinear dimension reduction method using the "kernel trick" and NCuts method, and applies the NCuts segmentation to a multispectral image. In Section 4, we evaluate our methods. In Section 5, we demonstrate the application for analyzing microorganisms on the bas-reliefs of the Bayon temple. Finally, we conclude the paper in Section 6.

Acquisition of a Multispectral Image

We developed a novel multispectral imaging system that has a wide view angle, high image quality, and an accurate spectrum. The system can efficiently measure a target object in an outdoor environment. In subsection 2.1, we describe the hardware construction of our system. In subsection 2.2, we describe the technique for capturing images in an outdoor environment. In subsection 2.3, we describe reconstruction of each band of images having different configurations, and how to stitch a multispectral image.

Panoramic multispectral camera

Our multispectral imaging system has been designed to be a handy system with spectrum accuracy in each pixel with a wide view angle. The system consists of a small monochromatic CCD camera with a liquid crystal tunable filter (LCTF), shown in Fig. 2, mounted on an automatic pan/tilt platform (CLAUS Inc. Rodeon VR head). The LCTF (CRI Inc. Varispec, Bandwidth 7nm) is an optical filter that allows the wavelength of the transmitted light to be electronically adjusted. The monochromatic CCD camera (Sony XCD-X710) with the LCTF mounted can obtain a series of two-dimensional spectral images by repeatedly changing the LCTF's transmittable wavelength with image acquisitions. The captured image has high image quality without distortion. The LCTF capturing system has a narrow field of view because the LCTF is mounted in front of the lens. We compensate for this problem by using an

Figure 1: Bayon temple in Cambodia.

Figure 2: Panoramic multispectral imaging system.

automatic panorama pan/tilt platform. The system captures a wide view multispectral image by synchronizing these three devices efficiently.

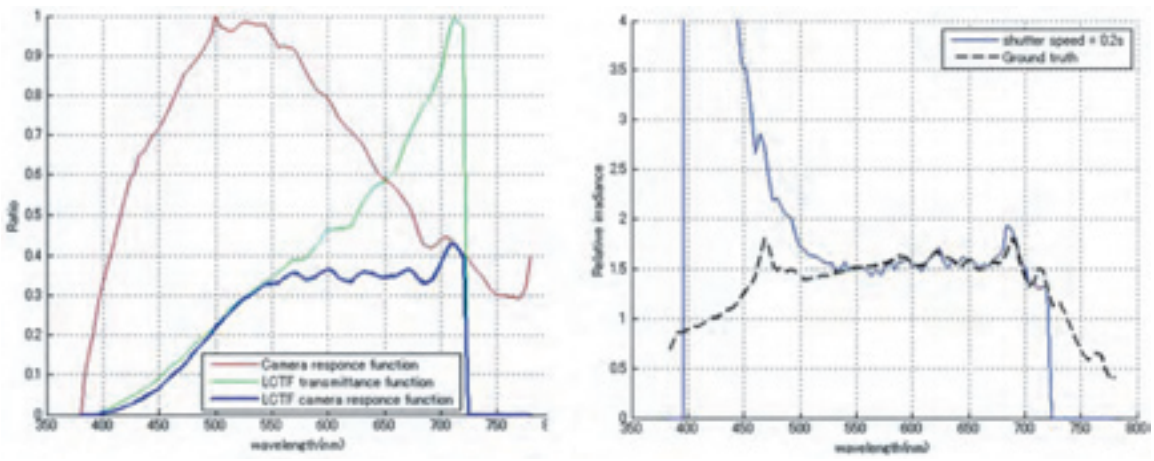
Estimation of adaptive exposure in an outdoor environment

The optimal exposure time is necessary to be determined in each wavelength due to the two reasons: uneven characteristics and varying illumination conditions. A multispectral imaging system using LCTF generally needs a fixed exposure time over the entire range of wavelengths for comparing pixel intensities over all wavelengths. However, the spectral sensitivity given by the combination of LCTF and monochromatic camera is very low in short wavelengths (e.g., 400-500 nm), as shown in Fig. 3a, and relatively high in other wavelengths. If the pixel intensity at a certain wavelength would be smaller than the dark current noise, we would not be able obtain a meaningful measurement at that wavelength. For instance, Fig. 3.b shows a measured spectrum under dark illumination. Longer exposure time is necessary for spectral accuracy with wavelengths from 400 nm to 500 nm than for other wavelengths.

Varying illumination conditions occur in an outdoor environment, in which many cultural assets are located. Our sensor samples spectral data by changing the LCTF's filtering characteristics and samples a series of images along the wavelengths. During this sampling period, it often occurs that the illumination condition varies due to the movement of clouds. If the intensity of illumination dramatically varies during measurement, it would induce saturation or underexposure at certain wavelengths. The dynamic determination of optimal exposure time at each wavelength is necessary for adjusting the effects of varying illumination conditions.

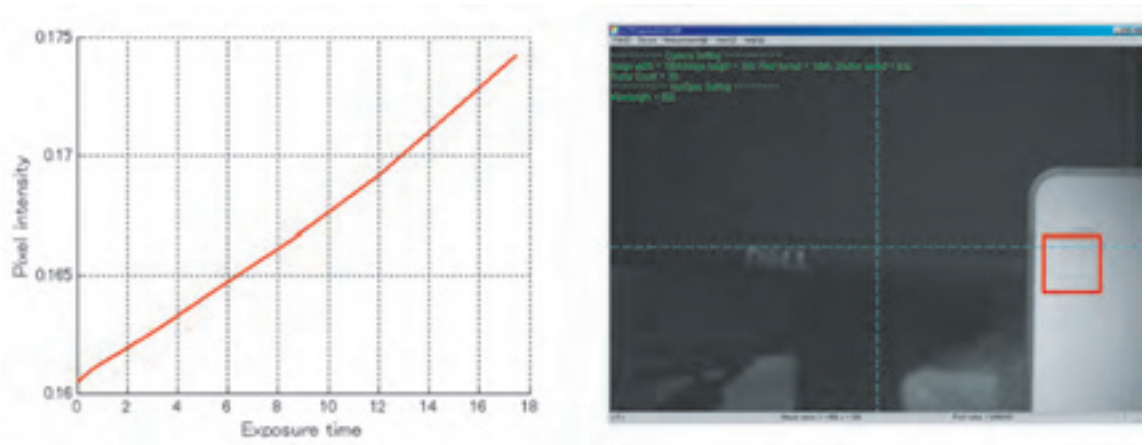
We attempt to estimate an optimal exposure time for each wavelength based on noise analysis (Reibel et al., 2003). The noise can be categorized into signal dependent noise (SDN) and signal independent noise (SIN). In this system, we mainly consider the effect due to the SIN, since the SDN is negligible compared with SIN. The SIN is composed of fixed pattern noise (FPN) and read-out noise, and photo response non-uniformity (PRNU). FPN is a dark current noise, a dynamic component. The read-out noise is composed of the reset noise, amplifier noise, and quantization noise. We focus on the FPN and the read-out noise, since PRNU is a static component easily calibrated in the initial stage.

The FPN depends on the temperature and the exposure time. Here, we assume that the sampling time is reasonably short, say 5 to 10 min, so that the temperature can be considered as constant. The FPN has a linear relation with the expo-



(a) (b)

Figure 3: (a) Spectral sensitivity function of monochromatic CCD camera and LCTF transmittance function (b) Illumination spectrum when the exposure time in all bands is fixed.



(a) (b)

Figure 4: (a) The correlation between the FPN and exposure time. (b) Captured image of panoramic multispectral imaging system.

sure time as shown in Fig. 4a. The linear relation can be expressed as follows $e_{DN} = at+b$, where t is an exposure time, a is the amount of the FPN increase depending on exposure times, and b is the amount of the FPN with zero exposure time at that particular temperature. These values are measured at the site before sampling from a series of images with various exposure times while the lens is covered with a cup.

The read-out noise appears randomly at pixel positions at each image. We model the read-out noise as a Gaussian distribution at each pixel. In order to evaluate the parameters of the Gaussian distribution, we obtain a series of lens covered images, and we calculate mean and standard deviation values. The mean value of images ε_{DC} are the FPN, and the standard deviation value of images ε_R are read-out noise. We use the upper bound of the SIN as $\varepsilon_{DC}+\varepsilon_R$.

Based on the discussion of the noise analysis, we design the procedure to determine the optimal exposure time at each wavelength. The procedure consists of two parts. The first part finds the exposure time that gives the brightest image of a white reference while avoiding saturation over all wavelengths. The second part determines any wavelength that gives lower value in the white reference than the SIN upper boundary, and, if this wavelength exists, it increases the exposure time while avoiding saturation.

The first part consists of:

Step 1. Select the brightest area ($m \times n$) on a white reference at each wavelength, λ, as shown in Fig. 4. b, and obtain the average brightness within the window, $L(\lambda)$. Repeat this step over all wavelengths

Step 2. Obtain the maximum value, L_{max}, among all the brightness values over all wavelengths.

Step 3. Determine the standard exposure time t_s as the longest exposure time when all the values in the brightest area found in Step 1 are not saturated. Namely, $L_{max} < 2^{16}$.

The second part rescues the particular wavelength image buried under the noise level. For this, we measure the FPN ε_{DC} and read-out noise ε_R by putting the cap in front of lens. Here, the average value is the FPN, and the standard deviation is considered as the boundary of the read-out noise.

In each wavelength, the optimal exposure time $t(\lambda)$ is adaptively estimated. The optimal exposure time $t(\lambda)$ can be represented as:

$$t(\lambda) = \begin{cases} t_s \dfrac{\varepsilon_{DC} + \varepsilon_R + \mu}{L(\lambda)} & (\text{if } L(\lambda) < \varepsilon_{DC} + \varepsilon_R + \mu) \\ t_s & (\text{otherwise}) \end{cases} \quad (1)$$

where μ is an offset value to bring the adjustment to the safer side.

Construction of panoramic multispectral image

After capturing images, we can synthesize the obtained images $L(i, j, \lambda)$ to the spectral power distribution image $L'(i, j, \lambda)$

$$L'(i,j,\lambda) = t_s \frac{(L(i,j,\lambda) - e_{DC}(i,j,\lambda))}{t(\lambda)} \quad (2)$$

Here, the FPN image $\varepsilon_{DC}(i, j, \lambda)$ in arbitrary exposure time can be estimated by using following equation, according to the linear correlation between the FPN and exposure time, as shown in Fig.4a:

$$\varepsilon_{DC}(i, j, \lambda) = \alpha(\lambda)\varepsilon^s_{DC}(i, j, \lambda) \quad (3)$$

where $\varepsilon^s_{DC}(i, j, \lambda)$ is measured as the FPN image first. This can be obtained to calculate the mean image of captured images when light is intercepted from the camera. The linear correlation between the FPN and exposure time is as follows:

$$\alpha(\lambda) = \frac{at(\lambda) + b}{at_s(\lambda) + b} \quad (4)$$

where a and b are, respectively, slope and intercept.

We calculate a spectral power distribution image $L(i, j, \lambda)$ which is divided into the channel values $L'(i, j, \lambda)$ in each pixel i, j by camera sensitivity function $C(\lambda)$, and LCTF transmittance function $T(\lambda)$. Fig. 3 shows the actual sensitivity functions of each.

$$L(i,j,\lambda) = \frac{L'(i,j,\lambda)}{C(\lambda)T(\lambda)} \quad (5)$$

Next, we stitch the multispectral images of different view angles. Stitching usually extracts image features from a pair of images, establishes correspondences among such extracted features, and calculates the translation and rotation parameters to superimpose overlapping areas for connecting these two images. Here, the features in multispectral images are different in each band image. To overcome this issue, we generate an intensity image using all the spectral images in each viewing direction. Second, we extract Scale Invariant Feature Transform (SIFT) features (interest points) (Lowe, 2004) from these intensity images and establish correspondences for obtaining the translation and rotation parameters. Finally, we stitch the spectral image of each view angle using these parameters. Fig.5 shows a synthesized panoramic multispectral image.

Multispectral Image Segmentation

Segmentation of a multispectral image needs dimensional reduc tion. For dimensional reduction, linear and nonlinear reduction methods exist. Our prime objects, microorganisms on the bas- relief of the Bayon temple, have a nonlinear characteristic in spectral distributions due to the combination of top and bottom layers. This nonlinear problem can be solved either by employing the "kernel trick" such as Kernel PCA (Schölkopf et al., 1998) or extending the Ncut method.

Nonlinear mixing

Some of the top layer's pixel spectra typically show mixed spectral characteristics between the top layers and bottom layer. In a remote sensing field, these cause a so-called spec-

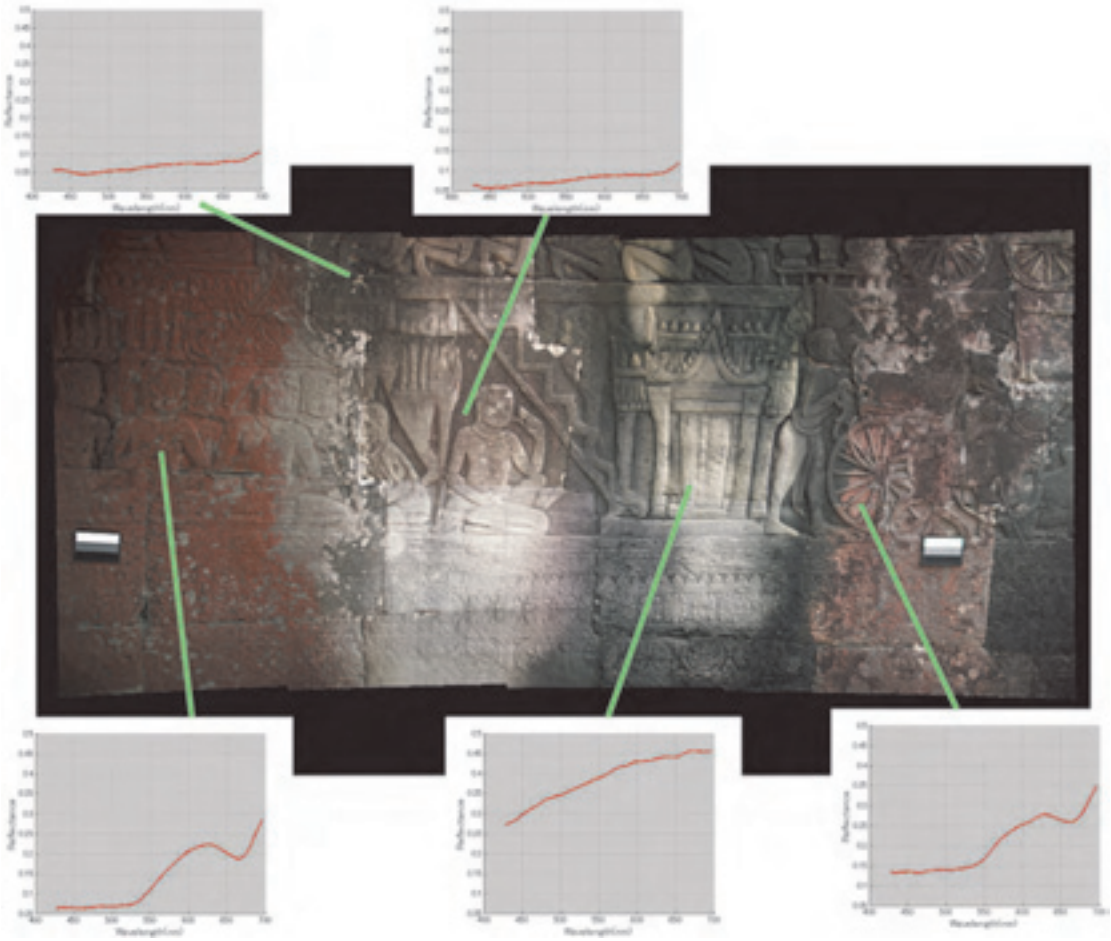


Figure 5:
Constructed panoramic multispectral image by pro posed system: this image has 81-dimensional spectrum in each pixel.

tral mixing (Keshava and F.Mustard, 2002). The spectral mixing can be categorized into two models: linear mixing and nonlinear mixing. The linear mixing occurs when one pixel consists of sub-parts from different materials; the different materials are distributed on the image plane. Generally, the linear mixing can be solved by reducing spectral dimension by using PCA, and clustering reduced data.

Our application, analysis of microorganisms, falls in the category of nonlinear mixing. This mixing occurs due to layer surfaces such as microorganisms and bottom rock surfaces. The different half-transparent materials are distributed along the line of sight. The PCA method cannot be applied to nonlinear mixing, but mixing can be achieved either by employing the kernel PCA (KPCA) (Schölkopf et al., 1998) or extending the NCuts method.

Normalized cuts

The NCuts method consists of nonlinear dimension reduction and clustering. Among various segmentation methods, the NCuts method has a unique feature of nonlinear dimensional reduction.

For this, let $I = \{I_1, I_2, I_3, \ldots, I_i, \ldots, I_N\}$, where I is input data, of m dimension, at the node i. Then, the NCuts method calculates the weight matrix W, representing similarity among the following formula:

$$W_{ij} = \exp\left(\frac{-\|I_i - I_j\|^2}{\sigma_I^2}\right) * \begin{cases} \exp\left(\frac{-\|x_i - x_j\|_2^2}{\sigma_x^2}\right) & (\text{if} \|X_i - X_j\|_2 < r) \\ 0 & (\text{otherwise}) \end{cases} \quad (6)$$

where Ii , Ij are input values of m dimensions at the node, i and j, σ_I^2 is the variance of input data, and r is the threshold of the proximity between two nodes in the image. NCuts solves the generalized eigensystem equation:

$$(D-W)y = \lambda Dy \quad (7)$$

Next, the Laplacian matrix, L = (D — W) can be calculated from the weight matrix, W. The normalized Laplacian matrix is given by:

$$\tilde{L} = D^{-\frac{1}{2}} L D^{-\frac{1}{2}} = I - D^{-\frac{1}{2}} W D^{-\frac{1}{2}} \quad (8)$$

where D is $N \times N$ diagonal matrix $D_j = \text{diag}(W(1,j), W(2,j) \ldots)$, $j = 1, 2, \ldots, N$, and W is $N \times N$ a symmetric matrix $W(i,j) = W(j,i)$. We can transform Eq. 8 into the standard eigensystem as follows:

$$D^{-\frac{1}{2}} W D^{-\frac{1}{2}} z = (1-\lambda) z \quad (9)$$

We can span a low dimensional space, of E dimensions, with the eigenvectors from the $E+1$ least significant eigenvalues, where E is the partition number, and we ignore the least

significant eigenvalue and the corresponding eigenvector. In the least significant space, all the input data have roughly same values due to the data normalization. We map the input data onto this low dimensional space.

$$y_{E_{ij}} = \frac{z_{i+1,j}}{\sqrt{D_{jj}}}, \quad (i=1,\ldots,E+1, j,\ldots,N) \qquad (10)$$

Finally, we can segment $y_{E_{ij}}$ into E clusters using the k-means method.

Applying NCuts to multispectral segmentation

Dimensionality is one of the issues in applying the NCuts method to the multispectral image segmentation method. The NCuts method requires making a weight matrix of a high-resolution image, of which the dimensions are $(N \times N)$, where N is the number of image pixels, typically more than 250,000. The NCuts method handles this issue by effectively using the proximity threshold, ignoring remote nodes for calculation, and ending up solving a sparse matrix of a high-dimensional image.

We employ a two-step method to overcome this high-dimensional issue. In our microorganism analysis, we cannot apply the proximity threshold because two remotely located regions from the same kind of microorganism should be classified into the same class. We assume that a nonlinear manifold of high dimension has a linear subspace in a low dimension such as local linear embedding (Roweis and Saul, 2000), or ISOMAP (Tenenbaum et al., 2000). First, we oversegment the multispectral image using a standard PCA method and k-nearest neighbor method, and form super-pixels corresponding to each segment. Then, we apply the NCuts method to these super-pixels.

Our implementation is as follows: First, we compute M super-pixels by over-segmentation using PCA dimension reduction and k-nearest neighbor method. Second, we calculate M mean spectra for all M super-pixels. Let $I = \{I_1, I_2, I_3, ., I_i, .., I_M\}$, where I is spectrum data of m dimensional. Third, we compute the weight matrix W from M (M < N) super-pixel values using the following equation:

$$W_{ij} = \exp\left(\frac{-\|I(i)-I(j)\|^2}{t^2}\right) \qquad (11)$$

In our experiment, we set t, a normalization factor, at 70% of the maximum distance in the weight graph. Finally, we can segment a multispectral image into material regions by using this weight matrix and NCuts.

Expeirmental Results

In this section, we describe two experiments. We conducted accuracy verification of Obtained multispectral image. We compared proposed segmentation method with a conventional method.

Accuracy verification of multispectral image

In this subsection, we evaluate image noise and spectral accuracy of a multispectral image given by our system.

Image Noise. Fig. 6a and b show, respectively, the captured image in fixed exposure, and the captured image by the proposed dynamic exposure method. The captured image from the fixed exposure method provides much noisier data. This effect is more apparent in the short wavelength area. On the other hand, the captured image given by our method is less noisy.

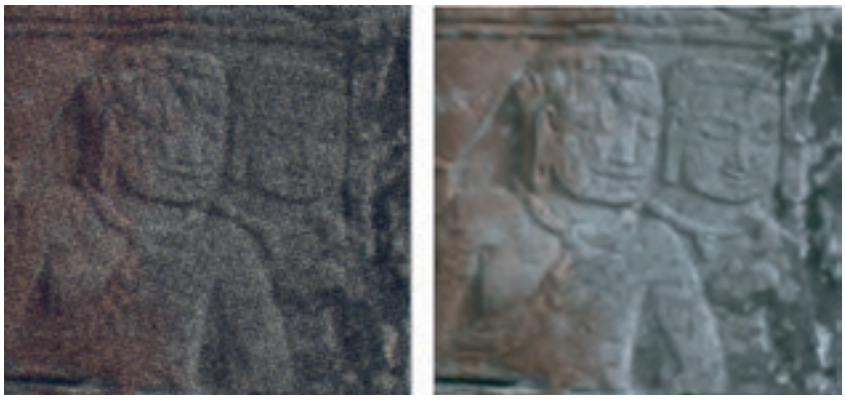
Spectral Accuracy. Table 1 shows the spectral accuracy of our system. In this experiment, we captured multispectral images of a color chart (X-lite Color checker), under artificial sunlight (Seric XC-100), by using both fixed exposure and the proposed dynamic exposure methods, respectively. Then, we measured the spectrum of each patch using a spectrometer (PhotoResearch PR-655) as the ground truth.

Table 1: *Spectral accuracy*

	RMSE				
Color	Fix	AE	Color	Fix	AE
DarkSkin	4.469	1.301	YellowGreen	0.914	0.764
LightSkin	1.347	1.064	OrangeYellow	0.915	0.870
BlueSky	1.254	0.909	Blue	0.627	0.398
Foliage	3.060	0.850	Green	1.204	0.657
BluishFlower	1.196	0.885	Red	0.953	0.887
BluishGreen	0.916	0.516	Yellow	1.102	0.914
Orange	1.460	0.987	Magenta	1.002	0.885
PurplishBlue	1.420	1.074	Cyan	0.619	0.449
ModerateRed	0.937	0.892	White	1.174	0.892
Purple	1.109	1.029	Mean	1.352	0.854

Second, we calculated the root mean square error (RMSE) between the obtained spectral data and the ground truth in each patch.

Compared with the RMSE values by the fixed exposure method, the RMSE values by the proposed method are much



(a) (b)

Figure 6: Image quality of obtained image (a) Captured multispectral image in fixed exposure time. (b) Proposed method.

Figure 7: Segmentation results of layered surfaces.
(a) Input image
(b) Method 1: PCA + k-means
(c) Method 2: KPCA + k- means
(d) Method 3: Proposed method.

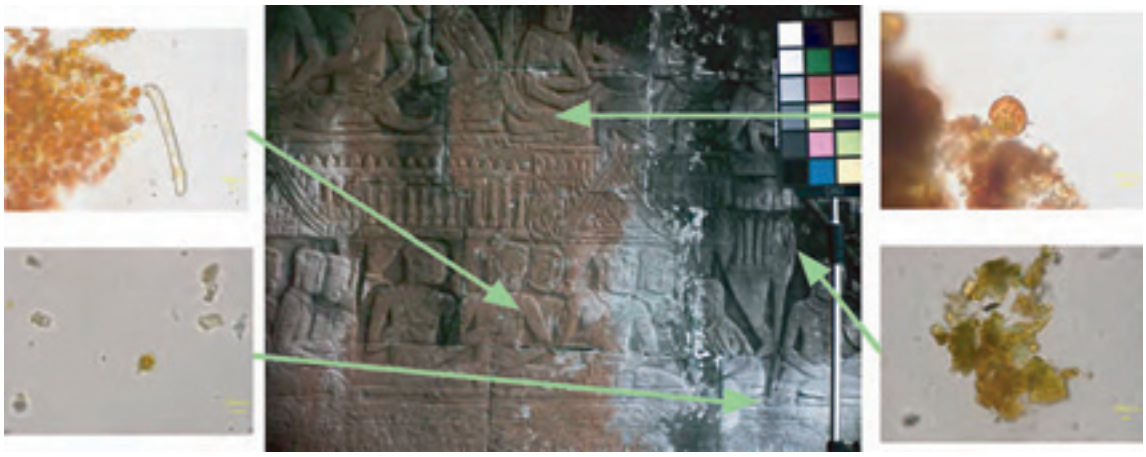


Figure 8: Microbial growth on the wall surface: microscope images of microorganisms observed at each spot.

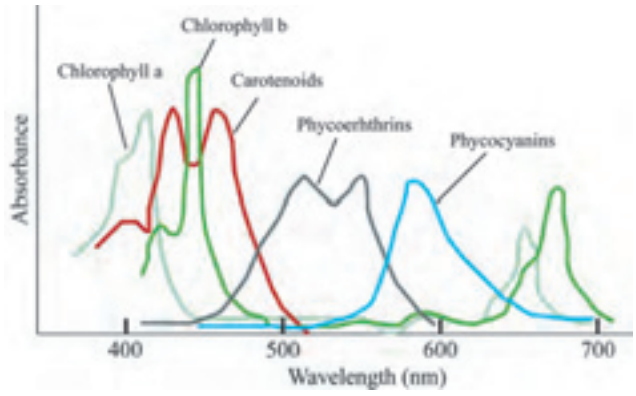


Figure 9: Absorbance of photosynthesis pigments: green algae mainly has chlorophyll A and B. Cyanobacteria mainly has chlorophyll A and phycocyanins.

lower. The result also showed that our system is effective for spectral analysis.

Compared with Conventional Segmentation Methods

We compared conventional segmentation methods with the proposed method. Figs. 7 show the segmentation results of layered surfaces for examining the effect on the nonlinear mixture. The input image is four watercolor pigments painted on a white paper. First, we calculated reflectance spectra from the input multispectral image by using our method. Second, we segmented the reflectance spectra image into different materials using three methods.

This image has complex color between the top layers and the bottom layer. Fig. 7b, by Method 1, and c, by Method 2, include significant segmentation error.

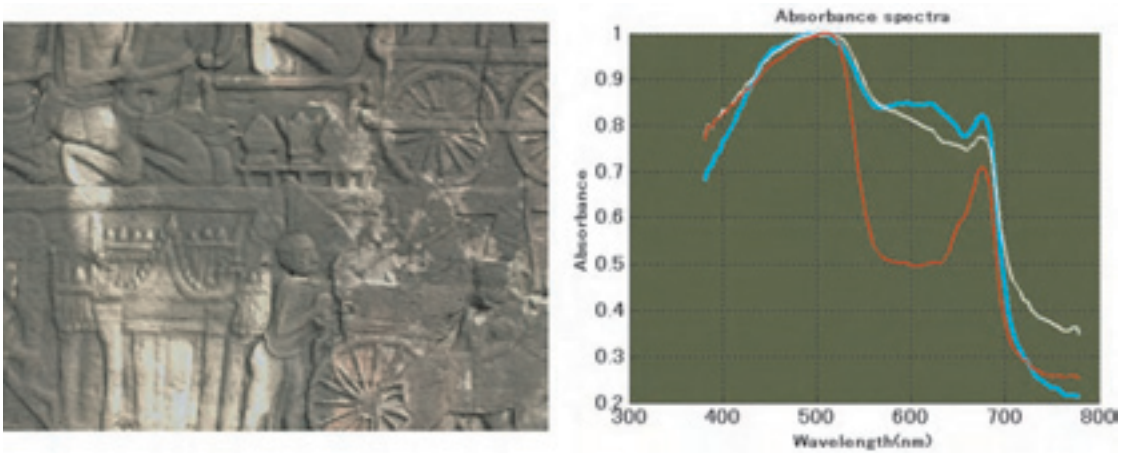
Multispectral Image Analysis for Bas-Relief

This section describes how we applied our proposed multispectral imaging system and segmentation method to analyze a cultural asset. At the Bayon Temple in Cambodia, microorganisms are one cause of deterioration in the inner gallery. Fig. 8 show the microscope images of microorganisms observed at each spot. Due to deterioration, the detailed bas-reliefs on the walls are losing their shapes. We examined the kind, distribution, and reproductive cycle of the microorganisms to find an effective method to remove them.

Microorganisms perform photosynthesis by absorbing the light of a specific absorbance spectrum via sunlight, so the waveforms of absorbance spectra vary according to the type of photosynthetic pigment in each microorganism, as shown in Fig. 9. For example, the absorbance spectrum of gleen agle is shown as the linear sum of the absorbance spectra of chlorophyll A and B. And, Cyanobacteria mainly has chlorophyll A and phycocyanins. Based on above understanding, we assumed that some of them could be discriminated by detecting the absorbance spectra of photosynthetic pigments in them, and we found we could calculate absorbance from reflectance.

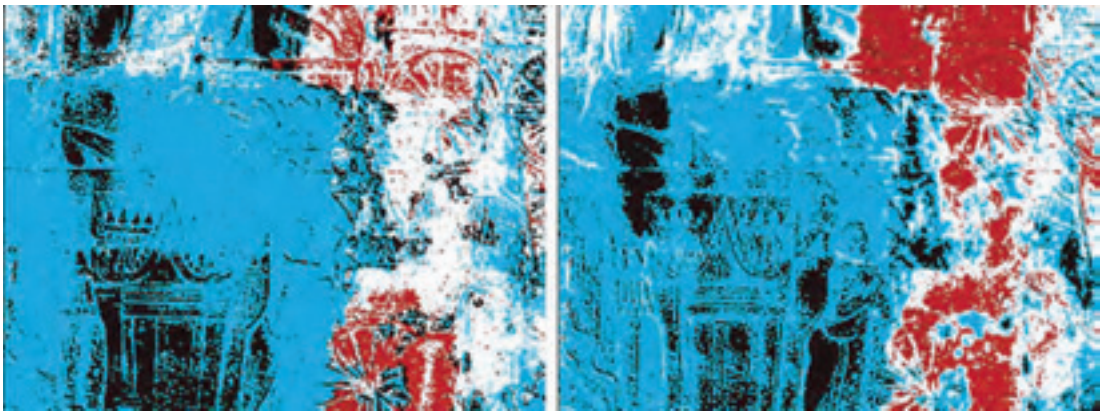
Figure 10a shows the image of the scene we observed. Then, we found correspondences among multispectral images in different seasons to the same area through 3D data.

The results in Fig. 10b show the measured absorbance spectrum of each segmented area. The three areas, depicted using blue, white, and red colors in the figure, should be differentiated by the quantity of phycocyanin. This is because



(a) (b)

Figure 10: (a) Observed scene image: this scene was made by mapping a multispectral image onto 3D data. (b) Absorbance spectrum in each class area.



(a) (b)

Figure 11: Segmentation results of microorganisms. (a) Rainy season (b) Dry season.

the areas' absorption has large differences at around 600 nm, which coincides with the phycocyanin's absorbance spectrum as shown in Fig. 9. As for Fig. 11 shows, white and blue areas decrease in a dry season compared to a rainy season, which implies that the quantity of phycocyanin has decreased in the dry season. The results indicate that the cyanobacteria, the main source of phycocyanin, increase in a rainy season and decrease in a dry season.

Summary

This paper proposed a novel multispectral imaging system and a segmentation method for multispectral images. Our system can efficiently obtain a wide view angle image in an outdoor environment, and also segment a high-dimensional spectral image effectively. In our experimentation, we found that our proposed multispectral imaging system has sufficient accuracy for material segmentation. Furthermore, our multispectral image segmentation method could effectively segment layered surfaces into different spectra. The system also analyzed microorganisms on bas-reliefs in the Bayon Temple. Our experimental results showed the reproductive cycle of microorganisms in rainy and dry seasons.

Our next task using the proposed system is to consider the relationship between the reproductive cycle of microorganisms and the environment of bas-relief.

References

Bishop, C. M., 2008. Pattern recognition and machine learning. Springer.

Ikeuchi, K. and Miyazaki, D., 2007. Digitally archiving cultural objects. Springer,New York.

Keshava, N. and F.Mustard, J., 2002. Spectral unmixing. IEEE Signal processing magazine.

Lowe, D. G., 2004.Distinctive image features from scale invariant keypoints. IJCV.

Reibel, Y., Jung, M., Bouhifd, M., Cunin, B. and Draman, C.,2003. CCD or CMOS camera noise charactarisation. The European Physical Journal Applied Physics 21(1), pp. 75–80.

Roweis, S. and Saul, L., 2000. Nonlinear dimensionality reduction by locally linear embedding. Science.

Scho¨lkopf, B., Smola, A. and Mu¨ller, K. R., 1998. Nonlinear component analysis as a kernel eigenvalue problem. Neural Computation 10, pp. 1299–1319.

Shi, J. and Malik, J., 2000. Normalized cuts and image segmentation. IEEE Trans. on PAMI.

Tenenbaum, J. B., de Silva, V. and Langford, J. C., 2000. A global geometric framework for nonlinear dimensionality reduction. Science 290, pp. 2319–2323.

Tominaga, S. and Okajima, R., 2000. Object recognition by multispectral imaging with a liquid crystal filter. Proc. 15th Int. Conf. on Pattern Recognition.

Introducing EDM survey for recording vernacular heritage and sites in Pakistan

Salman Muhammad

Aga Khan Cultural Service Pakistan, Shahrah-e-Quaid-e-Azam, Jutial, Gilgit 15100, Northern Areas of Pakistan, salmanmuhammadali@yahoo.com

ABSTRACT

The case study of the 200 year old Khaplu Palace, in a very remote and mountainous area of Pakistan, will present the outcomes and issues of recording an outstanding example of a vernacular monument using EDM device and related software for the first time.

Heritage conservation in Pakistan has always faced a lack of resources and expertise, and is invariably accorded low priority. Recording heritage, one of the most important prerequisites in conservation, is not addressed properly. Conventional methods for heritage documentation are in practice but have their own limitations - consuming a lot of time and resources and often resulting in technical errors. Additionally, architectural schools in the country have no training programmes or exposure to heritage recording available for their students.

Since 1991, Aga Khan Cultural Service Pakistan (AKCSP) has been involved in monument conservation in the Northern Areas of Pakistan, with the active participation of local people. Conservation of the 700 year old Baltit Fort and 400 year old Shigar Fort are prime examples. During these projects on-site training of architects and engineers was offered, as well as summer internships for students from architectural schools. This latter to enhance exposure to firstly, conservation and secondly, to the architectural survey as a basic step before any intervention.

Since 2005, on-site training programmes in EDM building and topographical surveys have been organised for local girls and boys, in order to build local capacity. These trained girls are now part of Women Social Enterprise (WSE) formed by AKCSP and working full time as an enterprise carrying out topographical and the architectural surveys in Pakistan. A team of architects and engineers were also given opportunities to extend their skills in architectural surveys whilst working on the projects of Khaplu Palace, the Wazir Khan Mosque Lahore and the topographical survey of the Walled City of Lahore.

Key words: Vernacular, REDM, Conservation, Recording, Image rectification, Topographical Survey.

Introduction

The conservation of the 700 year old Baltit Fort in Hunza by Aga Khan Cultural Service Pakistan (AKCSP is the Pakistani arm of Geneva based Aga Khan Trust for Culture's Historic Cities Programme) demonstrated a strong regional innovative model of heritage conservation, long term sustainability and its use for local development. It also presented the concept of architectural documentation for practical conservation in Pakistan. The conventional manual documentation practiced was later applied to other AKCSP projects in the Northern Areas of Pakistan. All these vernacular monuments have no such previous records of drawings, images or iconographical sources.

The repercussions of rapid development in the past four decades had already been observed on the built heritage of the remote Northern Areas of Pakistan. The high quality conservation work dictated AKCSP to upgrade the conventional recording practices of monuments and order them in a systematic way. In an area where the legislation regarding the protection and inventory of the monuments is not fully active, the documentation of vernacular monuments and settlements becomes even more crucial. Furthermore, international recognition in the form of UNESCO heritage awards for completed projects made AKCSP realize the process of documentation as being a specialized field. This was at a time when AKCSP had just finished conservation of the 400 year old Shigar Fort and had initiated the ground work for the conservation of the Khaplu Palace in Baltistan. Essentially, all the previous projects were following international guidelines for conservation but the more specific guidelines (Article 16, Venice Charter) relating to the precise recording and reinterpretation of monuments were slow to receive attention. Pursuing an advanced master's studies in architectural conservation at Leuven, Belgium provided me with the chance of getting hands-on experience and exposure to recent practices in heritage conservation. REDM was one of the methods which I intro-

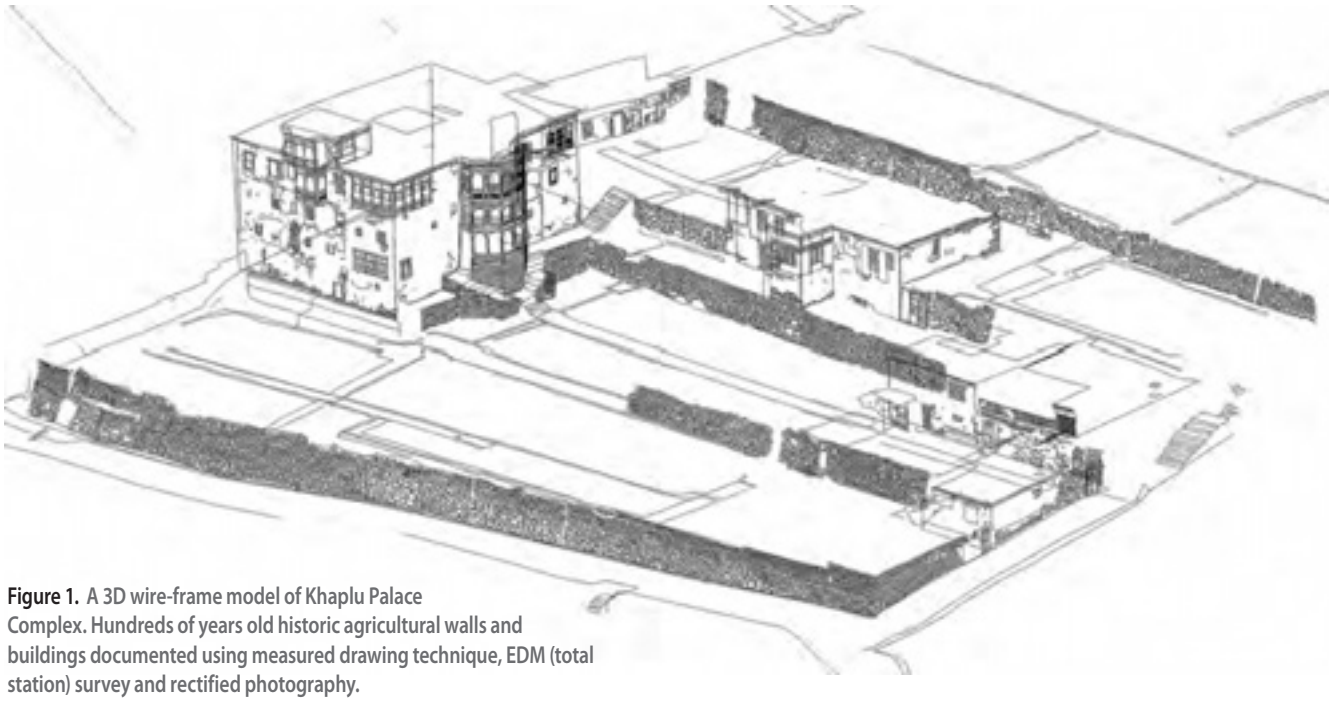


Figure 1. A 3D wire-frame model of Khaplu Palace Complex. Hundreds of years old historic agricultural walls and buildings documented using measured drawing technique, EDM (total station) survey and rectified photography.

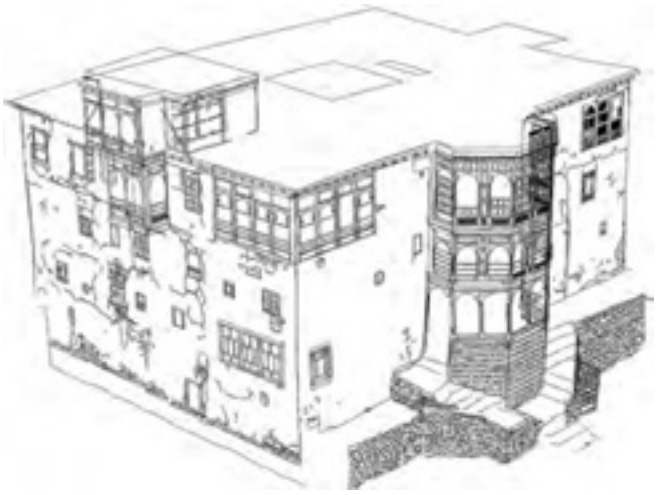


Figure 2. A complete 3D wire-frame model of the Khaplu Palace (north-eastern view).

duced for the first time in Pakistan for heritage documentation, and Khaplu Palace was the first monument surveyed using this method. This method was further strengthened by using allied image rectification software.

The Survey and Project Location

Located in the rugged Karakoram mountain range at the height of 2500 meters, the Khaplu Palace is the finest surviving edifice of royal residence in Baltistan, Northern Areas. Its significance lies in its cultural importance as a former seat of royal government in the area, and in its quality as a building, both aesthetically and as an exemplar of traditional building typology with influences from neighbouring regions (Kashmir, Ladakh, China, and central Asia). As part of a wider cultural heritage support programme in Baltistan, the long term sustainability is one of the prime objectives set by AKTC-AKCSP for this project. Working closely with the local community the project is contributing to the revival of traditional wood and building crafts, income generation activities and capacity building of locals.

Site surveys and documentation prior to any conservation and restoration works are now defined as the basic pre-requisite for understanding an historic building or site. This has been widely expressed in many national and international charters and conventions – from Athens Charter of 1933 to the Venice Charter of 1964 or the Burra of 1979. This discipline needs proper training, human resources and equipment. In the absence of any previous documentation efforts, the current documentation programme with EDM equipment was experimental in its own nature, its main objectives being:

- Disseminate and build capacity in recording techniques with REDM.
- Gather detailed information about a vernacular monument and site in the form of base drawings.
- Detailed recording of the as-found state of the monument, which ultimately allows us to propose conservation and re-use plans.
- Set an example of architectural surveying which would be available for researchers and experts for future studies.
- After conservation, this documentation will provide us the basis for management, monitoring and maintenance of the site and monument.

In a remote situation where documentation of heritage faces huge challenges including the lack of experts, communication, dissemination and standard guidelines, the basic aim of this documentation campaign was to address the cited chal-

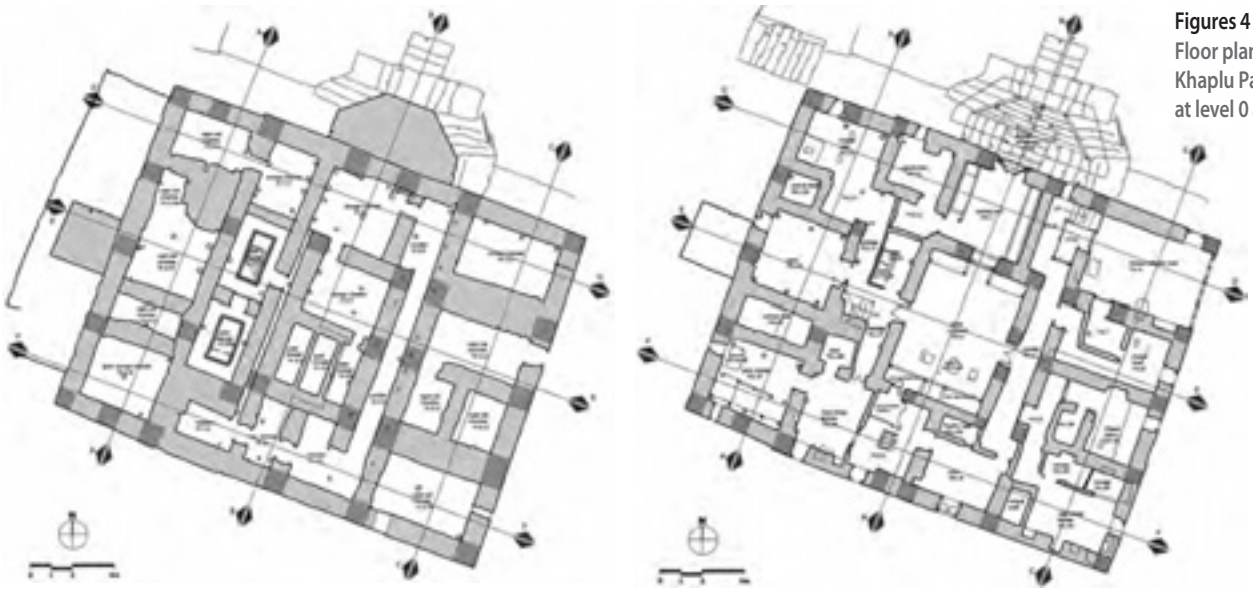
lenges. Documentation is a process which continues during the conservation of any monument and is the only accurate tool for recording information in order to understand the structure, ultimately leading to the management of cultural heritage.

The field survey, as a training process, was initiated in October 2005 primarily to cover the topographical features of this historic vernacular site. Initially, the field data was gathered with one total station (Leica TCR 405) and then downloaded on a computer and converted to vector form with the help of LisCAD and AutoCAD. Later, the more comprehensive stage of documentation of the historic buildings was initiated in March 2006 with the aim to document the monuments for the practical conservation works. The conservation activities running simultaneously made this documentation campaign more challenging as we needed to record the as-found state of the monument and site. Therefore, more practical solutions were worked out to fit the time constraints and conservation activities. The inevitable combination of EDM survey and rectified photography was used. A combination of a field laptop, TheoLT and AutoCAD software for real time survey and Trextify for image rectification purpose was practiced.

Figure 3. North view of Khaplu Palace with main entrance wooden loggia under restoration.

Drawings and Interpretation

In this project EDM survey provided us an opportunity to interpret the obtained data in a variety of ways. Most of the team members knew the technique of architectural documentation using conventional manual measurement and drawing methods. The new EDM survey technique, therefore, was never going to be easy to understand and initially it was critical that I provided them common and easy examples. For this we initiated introductory lessons about the instruments and the future interpretation of collected data in the form of drawings. In a remote environment this was not an easy job to do and it was therefore important for us to overcome the limitations of our



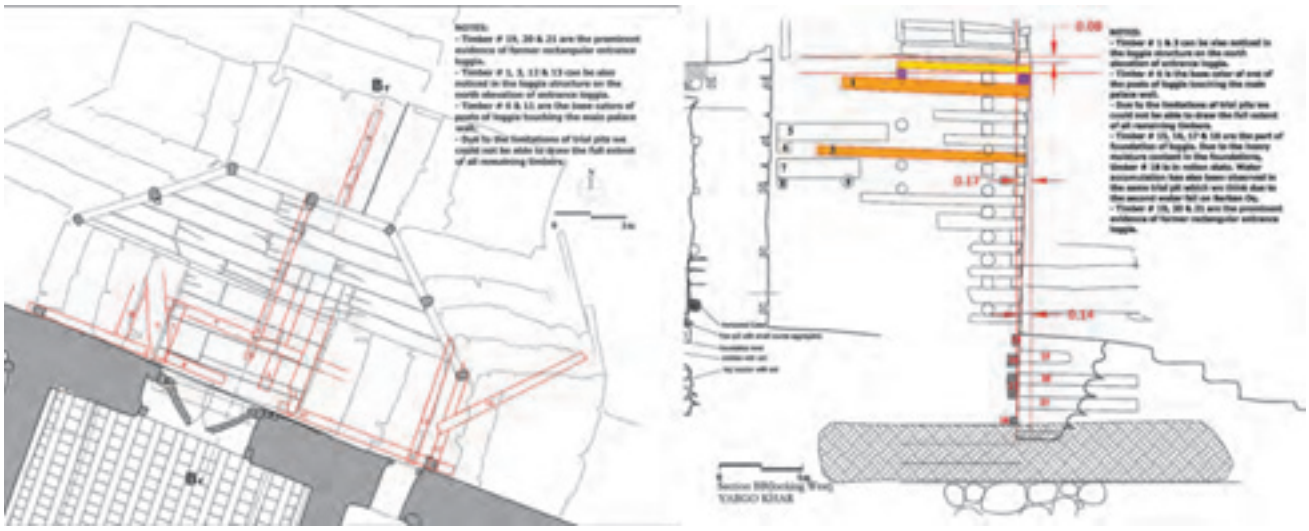
Figures 4 & 5. Floor plans of Khaplu Palace at level 0 and 1.

Figure 6. Rectified photography of western elevation of the 100 year old Darbar Khang.

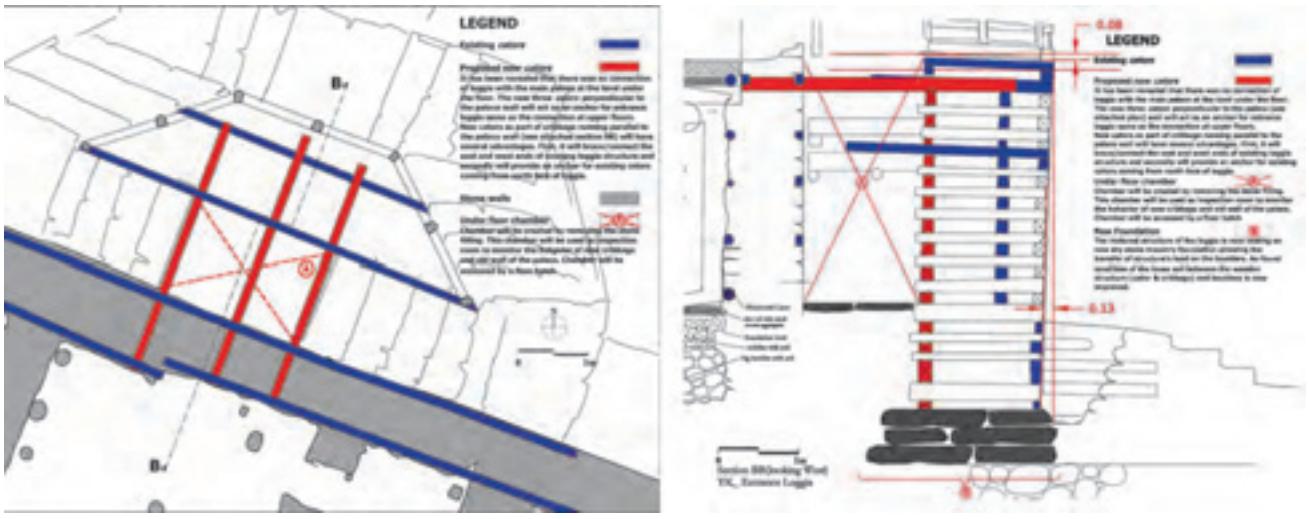
survey with new technology. Soon the team realised that this technique substantially reduced the amount of time and human resource required for the documentation in comparison to conventional and manual methods, and above all that the results are very precise and accurate.

The team were also aware of the limitations of manual documentation methods. The inaccuracies in the manual documentation process due to the manual sketches, hand measurements and the conversion of manually drawn scaled drawings into vector drawing through a laborious scanning and the

Figure 7. East elevation of Khaplu Palace site. Hundreds of years old historic agricultural walls and buildings are documented using EDM (total station) survey and rectified photography techniques. This drawing is a 3D wire-frame CAD model.



Figures 8 & 9. Set of drawings produced for the restoration of wooden entrance loggia about 10 meters high. This set of drawings shows the structure and location of timber elements in the plan and section. Additionally, the sectional drawing shows the subsidence and bulge in the structure.



Figures 10 & 11. This set of drawings shows the proposed interventions to restore the loggia structure.

drafting process were easily mitigated with this combination of EDM and rectified photography surveys.

Since 2006, most of the architectural documentation has been completed in the form of floor plans, reflected ceiling plans, structural drawings, detail elevations of each room, cross sectional drawings, building elevations and a complete 3D wire frame model. Most of the major elevations and elevation features in the cross sectional drawings were completed with the help of image rectification software combined with EDM survey. Rectified photography has been used to map the condition of external and internal elevations of the monument and was later converted into vector form.

Investigations and Conservation of Main Entrance Loggia

Primarily, the data in form of CAD drawings produced with the help of EDM survey has been used to study the monument and its adaptation for reuse. Secondly, the data was key to identifying and studying the dilapidated parts of the monument. Total station has been extensively used during the investigations of the structure of the main entrance loggia of the palace. The abnormal tilt and the subsidence recorded with the help of EDM survey of the loggia at the floor level of level 1 revealed that this part of loggia was not structurally connected with the main building of the palace. The investigations showed in the structure a tilt of 14 cm and subsidence of 8 cm. Based on other such structural connections in the palace, the intervention proposal was implemented. A new connection and additional wooden beams were proposed. In order to remove the tilt and subsidence in the structure, hydraulic jacks and turning buckles were used. The process of lifting and pulling back of the structure to a satisfactory position was closely monitored with the help of total station and allied software.

Conclusion

As part of dissemination, in the past three and half years, a total number of 25 people were trained in topographical survey with EDM technique. Additionally, 10 architects and engineers have also been trained in more advanced techniques of architectural building survey with EDM device and image rectification process. The process which was initiated on a vernacular monument in Northern Pakistan has now been actively practiced in the Walled City of Lahore, documenting the thick urban fabric and historical monuments of great importance. It's been encouraging to see all this progress, but there is still a long way to go in spreading and sharing this knowledge with other actors in the field.

In the context of Pakistan, the rate of uncontrolled development and the lack of updated technologies and expertise are the main causes of heritage loss and the main hindrance in documentation. Under these circumstances, the concerned authorities for cultural heritage should at least start updating the documentation process of deteriorated monuments in a more accurate and timely manner by utilising the best practices of EDM survey.

Refrences

Almagro, A., 2007. Traditional drawings versus new representation techniques. In: CIPA XX! International Symposium of Architectural Photogrammetry. 01-06 October 2007, Athens, Greece.

Bianca, Stefano, 2005. Karakoram: Hidden Treasures in the Northern Areas of Pakistan. Umberto Allemandi & C. for The Aga Khan Trust for Culture, Torino.

Muhammad, Salman, 2006. Conservation and adaptive reuse of Khaplu Palace. Thesis Report, RLICC Katholike University, Leuven, Belgium.

Figure 12. Traditional construction techniques are being implemented during the restoration of loggia.

Figure 13. Lifting and pulling back the loggia to a stable state is being closely monitored with total station.

Figure 14. Lifting of loggia to a stable state with the help of hydraulic jacks.

Figure 15. Turning buckles are being used to pull back the tilted loggia.

Figure 16. North façade of Khaplu Palace. The wooden entrance loggia at the centre was the subject of major conservation activity in 2008. This restoration is very closely monitored with total station.

Figure 17. Cross section at AA of Khaplu Palace. Rectified images were used extensively to document the features and damages of the monument. The abnormal tilt and subsidence in the entrance loggia at left is clearly visible.

Figure 18. Cross section at DD of Khaplu Palace. The periodical extensions on the upper floors left some walls built on the non-load bearing roofs of lower levels.

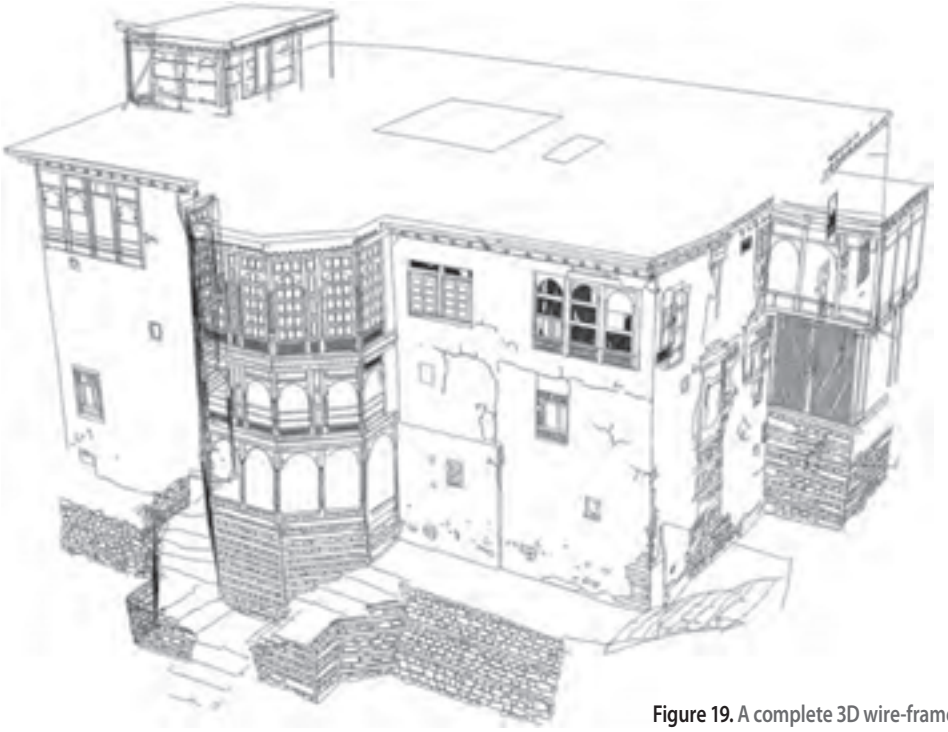


Figure 19. A complete 3D wire-frame model of Khaplu Palace. The north-western view of the Palace shows the severe damages on the western façade.

3D model of gedongsongo temple and topography using terrestrial laser scanner technology

Adi J. Mustafa, Fahmi Amhar

Geomatics Research Division, National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL), Indonesia, adijm2001@yahoo.com or adijm@bakosurtanal.go.id and famhar@yahoo.com

ABSTRACT

The paper reports the result of measurement of the Gedongsongo temples and the surrounding topography using laser scanning technique. Gedongsongo is located in Semarang District, Middle Jawa Province, Indonesia. The research is carried out by the Geomatics Research Division of National Coordinating Agency of Surveys and Mapping (BAKOSURTANAL) is cooperation with Borobudur Heritage Conservation Office (HCO). BAKOSURTANAL has a program to investigate the suitability of relatively new instruments for surveys and mapping, while Borobudur-HCO concerns about documentation of cultural heritage objects in form of 3D model. Gedongsongo, located in a beautiful hillside of Mountain Ungaran, has nine temples grouped in five Gedong (complex of temples). Gedong-1, Gedong-2 and Gedong-3 and the topography surrounding the three complexes have been successfully measured. The result of measurement is still in form of point clouds based on the accuracy of the measurements, i.e. between 5-15 mm for the temples and 20-25 cm at 100 meters distance for the topography. The accuracy of the measurements and the integration of the 3D model results into the national coordinate system are still to be performed.

Key words: 3D model, temple, topography, terrestrial laser scanning.

Background

Surveys and mapping activities are not limited to conventional works for mapping the earth surface. Many surveys and mapping instruments are developed to support various objectives. In archaeology, Geomatics technology has a significant potential to map and to document cultural heritage objects using medium and high resolution satellite imageries both from active and passive sensors, large format and linear array digital aerial camera, and other terrestrial instruments (Campana etc., 2009). One of the latest technologies is measurement and 3D modelling of cultural heritage object using terrestrial laser scanner instrument.

Three dimensional (3D) models of cultural heritage objects are needed to document people's collective memory about the objects. When unwanted condition, like earthquake, flood, volcanic eruption, or vandalism, takes place so that the objects are destroyed, then the reconstruction of the objects can be done accurately. Directorate General of Historical and Archaeological Object (DG-HAO), the Ministry of Culture and Tourism (2007) announced with heritage cultural object conservation through improvement the quantity and the quality of practical research, human resources, and establishing an excellent information system based on informatics technology in a form of Geographic Information System. 3D modelling can also assist related institutions to process the inscription of the heritage objects on the World Heritage List based on the World Heritage Convention [World Heritage Center, 2008]. Clear identification on location and area of the object plotted in an up-to-date map are required. The description should be completed with photographs. To fulfil the requirement, 3D model can be used as an effective representation.

The Geomatics Research Division of BAKOSURTANAL has a program to investigate relatively new instrument for surveys and mapping. This paper reports the use of terrestrial laser scanner Leica HDS-3000 to map and model Gedongsongo Temple and its surrounding topography. The objective is to have an experience and skill of using the instrument and to produce a 3D model of the temple and its topography. The authors hope that the research gives a significant contribution to the Indonesian government for conserving heritage objects. Therefore the research in carried out in cooperation with Borobudur Heritage Conservation Office (Borobudur-HCO), which is a unit of DG-HAO.

Application of Laser Scanner for Heritage Object

There are several methods to map and model 3D objects. Four of them are conventional terrestrial surveys, close range photogrammetry, airborne LiDAR and terrestrial laser scanner (Siu, 2007). Both airborne LiDAR and terrestrial laser scanner use laser to measure distance from the instrument to objects.

In principle laser scanner has five components, (1) a transmitter, laser pulse in HDS-3000, (2) a transmitter optics, two rotating mirrors in horizontal and vertical direction in HDS-3000 (3) a receiver optics, (4) a detector, and (5) an electronic system for data acquisition, processing, evaluation, display, and storage *(Figure 1)*.

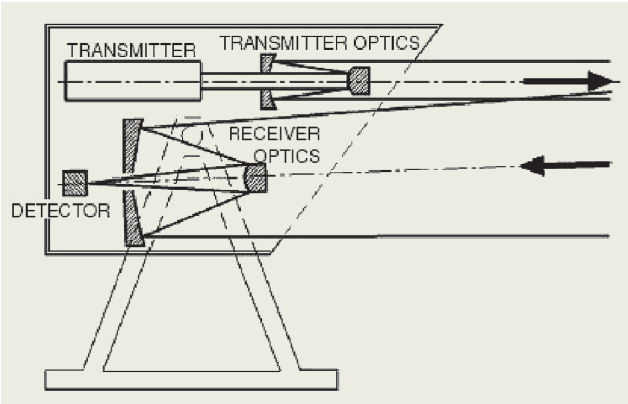


Figure 1. Optical components of a laser scanning system, from (Weitkamp, 2005).

3D laser scanner works using high-speed laser to scan the surface of objects which can capture a huge amount of 3D coordinate points of the surface model. These 3D coordinates can be integrated to form "point clouds" and high-resolution 3D models by using certain software. The distance of an object is determined by measuring the time difference of the emitted laser pulse and its return signal travel to and from the objects and the instrument. The angle of emission is controlled by two rotating mirrors.

Laser scanning technique has been used in 3D documentation important cultural objects, like the 3D mapping Old Star Ferry Pier area (Siu, 2007) using HDS-3000.

Meanwhile, in Indonesia cultural heritage area mapping has been rarely done. Borobudur HCO mapped Borobudur Temple, Prambanan Temple and other temples using HDS-3000 too, when an earthquake hit Jogjakarta city and the surrounding area in May 27th, 2006 to identify the damage on the temples. However, there is no scientific publication about the result of the mapping. Therefore the measurement of Gedongsongo temple becomes an important study to test the capability of laser scanning technique to map the temples and its surrounding topography.

Some technical specifications of HDS-3000 are summarized in Table 1.

Table 1. *Some technical specifications of Leica HDS-3000.*

Specifications	HDS3000
Metrology method	Pulsed time of flight
Field of view	3600 horizon. and 2700 vert.
Optimal scan distance	1 m – 100 m
Scanning speed	up to 1.800 points/seconds
Accuracy in distance (50m)	6 mm (single measurement)
Angular resolution	60 micro-radians
Divergence/spot size in 50m	≤ 6 mm
Calibrated video camera	RGB 64 mega-pixels, spatially rectified

Gedongsongo Area

Gedongsongo area is located in the Ungaran Mountain area, Candi Village, Ambarawa Sub-district, Semarang District, Middle Jawa Province, Indonesia. Gedong means building or temple, Songo means nine. Gedongsongo has, as reflected from its name, nine Hindu temples. These temples are however grouped in five complexes of temples.

The temples of Gedongsongo were found by Raffles in 1804. It is a Hindu culture heritage from the time of Syailendra Kingdom in the ninth century. The temples are located on the height on 1,300 meter above the sea level with a mountainous air temperature of about 19-270C.

The nine temples are surrounded with a beautiful landscape and pine-forest. *Figure 2* shows part of the beautiful landscape.

The position of five complexes of temples or Gedong, measured using GPS, is shown in *Figure 3*. In the figure contour lines, street or foot-path and river stream line are taken from the 1:25,000 scale topographic map produced by BAKOSURTANAL.

It is shown that the river crosses and divides Gedongsongo area into two parts. In the valley, near the river stream, hot volcano gas comes out from a small hole. A small hot spring swimming pool is located also there.

Gedong-3 and Gedong-4 are located in almost the same height, while the highest temple is Gedong-5.

Planning of and Process of Measurement

Instrument and Tie Points Location

Location of instrument and the target of tie points must be planned carefully before measurement. It is necessary to minimize un-scanned parts of temples and/or topography. Topographic measurement needs more systematic locations to ensure that the tie points can be seen from three or more locations in order to integrate all measurements and to get viewable height differences. In this study topography around Gedong-2 and Gedong-3 is constructed from five instrument locations.

Figure 2. Above photo is Gedong-2 potrayed from near of Gedong-3 location. The background in the lower place is Ambarawa-city. Below photo shows Gedong-3 with background of pine-forest and hillside of the Ungaran Mountain.

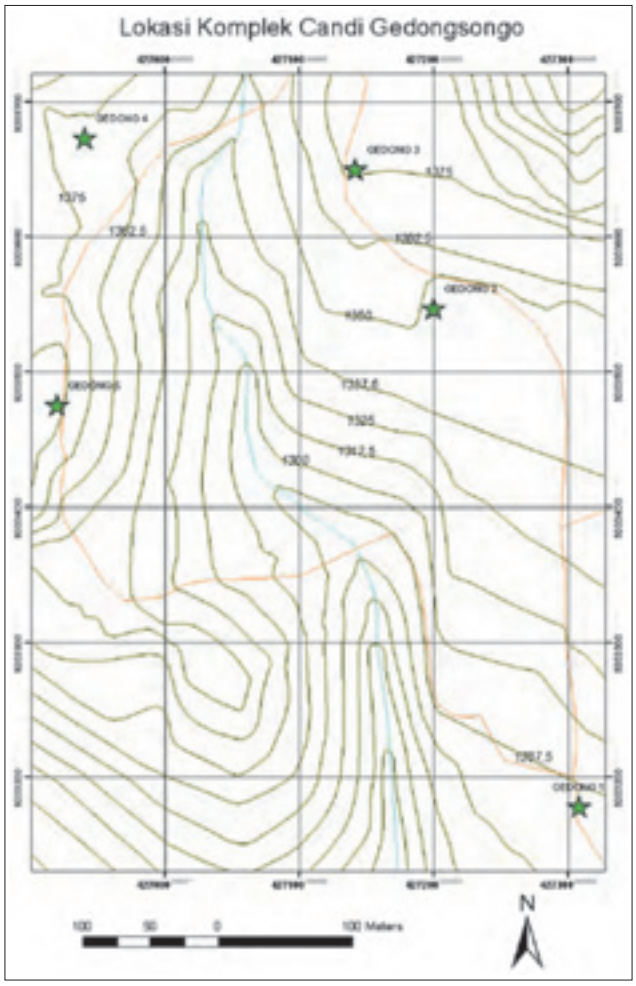


Figure 3. Location map of five complexes of Gedongsongo (symbolized with stars) drawn in the UTM Zone 49-South projection.

Measurement Process

Before measurement, the instrument can be set up to capture images in 00-3600 horizontal and certain angle interval in vertical direction. The images can be used to determine which part of landscape the surrounding area to be scanned and in which interval of angle the location of the temple by using measurement scripts. Once the scripts are set up, the measurement will be performed automatically.

In a normal weather, i.e. no rain and no fog, measurement of temple and topography from one point needs about two hours time. Detail measurement describing location of instrument, scripts, resolution and time is summarized in Table 2.

Table 2. *Total measurement setting.*

No	Instrument Location	Script	Resolution
1.	N-E of Gedong-1	Temple	5mm
2.	S-W of Gedong-1	Temple	5mm
3.	N-W of Gedong-3	Big Temple Small Temple Topography Target	10mm 10mm 20cm/100m 2mm
4.	S-E of Gedong-3	Big Temple Small Temple Topography Target	10mm 10mm 20cm/50m 2mm
5.	North of Gedong-2	Topography	25cm/100m
6.	50m S-W of Gedong-1	Topography	20cm/100m
7.	North of Gedong-2	Temple	15mm
8.	South of Gedong-2	Topography Temple	25cm/100m 15mm
9.	100m S-E of Gedong-2	Topography	25cm/100m

Figure 4. Measurement of Gedong-1 from SW direction (above) and from NE direction (middle). Left image shows location of the laser scanner, NE from the temple.

Result and Discussion

The result of measurement is divided into 3D temple and topography. This study has measured Gedong-1, Gedong-2 and Gedong-3. Each temple is measured from two points, while topography around Gedong-2 and Gedong-3 are measured from six points.

Temple

Figure 4 and *Figure 5* show the result of the measurements of temples.

Part of the temples has not been scanned, because the measurement is carried out only from two points. Further analysis from the result, especially related to the detail of measured result has to be performed in collaboration with experts and practitioners in cultural heritage objects.

Topography

Gedongsongo area has a unique and beautiful natural hilly landscape. Like depicted in Figure 3, the temples are located in separate positions with relatively long distances from one to another. The distance between Gedong-1 and Gedong-2 is about 380 meters, while Gedong-2 and Gedong-3 are separated with about 120 meters. Therefore, surveys and measurements of Gedongsongo's topography cannot be separated in our study.

As mentioned in Table 3, positions of the instrument for measuring topography are the same as positions of it for measuring the temples except one location, namely at the distance of 100 meters in the SE direction from Gedong-2. The results of topography 3D points are shown in Figure 6.

The result of topography model shows that the integration of some measurements from five points can be done well using at least four tie points between adjacent measurements.

Figure 5. Measurement of Gedong-2 (above) and Gedong-3 (middle). Left image shows location of the laser scanner, NW from the temples.

The targets of tie points is used to integrate the model if only the error of them is less than or equal to 4 mm.

In the scanning process, laser signal ran to trees and leaves. Therefore, the measurement has not resulted in earth terrain or elevation model yet. It is still in a form of surface model. The result needs to be processed carefully to produce 3D topography of earth terrain. The result has not been connected to the national coordinate reference yet. It is in a local coordinate system. However, applying a simple analysis, the 3D model of topography can be displayed from side cross-section, as shown in *Figure 7*. Using the display, the height different among some positions can be determined visually.

According to the measurement, height difference between Gedong-2 and Gedong-3 is about 28.6 meters. It is consistent to the data from the topographic map *(Figure 3)*. Gedong-2 is located near the contour line of 1,350 m and Gedong-3 is near the contour line of 1,375 m, so that the height difference is 25 m.

Closing Remark

The paper has described and discussed the result of measurement of the temples and the topography of Gedongsongo area using laser scanning techniques. Measurement of three temples, i.e. Gedong-1, Gedong-2 and Gedong-3 and the topography of about 400 m x 400 m (16 hectares) around Gedong-2 and Gedong-3 and about 150 m x 150 m (2.25 hectares) around Gedong-1 has been finished in 3 days or about 21 hours, with an assumption of 7 hours/day working.

From this research the authors recommend the use of laser scanning techniques to map temple areas and other cultural heritages in Indonesia. By this, the instrument owned and maintained by Borobudur-HCO and also trained and skilful human resources can be utilized optimally to support the program of Ministry of Culture and Tourism through DG-HAO. A comprehensive recommendation will be formulated systematically together with experts and practitioners from archaeology.

This preliminary study shows that laser scanning techniques can be applied to map topography accurately. However post processing is still required to produce 3D earth terrain model and to be used as height information in the topographic or the base map.

Acknowledgements

The authors would like to thank the Borobudur-HCO that actively participates in the study and provides the instrument HDS-3000 to be used in the laser scanning measurement. We are also thankful to the DG-HAO for the cooperation.

References

Siu Dominic, 2007, A Recent Case of 3D Survey for Heritage Conservation in Civil Engineering and Development Department - The Old Star Ferry Pier, Hong Kong Institute of Surveyors "Annual Conference 2007 Surveyors in Heritage - Preserving and Adding Value", 13 October 2007, JW Marriott Hong Kong.

Campana S., Sordini M., Remondino F., 2009, Integration of Geomatics Techniques for The Digital Documentation of Heritage Areas.

http://www.photogrammetry.ethz.ch/general/persons/fabio/EARSEL08_rome.pdf (accessed 18 August 2009)

Weitkamp C., 2005, Lidar: Introduction, in Takashi F. and Tetsuo F. (editors), Laser Remote Sensing, CRC Press, Taylor and Francis Group, Boca Raton.

Dirjen Sejarah dan Purbakala, Dept. Kebudayaan dan Pariwisata, 2007, Kebijakan Pengembangan Sejarah dan Purbakala 2008 (Policy on Conservation Historical and Archeological Objects), Rakor Depbudpar (Coordination Meeting of Ministery of Culture and Tourism), 28 Maret 2007.

http://www.budpar.go.id/filedata/2823_944-PAPARAN-SEPUR3.pdf (accessed 18 August 2009)

Subdir Konservasi, Dirjen Sejarah dan Purbakala (DG-HAO), Pemeliharaan Benda Cagar Budaya (BCB) dan Situs (Conservation of Cultural Heritage).

http://www.budpar.go.id/filedata/4554_1363-PEMELIHARAANBENDACAGARBUDAYA1.pdf (accessed 18 August 2009)

UNESCO World Heritage Centre, 2008, Operational Guidelines for the Implementation of the World Heritage Convention.

Wikipedia, Candi Gedong Songo.

http://id.wikipedia.org/wiki/Candi_Gedong_Songo (accessed 18 August 2009).

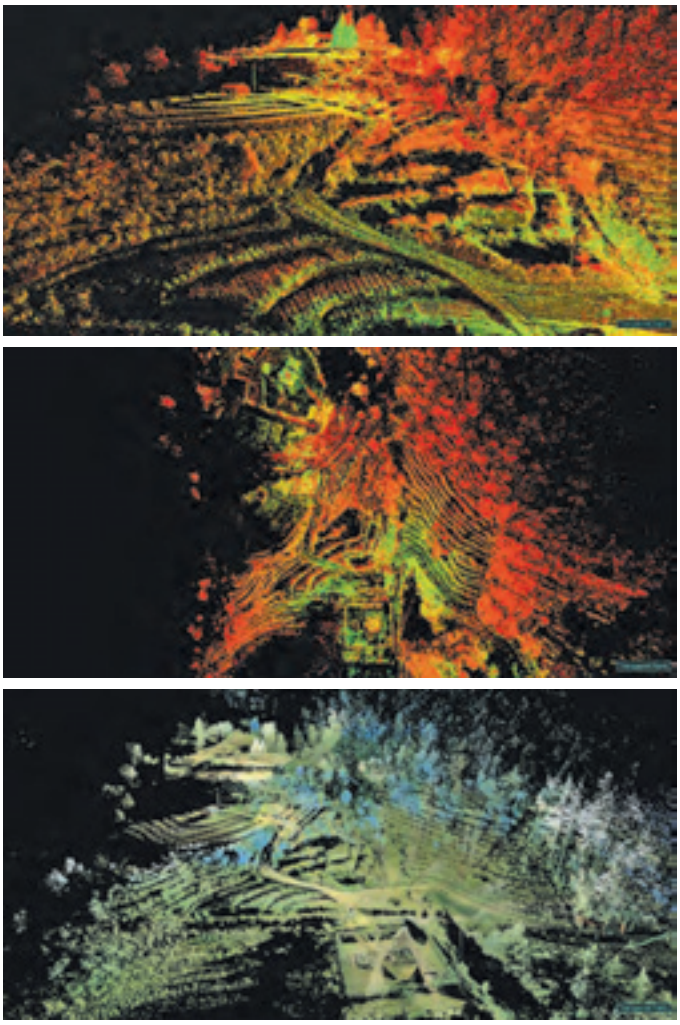


Figure 6. Above image is topography of Gedong-3, measured from Gedong-2; Middle image shows area around Gedong-2 and Gedong-3 viewed vertically; Below image shows the total landscape around Gedong-2 and Gedong-3.

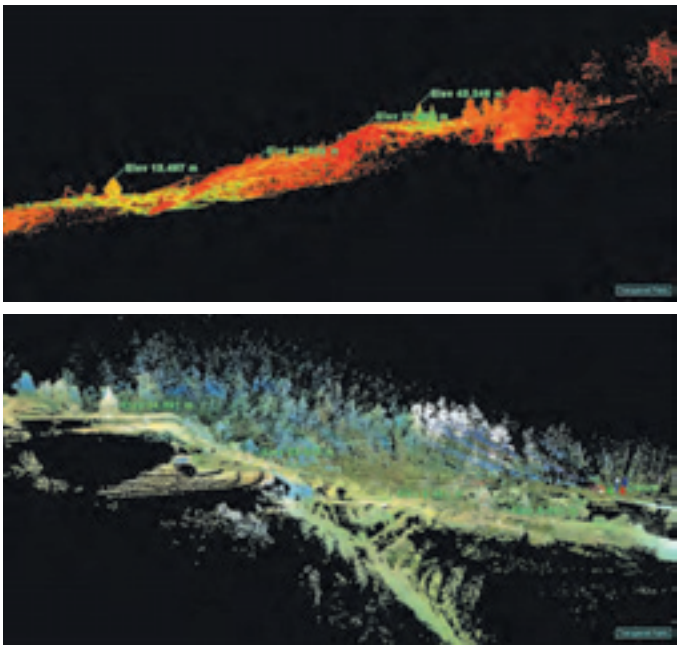


Figure 7. Above image shows a cross-section from South. Gedong-2 is located in 5.8 m height from local reference, while Gedong-3 in 34.4 m; Below image is the same cross-section but from North.

Digital Construction for Spatial Documentation of Beijing Old City

Ruoming Shi, Guang Zhu, Ling Zhu, Ruiying Wang, Yuqing Mu

Beijing University of Civil Engineering and Architecture
Email: ruoming@yahoo.com

ABSTRACT

Beijing old city has been changed on a large scale and the walls of the old city had been demolished entirely because of population increasing and infrastructure developing. However, historic notes in Beijing old city are objects of architectural or cultural interest since it includes a large number of traditional buildings and monuments dating from various historic periods. These buildings and monuments together with their access and surrounding areas are often a unified construction total, whose spatial design and planning characteristics had been fully recorded and documented by means of some analogy methods, such as the topography map, aerial photo, sand table and city map etc. before 1960s. Nowadays, it is feasibility to make a digital restoration of the old city notes, such the old city walls and Siheyuan are restored by virtual technique using the existed spatial information and documents. Therefore it is necessary to create a spatial system to manage, organize and protect the existed spatial information and further, combine those data with a variety of quality information, such as picture, videos, old maps and city plans and other available data. In this paper the background, a project design of digital construction is implemented to rescue the available spatial data and make their exploitation.

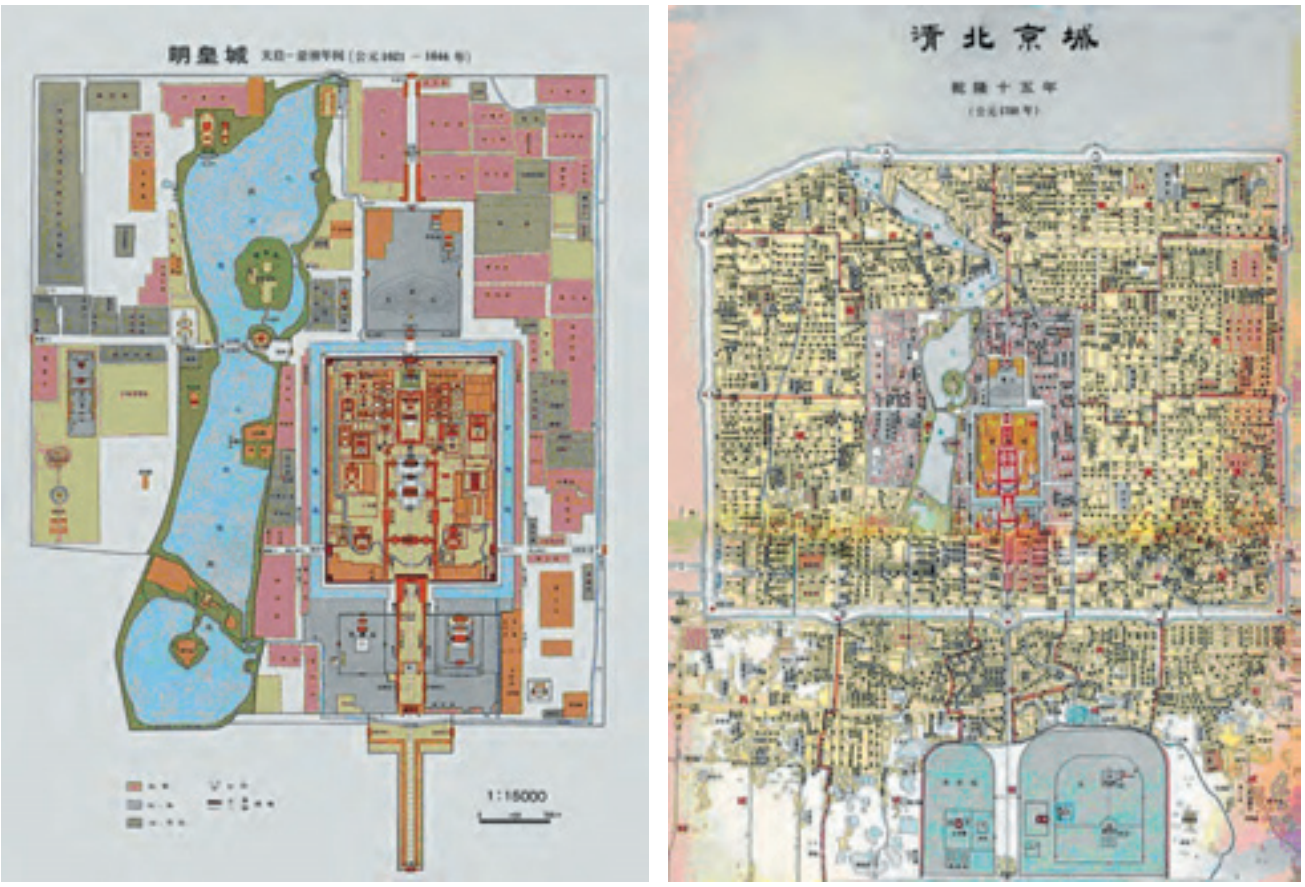
Key words: Old City, Historic Heritage, Spatial Information, Digital Restoration, GIS

Introduction

Before the middle of 1960s last century, Beijing's enceinte had little been changed; the wall of the old city had been kept about 500 years since the Ming Dynasty (A.D.1368-1644) and the Qing Dynasty (A.D.1644-1911). After the middle of 1960s, Beijing old city has been changed on a large scale and the wall of the old city had been dismantled entirely because of population increasing and infrastructure developing. However, an amount of non digital spatial documents of the old city, such as city map, topographic map sheet, aerial photo and city building and sand table, have still been preserved. Therefore, it is an actually significances and feasible on the historical culture heritage protection and urban planning to apply the non digital spatial recordings to construct the digital interface for Beijing old city so far. Figure 1 shows two period city maps, (a) the Ming Dynasty, (b) the Qing Dynasty.

The basic idea of the digital construction involves in researching the collection and procession methods of the multi-sources and multi-type spatial recordings of Beijing old city by colleting the large scale topographic map, ortho-image, and wood city sand table of 1950s, and researching organization, management and display methods of the multi-sources and multi-type spatial documents by designing a technique procedure and creating digital interface for the historical buildings and historical district in Beijing old city. Furthermore, a large number of buildings in the old city block belong to the state and private. Management and control of these properties under historic and present circumstances are very difficult almost impossible since many necessary information for that is not yet recorded. The creation of a spatial information system is expected to dramatically improve the situation and help to solve the problem. Practically the project aims at the reassessment of the functional use of spatial data and other relative information in the old city, most of them traditional.

A project design of digital construction is implemented to rescue the available spatial data and make their exploitation. The enhancement of the existed spatial information collection and architectural heritage restoration of the old city are the research area undertaken by Beijing Municipal Science & Technology Commission with the technical assistance of the Digital Archives Laboratory of Beijing University of Civil Engineering and Architecture(BUCEA). There are three phases to carry out the project, the first phase is for collecting data and building a spatial information management system; the second phase is for making three dimensional (3D) restoration of



(a) (b)

Figure 1. Beijing old city maps, (a) the Ming Dynasty, (b) the Qing Dynasty.

architectural heritage and the third phase is for integrating and displaying several of spatial data, 3D module, and multimedia of the old city. In addition, this paper describes an attempt on the first phase work of the project.

Historical Notes of the Old City in Beijing

The history of Beijing as a city may be traced back to about 3000 years ago when a small town appeared on the present site of south-western Beijing. It was named Ji and then changed to Yan. At the beginning of the 10th century, it was the second capital of the Liao Dynasty. From then on, the old city had been the capital of the Jin, Yuan, Ming and Qing dynasties until 1911. A long history has left numerous famous historical sites which possess great aesthetic and cultural valleys. Beijing old city divides as two parts, the Forbidden City belongs to the inner city of the old city *(Figure 1)* and it locates a centre of the city and is splendid crystallization of ancient Chinese architectural art, but also a lot of traditional buildings surrounding outer city. The old city is an area protected by a special legislation, which rules the construction development and defines very strict building- and land-use regulations to avoid alteration of the existing characteristic architecture and style.

Old City Wall

Chinese cities rarely centre on a castle. Instead, the city's administrative centre is spread over a relatively large area, which may or may not be surrounded by a second set of "inner" walls similar in shape and construction to the main, outer wall. The wall of Beijing's inner city was originally about 24 kilometres in length. The outer wall to the city was 16 meters in width, while the imperial city's wall was about 10 meters wide. The wall enclosing the Forbidden City still stands today, spanning 1,006 meters from south to north, and 786 meters from east to west. Thus the area of the Forbidden City is 72 hectares. The ruler of Ming Dynasty began constructing the wall spanning 40 kilometres in 1419. In the 1950s and 1960s, the majority of the wall was razed to develop the city. A section of the old city wall in Beijing has become an attraction for both travellers and local residents after a delicate renovation project. *Figure 2* shows a plan of the walls of Beijing old city and *Figure 3* shows two gates and towers photos of the old wall, Yongdingmen and Xizhimen.

After the founding of the People's Republic of China, a political dimension was added to the economic problem posed by city walls. In Beijing, for example, the proposed demolition of the city walls was at first opposed by experts ranging from architect Liang Sicheng, to Soviet advisor Mosin, on the

Figure 2. Plan of the walls of Beijing old city.

Figure 3. Yongdingmen (top), Xizhimen (bottom).

grounds that the city walls of Beijing were the most sophisticated and well-preserved system of city walls in China. However, in 1958 summiteers intervened, and declared that the demolition of the old city wall was a political issue, by 1970 almost all of the city wall had been demolished.

Si He Yuan

A Siheyuan (quadrangles) is a historical type of residence that was commonly found throughout China, most famously in Beijing. The name literally means a courtyard surrounded by four buildings. Fully developed Siheyuan date back as early as the Western Zhou period (1122 BC to 256 BC), and exhibit the most outstanding and fundamental characteristics of Chinese architecture. They exist all across China and are the template for most Chinese architectural styles. Studies put the estimates at about over 30,000 Siheyuan courtyards in Beijing old city.

Figure 4. Si He Yuan of Beijing old city.

Figure 5. Hu Tong of Beijing old city.

The four buildings of a Siheyuan are normally positioned along the north-south and east-west axes. The building positioned to the north and facing the south is considered the main house. The buildings adjoining the main house and facing east and west are called side houses. The northern, eastern and western buildings are connected by beautifully decorated pathways. These passages serve as shelters from the sunshine during the day, and provide a cool place to appreciate the view of the courtyard at night. The building that faces north is known as the opposite house. Behind the northern building, there would often be a separate backside building, the only place where two-story buildings are allowed to be constructed for the traditional Siheyuan.

The city of Beijing originally was protected by huge walls, and each Beijing home also had a wall built around it. Walled houses were attached, forming a labyrinth old city with narrow paths connecting the maze. The Hutongs they formed were orderly, lined by spacious homes and walled gardens. Farther from the palace, and to its north and south, were the commoners, merchants, artisans, and laborers. Their Siheyuan were far smaller in scale and simpler in design and decoration, and the Hutongs were narrower. It is record as the 978 Hutongs listed in Qing Dynasty and swelled to 1,330 by 1949. Figure 4 shows a classical Si He Yuan of Beijing old city and Figure 5 shows a typical Hu Tong of Beijing old city.

Modern Beijing's population boom has made housing one of city's biggest challenges. Siheyuan today are typically used as housing complexes, hosting multiple families, with courtyards being developed to provide extra living space. The living conditions in many Siheyuan are considered squalid. In the 1990s, systematic demolition of old urban buildings took place in Beijing under rapid economic development. Siheyuan are being torn down to address, and the hutong area is rapidly disappearing, replaced by modern apartments and stores.

Figure 6. Plan of protection area in Beijing old city.

Figure 7. Renovation of the Siheyuan (top) and the Tower wall (bottom) of Beijing old city.

Protected Area

The Plan to Protect the Historical and Cultural Heritage of Beijing will be fully implemented. Special attention will be given to the protection of the royal city and the historical buildings situated along the ancient city axis and within the 25 historical and cultural protection areas, the protected major historical and cultural sites, the ancient urban water systems and the layout of the ancient city. The first group of Old City Conservation zones (25 zones with a total area of 1038 hectares) has been protected strictly in accordance with the Protection Plan approved by Beijing City in 2002. The protection of the second group of Old City Conservation zones (5 zones occupying 249 hectares) concentrated efforts made between 2002 and 2008 recovered or restored Beijing's cultural relics in places named "two lines, five areas and six sites". The "two lines" refer to the Middle Axis Avenue and the Chaobu Road. The "Five Areas" refer to the Shishahai scenery area, the Imperial College ancient architecture area, the Azure Stone Workshop commercial area, the Forbidden City scenery area and the Bell Tower and Drum Tower ancient street area in the old city. With all these, Beijing old city will achieve a balanced distribution and distinct presentation of its famous history and traditional culture *(Figure 6)*. Nowadays, according to the Beijing Municipal Administration of Cultural Heritage, there are over 3,000 "well-preserved" courtyards remaining in Beijing, and over 539 are in Cultural and Historical Conservation Areas *(Figure 7)*.

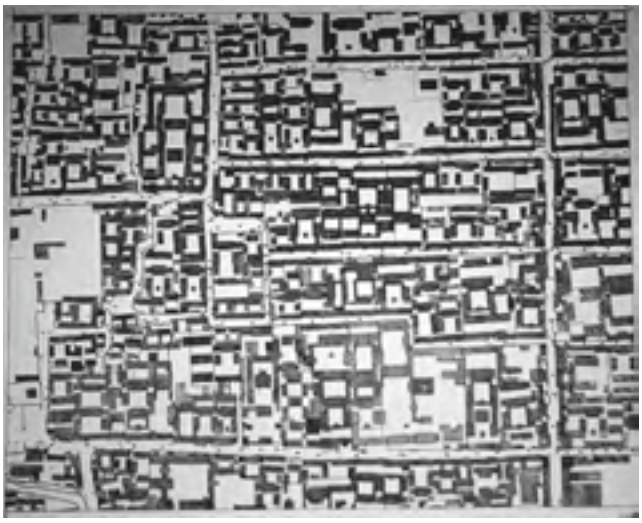
The Project Underway

A project design of digital construction is implemented to rescue the available spatial data and make their exploitation. Finally, with the rapid development of computer graphics, distributed-computing and Internet, it is possible to achieve Internet-based virtual old city restoration. There are three phases to carry out the project, in present, the first phase is working to collect data and building a spatial information management system and the second phase is working to make 3D restoration of some architectural heritage. The main technological procedure and their benefits are discussed as below.

Data Preparation

The first phase of the project is the compilation of a digital framework for the whole area of the old city. This includes: the detailed recording of the 1950s situation, the creation of different layers of geometric information, each one of them contains the situation at various time periods, using all available information, e.g., topographic maps at a scale of 1:1000 and 2000, any other geometric data at appropriate scales, such as a sand table of Beijing old city at a scale of 1:1000, made use of wood in 1950s, existing aerial photos at a scale of 1:2000, street maps compiled in 1950s, urban plot maps, plans of specific monuments, etc. The utilization of the available large scale aerial photos plays an important role for the creation of integrated surveys, which represent the development of the old city in the area through time. Figure 8, 9, 10, 11, 12 show two

(a)



(b)

Figure 8. Topological maps surveyed in 1950s, (a) 1: 2000, (b) 1:1000.

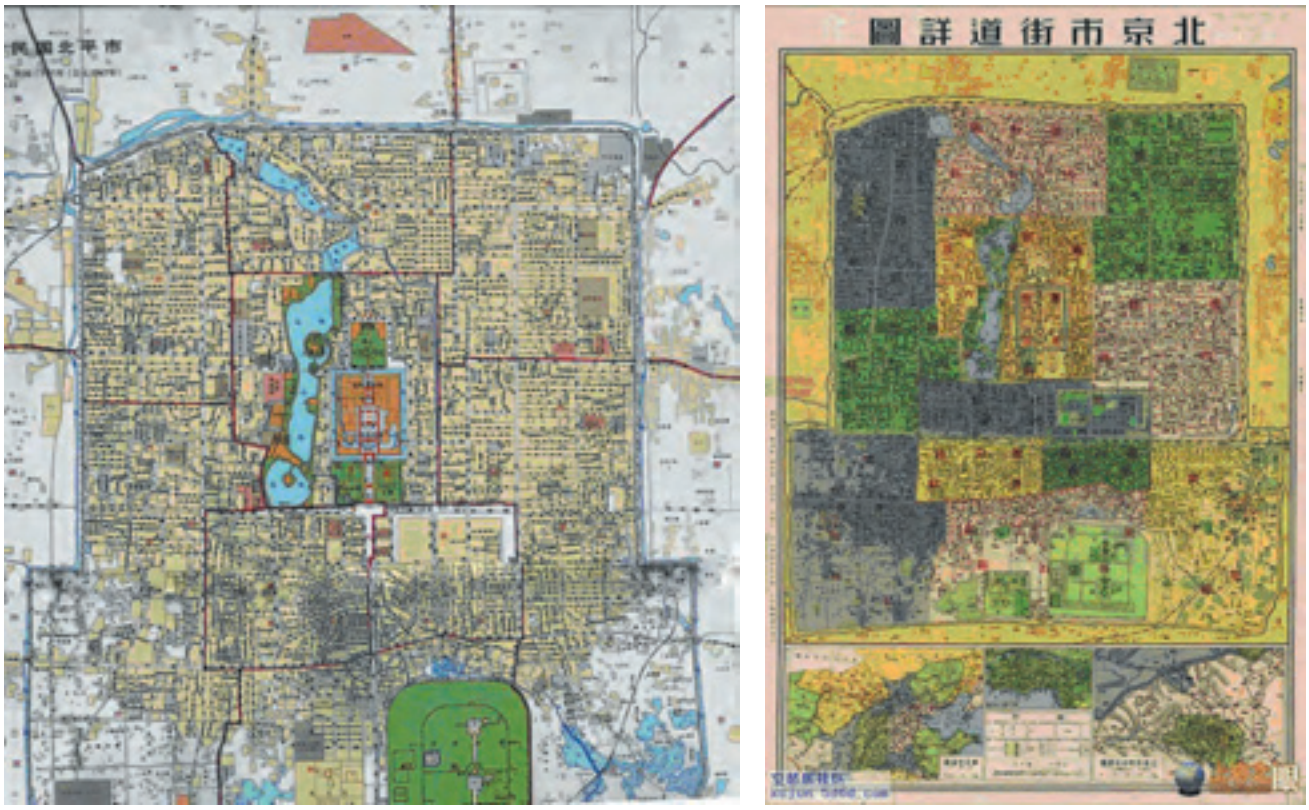
Figure 9. Ortho-image of Beijing old city in 1959.

Figure 10. Mosaic aerial photo of Beijing old city in 1949.

(a)

(b)

Figure 11. Sand table of Beijing old city, 1:1000, made use of wood in 1950s.
(a) Courtyard housing, (b) Forbidden City.



(a) (b)

Figure 12. Street maps of Beijing old city compiled (a) in 1940s, (b) in 1950s.

topographic maps, ortho-image, mosaic aerial photo, sand table and street map of Beijing old city in 1950s respectively.

From those, combination of various data is used in order to provide a powerful tool for recording and monitoring the development in Beijing old city certain time. Further, a structured light scanning processing of that sand table and photogrammetric processing of that aerial photo will produce 3D geometric information about the architectures in the old city. This will include the city walls and their evolutions, the various traditional buildings with information about their heights and volumes. This document will be the basis for all subsequent actions towards part of the final goal of the project too.

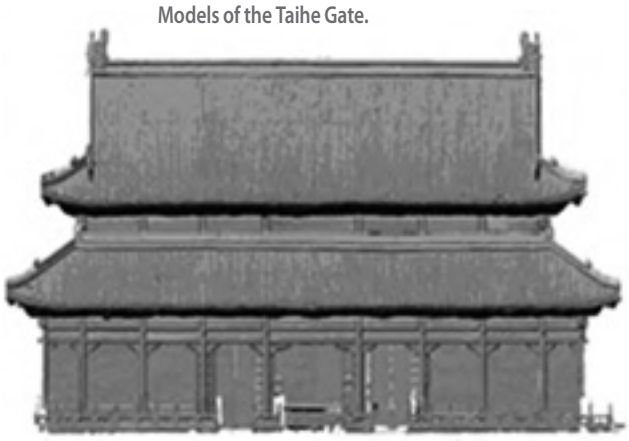
Data Processing

Technological route of data processing is described as follow as below:

1) Collecting multi-source and multi-type data: Scanning and digitizing topological maps of 1: 1000; scanning air photos of 1:2000; scanning the sand table of 1:000 using a structured light system to acquire 3D point cloud of the city walls and some historical architectures, and scanning some existing historical buildings using a terrestrial laser scanner(TLS) to acquire 3D point cloud of the architecture in large scene *(Figure 13)*. Adoping different tech-

Figure 13. TLS and Scanning.

Figure 14. Simplified Triangle on the site Models of the Taihe Gate.



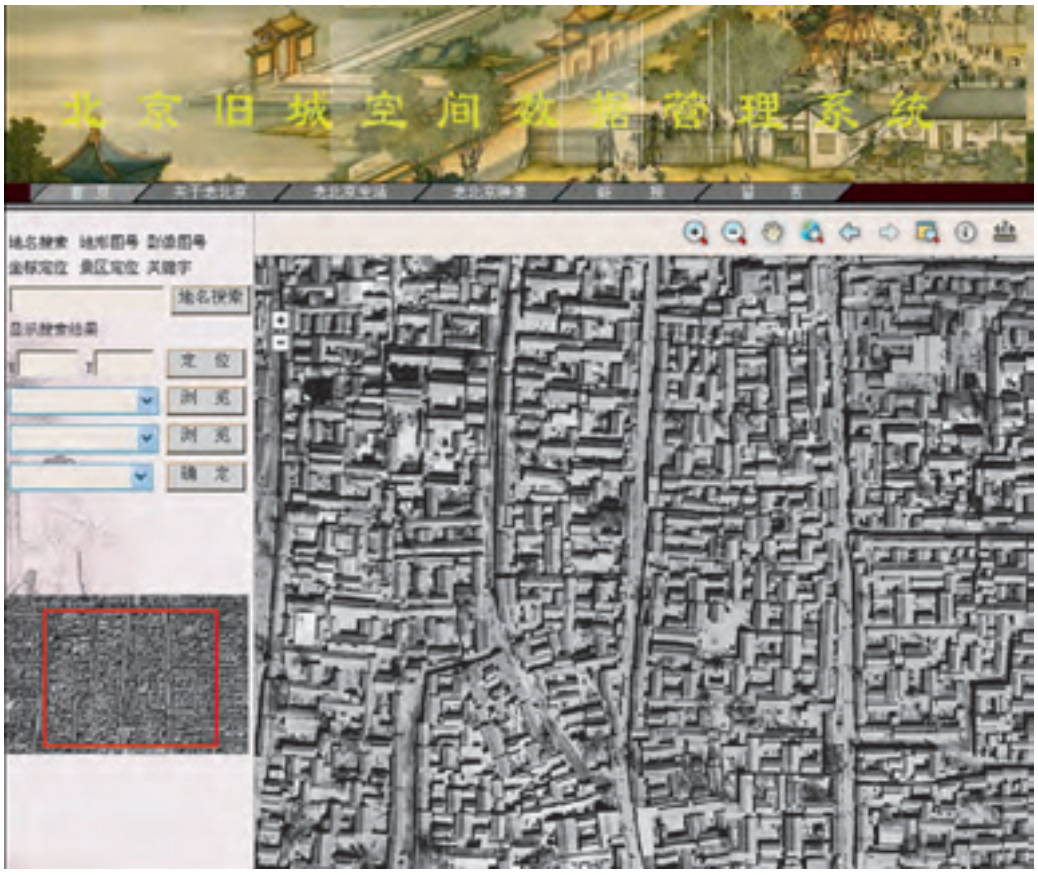


Figure 15. Preliminary interface of the spatial information management system.

nique to acquire different type of historic spatial data, and meanwhile, take them to contract and correct for each other.

2) Processing data: Transforming the scanning coordination of these data to unified Beijing local coordination system based on the topographic map in 1:1000, and then, making the geometry correction and joint respectively. The vetcor represents are archieved with extracting 3D models from the point cloud data scanning the buildings *(Figure 14)* and scanning the sand table. Jointed and edited vector models will be enclosed the unified local coordinate system.

3) Organizing and managing data: A basic framework is organized using the topological map of 1: 1000 of 1950s, other data are embedded in the basic framework, including the vector models which scanning from the old city model. The 3D data and models are organized with multi-layer and tree structure to implement an effective visulization and management for large scene and details of the objects.

Spatial Information Management System

Basic spatial data frame and spatial data database, the qualitative (attributes) and their geometric characteristic, multimedia of Beijing old city are constructed using GIS software,database and integrated developing method to store, record, manage and utilize them. An interface and index of these digital documents are developed to search and display the historical spatial information and other related data of the old city using integrated technology. The linkage windows of two dimensional (2D) and 3D data in the interface are designed to display this main city walls and important histoic buidlings. The system's architecture allows the integration of additional geometric or other type of information, such as "time window" can be opened to show the spatial documents which are in different historical term of Beijing. *Figure 15* shows a preliminary interface of the spatial information management system.

Animation and Visualization

The completion of this project will be achieved through the final phase, in which animations and virtual walk-through paths along selected routes are going to be produced. These works will be done after the finalization of the third phases of the project and it is scheduled that they will refer to the old city walls and part of the protected area mentioned above.

An application of 3D animations will be developed; all buildings will be presented in real time and the buildings of special interest will be represented in detail. In this task terrestrial images will be draped on the 3D models produced in previous phases. The level of detail on the 3D models will be such that would enable the users to perform their own actions. Finally, with the rapid development of computer graphics, distributed-computing and Internet, it is possible to achieve Internet-based virtual old city restoration.

Concluding

During the recent years there was a significant development of the techniques and the methods used for the digital geometric documentation of Beijing old city and historical monuments; in parallel, collection data techniques of the structured light instrument and terrestrial laser scanner, software for the management of spatial information, 3D data, virtual environments and the Internet is developed. These technique tools pushed the development of the restoration of the old city, and especially the detailed models of the historical city notes which were dismantled in various historic heritage cities using a lot of existing spatial documents.

Beijing Municipal Science & Technology Commission realized that the protection of that spatial information for Beijing old city is necessary, and the creation of such a spatial information management system; in cooperation with the Beijing University of Civil Engineering and Architecture, the design of a specific project is made and the execution of the first phases is implemented. During its application procedure, the results and the products of the created spatial information management system will be analyzed and criticized, together with the difficulties and the problems for the development of the system. This will lead to corrections and adjustments of the whole process for the integrated implementation in the whole area. Finally, some recommendations about the further improvements and the possible perspectives of the system will be given, for a possible use by Beijing public services and organizations as well as library of BUCEA.

Acknowledgement

This paper was supported by the Funding Project "Study on key technique for spatial information digitization of Beijing old city", Project No. Z090406005809011, which is from Beijing Municipal Science & Technology Commission, and by the Funding Project "Digital City and Architecture Simulation", Project No. PHR 20070101, which is for Academic Human Resources Development in Institutions of Higher Learning Under the Jurisdiction of Beijing Municipality.

References

Beijing Cultural Heritage Protection Center, 2005. " Protection of the old city of Beijing: Good Plan". http://en.bjchp.org/english/mzpl_view.asp?NewsID=76(accessed July, 2009)

Crespi, M., De Vendictis, L., Fabiani, U., Luzietti, L., Mazzoni, A., 2005. The Archaeological Information System of the underground of Rome: A challenging proposal for the next future. In: Proceedings of CIPA XX International Symposium, Turin, Italy, IAPRS, vol. XXXVI, part 5/C34, pp. 209-214.

El-Hakim, S.F., Beraldin, J.A., Gonzo, L., Whiting, E., Jemtrud, M., Valzano, V., 2005. A hierarchical 3D reconstruction approach for documenting complex heritage sites. In: Proceedings of CIPA XX International Symposium, Turin, Italy, IAPRS, vol. XXXVI, part 5/C34, pp. 790-795.

H.-J. Przybilla, J.Peipe, 2007. 3D Modeling of Heritage Objects by Fringe Projection and Laser Scanning Systems, In: Proceedings of CIPA XXI International Symposium, Athens, Greece, ISPRS, vol. XXXVI-5/C53, pp. 615-618

Hou Renzhi, 2007. "City Wall and Gate of Beijing". http://oldbeijing.org/Article/Class4/Class42/11047.html (accessed July, 2009)

Lelo, K., Travaglini, C.M., 2005. The GIS-based historical atlas of Rome. In: Proceedings of CIPA XX International Symposium, Turin, Italy, IAPRS, vol. XXXVI, part 5/C34, pp. 891-895.

N. Charkiolakis, Ch. Ioannidis, Ch. Kantza, I. Keramida, A. Koumna, M. Leni, M. Liakak, V. Pragast, M. Psallida, A. Georgopoulos, 2007. Spatial Information System for 3D Documentation of Plaka, the Historical Centre of Athens, In: Proceedings of CIPA XXI International Symposium, Athens, Greece, ISPRS, vol. XXXVI-5/C53, pp. 769-774

Wikipedia, 2008. "Siheyuan". http://en.wikipedia.org/wiki/Siheyuan (accessed July, 2009)

Yuan Yuan, Follow our China Today Reports in 2005. "Preserving the Soul of Beijing". http://www.chinatoday.com.cn/English/e2005/e200502/p28.htm(accessed July, 2009)

Laser scan documentation and virtual reconstruction of the Buddha figures and the archaeological remains (Bamiyan)

G. Toubekis[1],* I. Mayer[2], M. Döring-Williams[2], K. Maeda[3], K. Yamauchi[3], Y. Taniguchi[3], S. Morimoto[4], M. Petzet[5], M. Jarke[6], M. Jansen[1]

1. *RWTH Aachen University, Aachen Center for Documentation and Conservation, 52056 Aachen, Germany (toubekis, jansen)@sbg.arch.rwth-aachen.de*
2. *Technical University Vienna, Department of Art History, Karlsplatz 13/251, 1040 Vienna, Austria*
3. *Japan Center for International Cooperation in Conservation, NRICPT, 13-43 Ueno Park,Tokyo, Japan*
4. *Nara National Research Institute for Cultural Properties, 2-9-1 Nijo-cho, Nara, Japan*
5. *ICOMOS Germany, P.O. Box 100 517, 80079 Munich, Germany*
6. *RWTH Aachen University, Information Systems & Database Technology, 52056 Aachen, Germany jarke@dbis.rwth-aachen.de*

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 that adapts the projected image to the spectator's view 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 are embedded in the long term management plan for the entire World Heritage Site.

Key words: Cultural Heritage Management, 3D, Laser Scanning, Modelling, Visualization.

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 kilometres 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 kilometres on the north side of the valley facing south leaving the fertile plane open for agriculture (Fig. 1). 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 out-

* Corresponding author

Figure 1: The site of the Bamiyan Buddhas in October 2004 with the empty niches (view in NE direction).

standing 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. 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 travelling Chinese monk Xuanzang 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 rose 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 centre 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 have been copied various times by others travellers. 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 valley was drawn by Jacques Meunie in 1936 and a comprehensive photographic documentation of the condition of the monument was elaborated (Hackin & Meunie 1933; Hackin, Carl & Meunie 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 the destruction of the Giant Buddha figures at the very beginning of the 21st century. International intervention and protest could not prevent their complete destruction 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 comprising eight individual areas representing artistic and religious developments from the 1st to the 13th century AD.

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 fact finding mission took place to Bamiyan. 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 *(Fig. 2)* 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 the president of ICOMOS International (Petzet 2002). Con-

Figure 2: Condition of Eastern 38m Buddha before and after the destruction.

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

servation 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 groundtruethed analysis of IKONOS 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). 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, Taniguchi & Tomoko 2007).

On the lateral sides of the niches that were in danger to collapse completely due to the impact of the detonations emergency consolidations had to be 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 since 2003 in the international expert campaign of UNESCO for the Safeguarding of the Bamiyan World Heritage Site (ICOMOS 2005; Petzet 2009). 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 investigations 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. This Master Plan *(Fig. 4)* 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.

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.

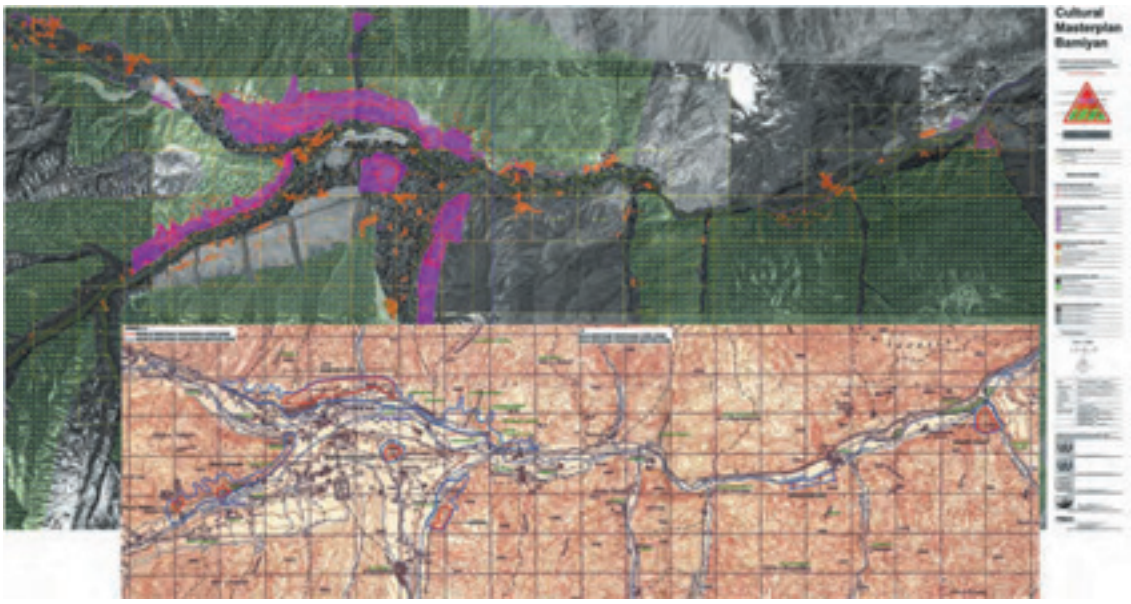


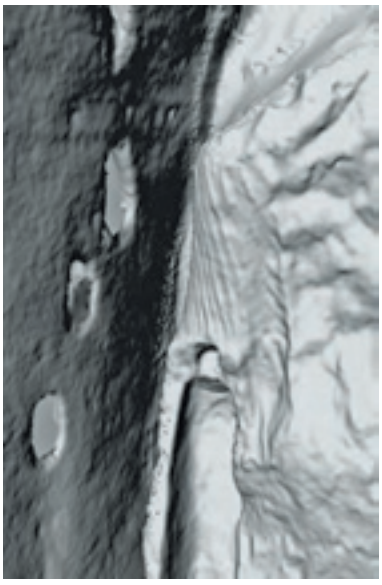
Figure 4: Cultural Master Plan of the Bamiyan valley and map from UNESCO nomination file.

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 by Irmengard Mayer to document the condition of the cleaned niche prior to the installation of a scaffold for the following consolidation works at the back wall *(Fig. 5-6)*.

A Riegl Laser Measurement System Z420i 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 colour 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

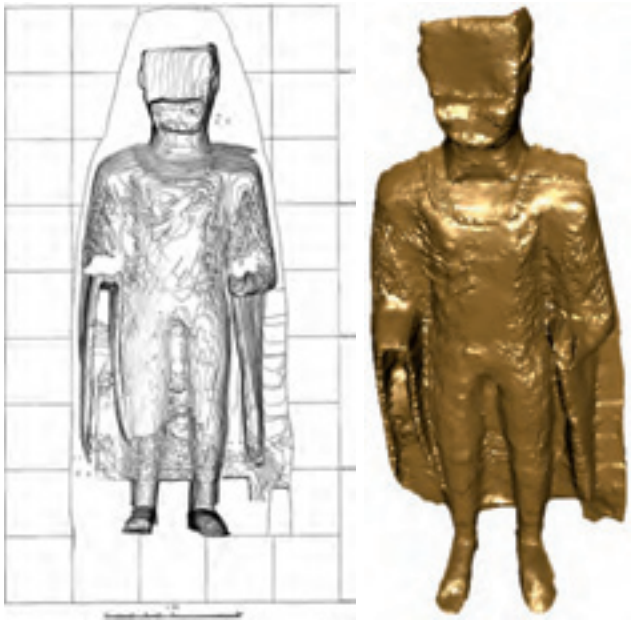
(a) Riegl Z420i



(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) (b)

Figure 7: (a) Eastern Buddha 38(m) drawing courtesy of Prof. Higuchi Kyoto University Archaeological mission to Central Asia (b) 3D model derived from isoline drawing.

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

the laser scanner manufacturer Riegl.

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. In close range to the most eastern Ground Control Point B3 and complementary to already existing fix points of the site reference system a new fix point directly in front of the Eastern Buddha niche was determined and fixed into the ground.

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 have 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 1970-1978. The entire cliff was documented by means of stereoscopic analysis of metric images taken during the field campaign. A scaled isoline drawing of the entire cliff was drawn afterwards including both Giant Buddha figures (Higuchi 1984). The Western Buddha (55m) was also documented with stereo metric 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 explored by ETH Zürich (Grün, Remondino & Zhang 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 is clearly readable and was manually digitized. The 3D surface of the Eastern Buddha was generated with Geomagic Studio v.10 Software *(Fig. 7)*. 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 RWTH Aachen University represents an advanced version of the system (Cruz-Neira, Sandin & Defanti 1993). It 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.

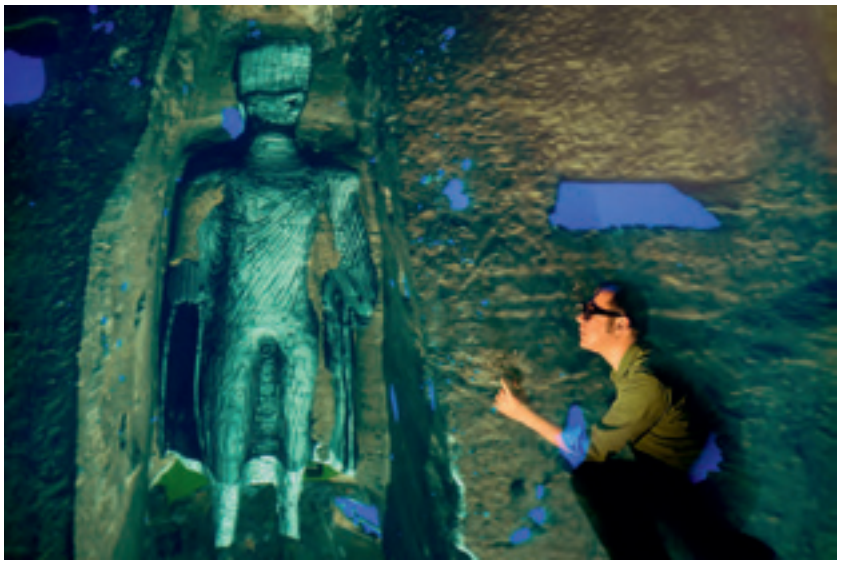
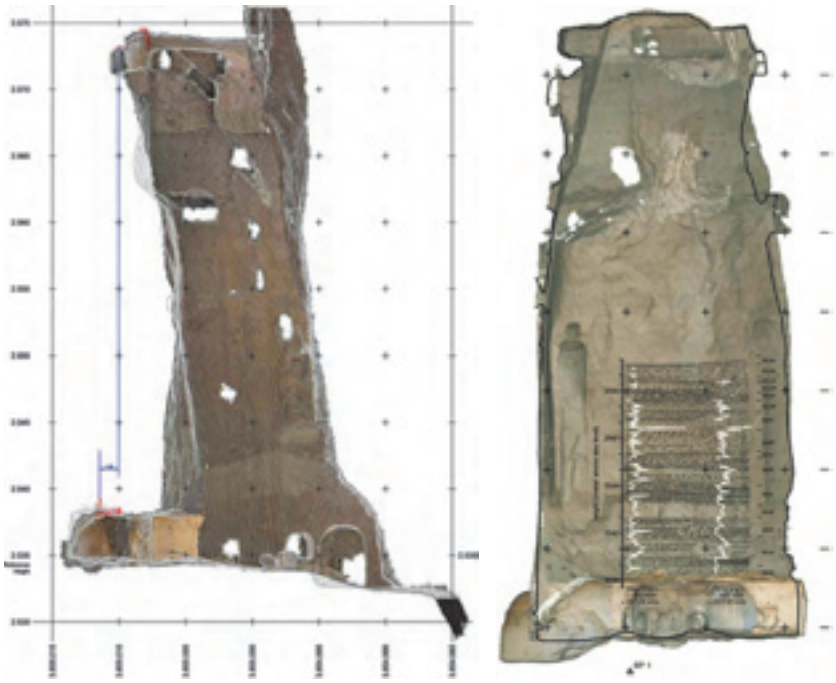


Figure 9: Immersive Virtual Environment CAVE.



(a) Geological profile (b) Section

Figure 10: Various Maps of the niche from 3D Model.

The user of the Cave wears a pair of polarized glasses with attached reflectors so that his position in space 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 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 Technology (FIT) in Bonn/Birlinghoven.

A space of 50m² 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 FIT 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.

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 & 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.

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. Dispersed Information has to be made accessible by younger scientists using modern IT and scientific knowledge to actualize the knowledge on the site and monuments. Facing such problems conservation activities have to be prioritized and integrated in sustainable development plans that both meet the requirements of protecting the inherit value of a cultural site and the necessity to identify economic and social benefits such income generation from 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 Department for Databases and Information Systems (Prof. Mathias Jarke) at RWTH Aachen University it is being examined how far current developments in collaborative work on multimedia artefacts and web-based learning approaches are applicable to Cultural Heritage Management scenarios. The addressed requirements include the promotion of awareness and knowledge raising activities about the existence and value of cultural sites to a 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 re-contextualisation of the multimedia artefact 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. 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).

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 a 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.

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 area as the Bamiyan site and the complexity of its management justify 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, 2008). 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.

Acknowledgments

This work is supported by the Culture Section of the Foreign Office of Germany (Kulturreferat Auswärtiges Amt) through the ICOMOS Project for the preservation of the remains of the Bamiyan Buddhas and by the German National Science Foundation (DFG) within the research cluster UMIC- Ultra High Speed Mobile Information and Communication established under the excellence initiative of the German Government. We thank Masanori Nagaoka from UNESCO for his help and also Prof. Minoru Inaba and Prof. Bunkyo Kin of the Institute for Research in Humanities at Kyoto University for making the contour line drawing available.

Selected Bibliography

References from Journals:

Kostka, R., 1974. Stereophotogrammetrische Aufnahme des großen Buddha von Bamiyan. Afghanistan Journal, 1(3), pp. 65-74.

References from Books:

Burnes, S.A., 1834. Travels Into Bokhara: Narrative of a voyage by the river Indus. Memoir of the Indus and its tributary rivers in the Punjab, J. Murray.

Cruz-Neira, C., Sandin, D.J. & Defanti, T.A., 1993. Surround-screen projection-based virtual reality: the design and implementation of the CAVE. In: SIGGRAPH '93-Proceedings of the 20th annual conference on Computer graphics and interactive techniques. ACM Press, pp. 135-142.

Hackin, J., Carl, J. & Meunie, J. (eds.), 1959. Diverses Recherches Archéologique en Afghanistan (1933-1940), Paris: Délégation Archéologique en Afghanistan -DAFA.

Hackin, J. & Meunie, J. (eds.), 1933. Nouvelles Recherches Archéologiques à Bamiyan, Paris: Délégation Archéologique en Afghanistan - DAFA.

Higuchi, T., 1984. Bamiyan. Art and Archaeological researches on the Buddhist cave temples in Afghanistan 1970-78, Dohosha.

ICOMOS, 2005. Afghanistan - Icomos Actions in Afghanistan. In: M. Truscot et. al. (eds.) Heritage at Risk 2004/2005, K.G. Saur, p. 26-31.

Jansen, M. et. al., 2008. Laser scan measurement of the niche and virtual 3D representation of the Small Buddha in Bamiyan. In: Axel Posluschny et. al. (eds.) Layers of perception: proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA); Berlin, Germany, April 2-6, 2007 , Kolloquien zur Vor- und Frühgeschichte, 10, Bonn: Habelt, pp. 83-90.

Klimburg-Salter, D., 1989. The Kingdom of Bamiyan, Naples: Istituto per il Medio ed Estremo Oriente (ISMEO).

Margottini, C. et. al., 2005. Emergency Intervention for the Geo-Mechanical Conservation of the Niches of Bamiyan Buddhas (Northern Afghanistan), In: H. F. Kyoji Sassa et. al. (eds.) Landslides-Risk Analysis and Sustainable Disaster Management, pp. 75-79.

Miyaji, A., 1976. Wall paintings of Bamiyan Caves: stylistic analysis. In Japan-Afghanistan Joint Archaeological Survey in 1974. Kyoto: Kyoto University Archaeological Mission to Central Asia, pp. 17-31.

NRICP, 2004. Protecting the World Heritage Site of Bamiyan. Key issues for the Establishment of a Comprehensive Management Plan, Tokyo: National Research Institute for Cultural Properties. Japan Center for International Cooperation in Conservation.

Ohlenburg, J. et. al., 2004. The MORGAN Framework: Enabling Dynamic Multi-User AR and VR Projects. In VRST '04: Proceedings of the ACM symposium on Virtual reality Software and Technology. Honk Kong, pp 166–169.

Petzet, M., 2002. Anastylosis or Reconstruction - the conservation concept for the Remains of the Buddhas of Bamiyan. In: Strategies for the World Heritage. Preservation in a globalized World. Proceedings of ICOMOS Spain for the ICOMOS 13th General Assembly 2002, Madrid, pp. 189-192.

Petzet, M., 2008. Das Fragment als Denkmal: Die Buddhas von Bamiyan. In: Das Denkmal als Fragment - Das Fragment als Denkmal. Denkmale als Attraktionen: Jahrestagung der Vereinigung der Landesdenkmalpfleger, June 10-13, 2007 Esslingen a. N., Arbeitshefte des Landesamtes für Denkmalpflege Baden-Württemberg. Stuttgart, Esslingen a. N.

Petzet, M. (ed.), 2009. The Giant Buddhas of Bamiyan, Berlin: Bäßler.

Tarzi, Z., 1977. L´ Architecture et le Décor Rupestre des Grottes de Bamiyan, Paris.

Yamauchi, K., Taniguchi, Y. & Tomoko, U. (eds.), 2007. Mural Paintings of the Silk Road: Cultural Exchanges Between East and West, Tokyo: Japan Center for International Cooperation in Conservation, National Research Institute for Cultural Properties, Tokyo.

References from Other Literature:

Grün, A., Remondino, F. & Zhang, L., 2002. Reconstruction of the Great Buddha of Bamiyan, Afghanistan. In: International Archives of Photogrammetry and Remote Sensing. (ISPRS) Technical Commission V Symposium 2002. Close-Range Imaging, Long-Range Vision, Corfu (Greece), Vol. XXXIV, Part 5, pp. 363-368.

PASCO, 2003. Final Report for the Preparation of Topographic Maps and 3-Dimensional Model of the Bamiyan and Foladi Cliffs. UNESCO/Japan Funds-in-Trust Project for the Safeguarding of the Bamiyan Site, Tokyo: Pasco Corp.

Santana, M., 2002. Report on the UNESCO/ICOMOS mission to Bamiyan 2002, RWTH Aachen Center for Documentation and Conservation.

Urbat, M. & Krumsiek, K., 2004. Paleo- and Rockmagnetic Criteria for the Reconstruction of the Giant Buddha Statues, Bamiyan / Afghanistan. In Geophysical research abstracts, Volume 6, EGU 1st General Assembly. Nice, France.

References from websites:

UNESCO, 2006. Recommendations of the UNESCO/ICOMOS Expert Group for the Safeguarding of the Bamiyan site (5th meeting), Available at: http://whc.unesco.org/en/events/354, accessed 30.05.2010.

4 Future Trends in Heritage Documentation

P. Patias

Aristotle University of Thessaloniki, Department of Cadastre, Photogrammetry and Cartography, Univ. Box 473, GR-54124 Thessaloniki, patias@auth.gr

New work habits, new research opportunities, and even new forms of institutions reform the CH documentation activities and consequently force photogrammetry to offer its services in many aspects. Photogrammetry provides large amounts of highly detailed, very accurate, geo-referenced, 3-D vector and texture data, with stereo-viewing abilities and metadata information. This constitutes its comparative advantage over other techniques and procedures.

Evaluating the current status and envisaging the future evolution of CH documentation, one could note that:

- Classic technology is very mature and the applications based on it are straightforward. Therefore, there are many different applications reported, and this has a favourable impact on the end-users, since it attracts their attention.
- New technology is entering the picture at a growing rate and this drives innovative research. This fact gives rise to rapidly emerging new concepts and, as a spin-off, it attracts participation from related disciplines.
- In addition to the photographic imaging systems, 3-D scanners and other non-imaging sensors play an important role in heritage and will continue to progress. The variety starts from airborne LIDAR systems for terrain/surface modelling and site mapping, followed by mid-range scanners for facades/buildings mapping, and goes down to close range 3-D scanners for detailed documentation of finds, artefacts and sculptures. The spectrum of technology will include range sensors with time-of-flight, phase difference or triangulation using laser points, fringe or other patterns projection. The challenge in Cultural Heritage applications is therefore the sometimes very complex data fusion from these heterogeneous sources.
- New issues are entering the research agenda, like standardization issues, systems for quality management, intellectual property issues. It is quite important to note that, although conformance to intrinsic quality measures (i.e. standards) will always be necessary, it is only one part of the story. Quality can only be determined by "fitness for use". Ultimately, quality evaluation needs to include user demands.

Authors Index