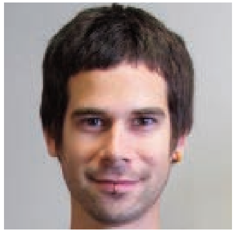
ISSN 1828-5961


José Luis Lerma
Il dottor Lerma è un ingegnere e professore associato in Fotogrammetria presso l'Università Politecnica di Valencia (UPV). Egli è il Capo della Fotogrammetria e Laser Scanning Research Group (Gifle) presso l'UPV.. E' membro di numerosi comitati scientifici internazionali come CIPA e VSMM. Autore di sette libri riguardanti fotogrammetria e LiDAR.

Santiago Navarro
Ingegnere in Geodesia e Cartografia della UPV, ed è attualmente uno studente di dottorato. Membro di GIFLE dal 2006. La sua ricerca si concentra sullo sviluppo di software di fotogrammetria e implementazione di algoritmi per la fotogrammetria architettonica, modelli 3D, visione artificiale e sistemi di navigazione inerziale.

Miriam Cabrelles
Ingegnere in Geodesia e Cartografia della UPV. Membro di GIFLE dal 2007. I suoi attuali campi di ricerca sono: rettifica delle immagini e calibrazione di telecamere; analisi termografica in edilizia e restauro: integrazione di termografia e fotogrammetria e laser terrestre scansione per la generazione di modelli 3D con texture.



Santiago Fabado
Ing. Geodesia e Cartografia della UPV. Si unisce GIFLE nel 2010 con una ricerca e di una borsa di studio di specializzazione. Le linee di interesse che segue sono grafica 3D per computer, visualizzazione 3D e gestione di point cloud e mesh. Si sta sviluppando principalmente applicazioni in .Net Framework, così come per i dispositivi mobili e Web.


# Dalla fotografia digitale alla fotogrammetria per i Beni Culturali Documentazione e Divulgazione

# *From Digital Photography to Photogrammetry for Cultural Heritage Documentation and Dissemination*


La fotografia digitale è considerata un valido strumento per la documentazione del patrimonio culturale.
Topografia e fotogrammetria sono necessari per ottenere risultati metrici precisi nei disegni, modellazione 2D/3D e texturing.
Questo articolo descrive il processo di lavoro adottato dall'acquisizione dati alla modellazione 3D fotorealistica. Inoltre, sono documentati alcuni casi studio relativi a diversi siti.
I Manager e gli esperti di comunicazione sul patrimonio culturale, dovrebbero considerare la fotogrammetria uno strumento non solo per arricchire la conoscenza, per migliorare la comprensione e fornire registrazioni scientifiche, ma anche per facilitare la diffusione delle risorse del patrimonio.

*Digital photography is considered a valuable tool for cultural heritage documentation. Surveying and photogrammetry are required to achieve metric and accurate results in drawings, 2D/3D modelling and texturing. This paper presents the photogrammetric workflow from data acquisition to photorealistic 3D modelling and four heritage documentation case studies in different sites. High resolution and high accuracy photorealistic 3D models allow experts to recreate and interact virtually with cultural heritage either before, during of after intervention. Managers and information experts of cultural heritage monuments and sites should consider photogrammetric by-products not only to enrich knowledge, improve understanding and provide scientific records but to ease dissemination of heritage resources.*



***Parole chiave***: beni culturali, documentazione, fotogrammetria, laser scanning, modello fotorealistico 3D
***Keywords****: cultural heritage, documentation, photogrammetry, laser scanning, photorealistic 3D models*

ISSN 1828-5961


## INTRODUCTION

Digital photography is a powerful widespread technique used by general public for travelling, celebrations, parties, art, advertisement, publications, etc. However, not all photographers (broadly speaking people taking pictures but also scientists acquiring data on site) consider their cameras as a powerful tool to undertake architectural and/or archaeological surveys in three-dimensions (3D).

Different digital cameras can be found nowadays in the market, ranging from professional to amateur models, where a large variety of solutions, bodies, lenses, formats and accessories can be used to deliver direct expressions of life and art. Any of the afore-mentioned cameras might be used to deliver accurate metric information as far as the camera is properly calibrated. Waldhäusl and Ogleby (1994) presented the 3 x 3 rules for simple photogrammetric documentation of architecture where nine guidelines were specified about the geometry (three), the photography (three) and the organization (three) to make valuable surveys from imagery acquired on site. GIFLE (2012) introduces twelve recommendations for metric photography of architectural and archaeological cultural heritage with low cost devices.

It is also well-known that a wide range of scientific applications can be undertaken due to scientific imaging sensors, not only in cultural heritage but also in astronomy, industry, geology, medicine, among others. There is a scientific way to record and document cultural heritage making use of cameras or imaging sensors, as part of basic surveying equipment (e.g. tape, laser meters, calibre, plumb-line) and modern high-end electronic devices (e.g. automatic reflectorless total stations and laser scanners). For documentation of cultural heritage namely in architecture and archaeology, digital imagery can also be used for a large range of purposes such as archiving, inventory, drawings, 2D and 3D recording, 3D modelling, monitoring over time (also known as 4D monitoring) and texturing.

A revision of image-based solutions for different documentation purposes can be found in Grussenmeyer et al. (2002) and Remondino and El-Hakim (2006).

Böhler (2006) and Jones (2011) classify the recording techniques in two large groups, direct and indirect, and specify the optimum scale and performance based on object's complexity and size.

Photogrammetry is considered one of the most successful indirect techniques to measure and reconstruct objects in 3D from one, two or multiple imagery (Lerma, 2010). Photogrammetry either standalone or integrated with laser scanning (Lerma et al, 2010, 2011) is considered an ideal indirect technique for cultural heritage documentation independently of the scale of the survey and the platform (static/mobile, terrestrial/aerial/underwater/underground) used to acquire the pictures.

Automation has without any doubt revolutionised the image-based performance to derive either 3D colour point clouds or texturized 3D models. First attempts started some years ago in the photogrammetric community (Läbe and Forstner, 2006; Remondino and Ressl, 2006).

After them, many papers can be found in literature that integrate computer vision algorithms in the photogrammetric performance to drive photogrammetric computer vision solutions (Barazzetti et al. 2010; Pierrot Deseilligny and Cléry, 2011; Lerma et al., 2013). Computer vision solutions for image-based modelling rely on powerful algorithms such as structure from motion (Pollyfeys et al. 1999), invariant detectors and descriptors (Lowe, 2004, Moreels et al., 2007) and dense image matching (Courchay et al., 2010; Furukawa and Ponce, 2010).

There is a new trend to achieve automatic 3D object reconstructions from multiple images from low cost software packages and/or web services. Despite the non-straightforward usability of the raw data produced (Dellepiane et al., 2013), studies report promising results when compared with terrestrial laser scanning (Kersten and Lindstaedt, 2012; Forte et al., 2012) while others confirm that some distortions can be obtained due to lack of reliability and repeatability with structure from motion algorithms (Remondino et al., 2012).

This paper is structured as follows. Section 2 reviews the image-based and range-based photogrammetric workflow from data acquisition to 3D modelling for the virtual reconstruction of large objects in 3D. Section 3 presents four close range outdoor recording applications on two different architectural features and two different archaeological sites. Section 4 explores a new in-house developed software that facilitates the virtual interaction of high-resolution architectural and/or archaeological 3D models for both information users (conservation experts) and information providers (heritage recorders), as pointed out by Letellier et al. (2007).

Finally, Section 5 discusses the issues tackled in this paper and draws some conclusions.

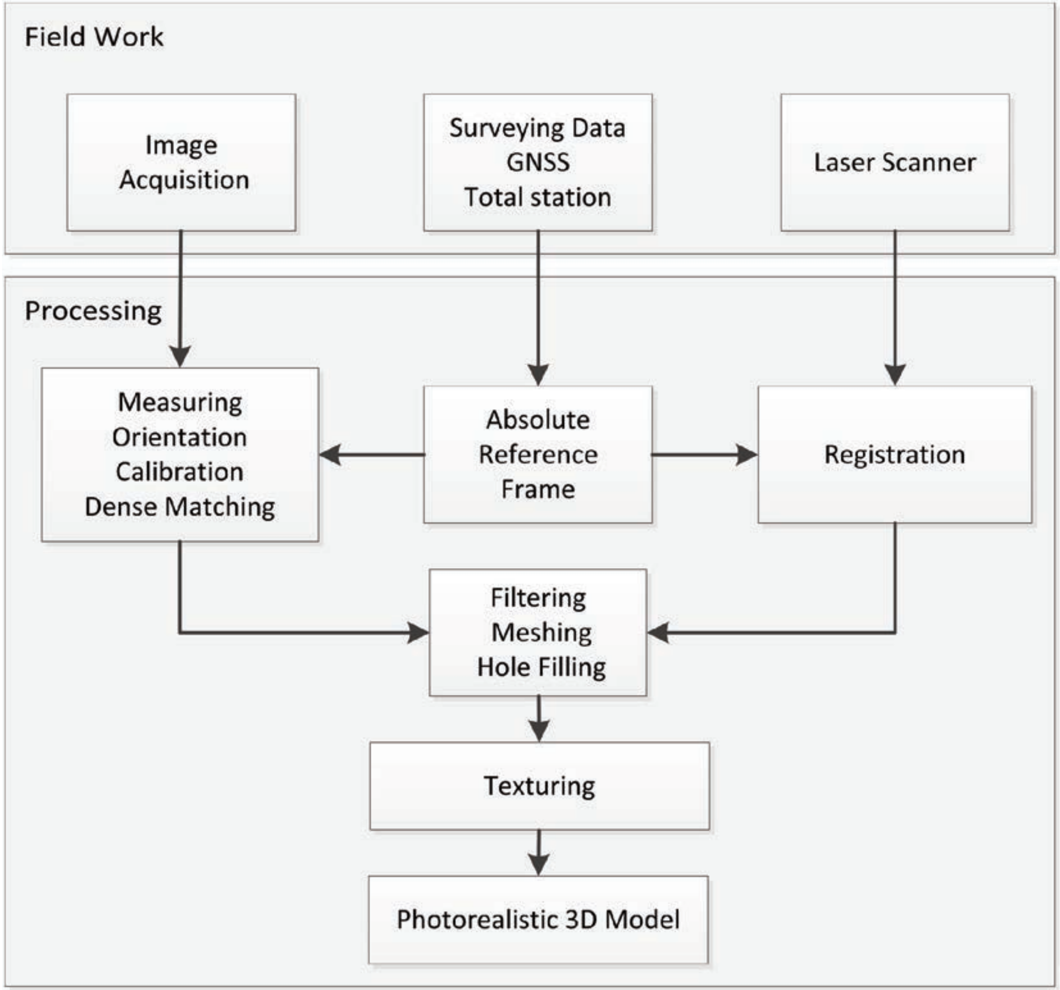
## PHOTOGRAMMETRIC WORKFLOW

Photogrammetry can be defined as the art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena (Slama et al., 1980).

The workflow for metric surveys and recording is illustrated in Fig. 1. From Field Work where diverse data can be acquired, namely, surveying data and pictures, independently of the equipment (ruler, level, total station... up to laser scanner).

Next step is Processing where a wide range of steps should be undertaken to achieve a proper camera calibration (estimation of the interior orientation parameters of the camera, namely, principal distance, principal point offsets and distortion parameters), orientation (estimation of the exterior parameters of the camera, namely position and attitude, as they where when the pictures where taken), point clouds determination by image matching or point clouds registration in case of using laser scanning systems, meshing to build up 3D models and finally texturing. When the texture used to drape the model is non-true the output 3D model will be considered a virtual model. However, when the texture used to drape

ISSN 1828-5961


1. Image-based and range-based photogrammetric workflow to yield photorealistic 3D models.

the 3D models comes from the oriented imagery acquired on site, photorealistic 3D models will be produced. Reality-based documentation follows this latter stage where only true input data is used to create eventually the photorealistic 3D models. More information about the integration of close range digital imagery and terrestrial laser scanning data sets can be found in Lerma et al. (2010, 2011). In addition, Kersten and Lindstaedt (2012) highlight the degree of automation of the individual steps that can be achieved nowadays with low cost software packages, including web services.

From the input digital photography imagery, not only pictures but colourful point clouds (in an initial stage) and photorealistic 3D models (in an eventual stage) are achieved. Nevertheless, stages such as camera calibration and orientation are considered essential to confirm the quality of the output results. Traditionally from photogrammetric surveys, plans/maps, elevations and cross-sections and contour plotting were the typical products.

With the advent of digital photogrammetry, orthoimages (digital orthophotos) and digital elevation/terrain models (DEM/DTM) were primary outputs for Geographic Information Systems (GIS). Nowadays, multimedia deliverables can be found as part of the documentation business.

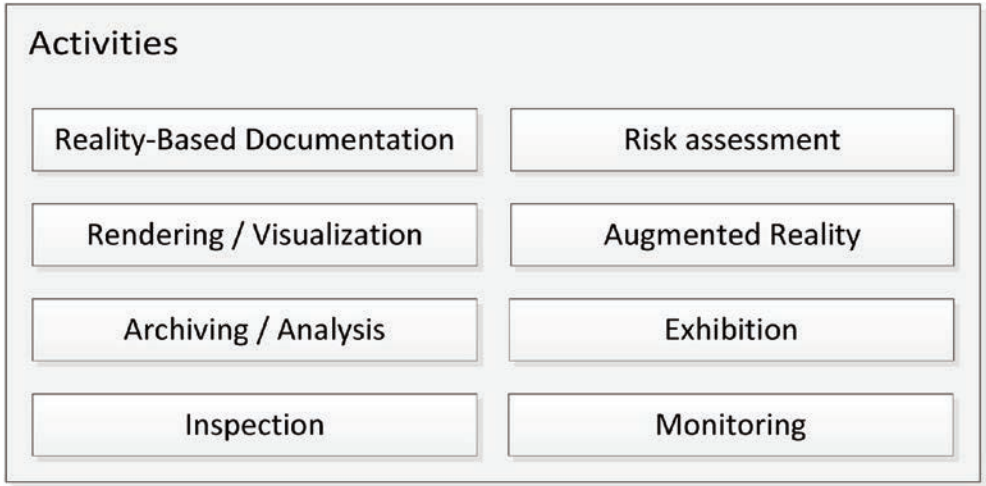
A summary of straightforward activities that might come from the photogrammetric workflow is presented in Fig. 2.

From inexpensive surveys in the field, even with minimum resources, many activities might be undertaken by photogrammetric computer vision users taking pictures with whatever digital camera.

A simple example would be for instance the monitoring over time of archaeological sites, architectural monuments, buildings, objects and artefacts. The minimum resources are the pictures acquired on site by any experience user.

The idea is not photogrammetry per se but to improve management of cultural heritage objects, monuments and sites where resources for heritage all over the world are always not enough.

ISSN 1828-5961


2. Summary of activities that might be undertaken after a photogrammetric workflow.

RECORDING APPLICATIONS IN ARCHITECTURE AND ARCHAEOLOGY

In this section four documentation case studies are presented: two architectural and two archaeological projects.
The documentation case studies were undertaken by the authors in the last years. The variety of shapes can be considered enough to confirm the photogrammetric performance of the surveys.
More room would be required to present small objects and artefacts obtained either from archaeological excavations or architectural features. Nevertheless, the results can be extrapolated to further monuments and sites.
Fig. 3 displays the four selected case studies: a) wall of masonry sandstone in Taybeh Village - Petra (Jordan); b) main façade of the Palace of Marquis of Dos Aguas (currently National Ceramics Museum) in Valencia (Spain); c) Djin Block No. 9 in Petra Archaeological Park (Jordan); and d) Cova Remígia, Ares del Maestre, Castellón (Spain).
The sizes of the four case studies range between 24-200 m2. Photographs were acquired with a compact Panasonic Lumix DMC-LX3 digital camera for case study a, and with a Canon 1Ds Mark III (different wide angle lenses were used) on case studies b-d from different positions: 9, 24, 38 and 122 respectively. The resolution of the former camera was 3776 x 2520 pixels while for the latter 5616 x 3744 pixels.
All the image-based photogrammetric processing was carried out with FOTOGIFLE software developed in-house by the authors in our department. The camera was always calibrated on purpose. It means that pictures were not only taken to yield photorealistic 3D models but camera calibration, orientation in space, dense image matching (Fig. 4a) and orthoimagery (Fig. 4b), among other deliverables. Besides, 3D models might be worth printing out in 3D in a variety of materials with 3D printers at different scales.
Heritage objects, monuments and places require most of the times colour photorealistic 3D models instead of point clouds. Depending on the purpose, it might be necessary to deliver just standard 3D models instead of photorealistic models. Fig. 5 illustrated the difference between visualising 3D point clouds, 3D models and photorealistic 3D models. Worth mentioning is that the better the quality of the input pictures used for draping (texturing) the better will be the feeling of realism of the output photorealistic 3D model.

INTERACTION AND DISSEMINATION WITH 3DVEM – 3D VIEWER, EDITOR AND METER SOFTWARE

The chances to improve understanding and foster dissemination are paramount whenever virtual interaction starts either at home, in the office, in an exhibition centre, in a museum, etc. 3DVEM – 3D Viewer, Editor and Meter is a new free software released to the market to easy communication between information users and information providers. It is possible to interact either with georeferenced point clouds (Fig. 5a), standard 3D models (Fig. 5b) and photorealistic 3D models (Fig. 5c) individually or layer-by-layer, turning the different datasets on and off using a simple menu.
In addition, different rendering modes are implemented to enhance understanding of the data. There is a chance to add: personal points of view at a wide range of attitudes, annotations and references on the models, as well as take unlimited number of measurements (Fig. 6).
Furthermore, the visual presentation of the results can be displayed in both perspective and orthogonal projection. The perspective visualisation resembles the way users visualise and feel the object, monument or site. However, the orthogonal projection is preferred to print out plans and elevations at a specific object scale.
3DVEM – Live software enhances the capabilities of 3DVEM – Viewer, Editor and Meter and allows users to create animations on-the-fly as well as on standard/customized movie formats (Fig. 7).
Two additional features should be highlighted

3. a) Wall of masonry sandstone; b) Palace of Marquis of Dos Aguas; c) Djin Block No. 9; d) Cova Remígia.

from 3DVEM – Live: first) the chance to add your personal pictures to the photorealistic 3D model; second) the chance to change on-the-fly the camera setting, ranging from super wide angle lenses up to tele lenses.

## DISCUSSION AND CONCLUSIONS

There is an increasing demand of derived 3D models to be integrated in current heritage documentation workflows. The chances to monitor in a virtual environment the evolution of architectural surveys, archaeological excavation/sites, and found objects/artefacts are limitless.

From our own experience, the creation of accurate high quality replicas is not straightforward. Delivery of accurate photorealistic 3D models requires experienced users in the fields of geomatics, cultural heritage and geosciences, just to name a few. However, almost everybody enjoys interacting with virtual worlds. Therefore, more well-driven automatic solutions are required to fulfil information user requirements, in a way that conservation managers, art historians, architects and archaeologists make extensive use by their own of deliverables such as photorealistic 3D models achieved through cultural heritage recording. But one thing is delivering simplistic virtual words (that definitely have their room to carry out better hypothesis of the past, complex analysis, dissemination through mixed and augmented reality, and last but not least videogames), and even unstructured 3D point clouds, and another high quality, high resolution, high accuracy photorealistic 3D models that might be considered real replicas of both the past and the present.

Many different computer vision, photogrammetry, and laser scanning solutions can be found in the market today. Without any doubt, there exist powerful image-based computer vision packages that allow users to speed up the documentation process and reduce costs, for instance, during excavations (Dellepiane et al. 2013; Forte et al, 2012) or even for objects in architecture, cultural heritage and archaeology (Kersten and Lindstaedt, 2012). One of the main concerns is the reliability of the derived outputs, considering careful data

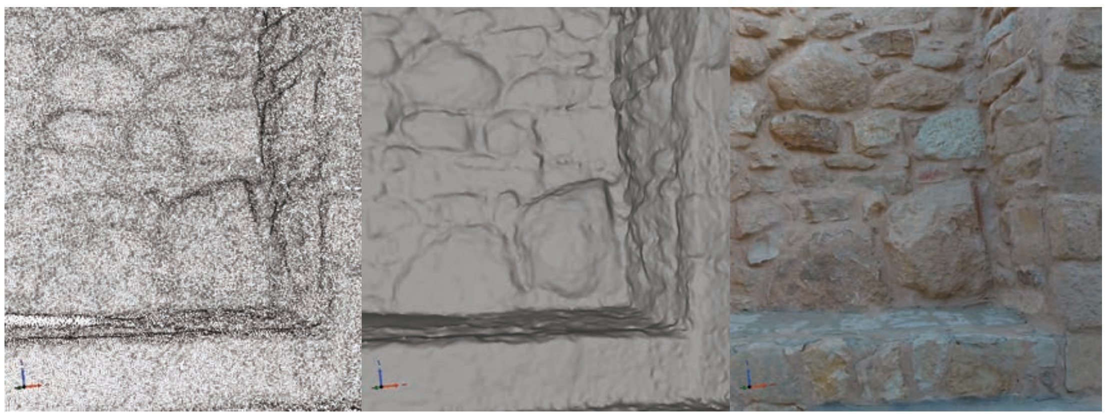
ISSN 1828-5961



acquisition and autonomous processing. Therefore, photogrammetry still will have its place to guarantee the precision of the whole processing pipeline either standalone with semi-automatic approaches, combined with powerful computer vision solutions or integrated with terrestrial laser scanning.
This paper presented a state-of-the-art photogrammetric workflow that allows the creation of high quality photorealistic 3D models in two architectural features and two archaeological sites. The diversity and complexity of the close range objects allow us to confirm the feasibility of the processing to achieve high quality virtual outputs either in 2D (orthophoto mosaics) or in 3D (photorealistic models). Furthermore, high quality interactions and animations can be quickly rendered through the 3DVEM software.
New tools and approaches are increasingly presented to the market, as well as extensive datasets acquired by digital cameras and laser scanners. Altogether with improved computer technology will figure more efficient photogrammetric computer vision algorithms that will improve the performance of the derived products.

4. Image-based processing for case study c: a) orientation and dense image matching in object space; b) orthoimagery.

5. Visualisation of case study a as: a) single colour point cloud; b) 3D model; and c) photorealistic 3D model.



ISSN 1828-5961


6. 3DVEM – 3D Viewer, Editor and Meter with inserted coded labels (points), measured features and viewpoints.

7. 3DVEM – Live software displaying the camera path to create the animation.

ISSN 1828-5961


REFERENCES


Barazzetti, L., Scaioni, M., Remondino, F. (2010), Orientation and 3D modelling from markerless terrestrial images: combining accuracy with automation, in THE PHOTOGRAMMETRIC RECORD, 25(132), pp. 356–381.

Böhler, W. (2006), Comparison of 3D laser scanning and other 3D measurement techniques, Recording, Modeling and Visualization of Cultural Heritage (Baltsavias, E., Gruen, A., Van Gool, L., Pateraki, M. Eds.), Taylor & Francis Group, London, pp. 89-99.

Courchay, J., Pons, J.-P., Monasse, P., Keriven, R., 2010, Dense and accurate spatio-temporal multi-view stereovision, in Computer Vision – ACCV 2009, LECTURE NOTES IN COMPUTER SCIENCE, 5995, pp. 11-22.

Dellepiane, Matteo, Dell'Unto, Nicolò, Callieri, Marco, Lindgren, Stefan, Scopigno, Roberto (2013), Archaeological excavation monitoring using dense stereo matching techniques, in JOURNAL OF CULTURAL HERITAGE, 14(3), pp. 201-210.

Forte, M., Dell'Unto, N., Issavi, J., Onsurez, L., Lercari, N., 2012. 3D archaeology at Çatalhöyük, in INTERNATIONAL JOURNAL OF HERITAGE IN THE DIGITAL ERA, 1(3), pp. 351-378.

Furukawa, Y., Ponce, J., 2010, Accurate, dense, and robust multiview stereopsis, in IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLI GENCE, 32(8), pp. 1362-1376.

GIFLE (2012), 12 Tips for metric photography of architectural and archaeological cultural heritage to extract 2D/3D/4D measurements, Grupo de Investigación en Fotogrametría y Láser Escáner. http://gifle.webs.upv.es/Miscellany.php (Access on July 3, 2013).

Grussenmeyer, P., Hanke, K., Streilein, A. (2002), Architectural Photogrammetry, Digital Photogrammetry (Kasser, M., Egels, Y., eds.). Taylor & Francis, London, pp. 300-339.

Jones, David M. (2011), 3D Laser Scanning for Heritage. 2nd Edition. Advice and guidance to users on laser scanning in archaeology and architecture (Ed). English Heritage Publishing.

Kersten, T.P., Lindstaedt, M., 2012, Potential of automatic 3D object reconstruction from multiple images for applications in architecture, cultural heritage and archaeology, in INTERNATIONAL JOURNAL OF HERITAGE IN THE DIGITAL ERA, 1(3), pp. 399-420.

Läbe, T., Förstner, W. (2006), Automatic relative orientation of images. Proceedings of the 5th Turkish-German Joint Geodetic Days, Berlin. 6 pages. http://www.ipb.uni-bonn.de/fileadmin/publication/papers/2006/laebe06.automatic.pdf

Lerma, J.L., Navarro, S., Cabrelles, M., Seguí, A.E., Haddad, N. Y Akasheh, T. (2011), Integration of Laser Scanning and Imagery for Photorealistic 3D Architectural Documentation, Laser Scanning, Theory and Applications (Wang, C.-C., Ed.). InTech, Rijeka, pp. 413-430. http://cdn.intechopen.com/pdfs/15818/InTech-Integration_of_laser_scanning_and_imagery_for_photorealistic_3d_architectural_documentation.pdf.

Lerma, J.L., Navarro, S., Cabrelles, M., Seguí, A.E., Hernández, D. (2012), Automatic orientation and 3D modelling from markerless rock art imagery, in ISPRS JOURNAL OF PHOTOGRAMMETRY AND REMOTE SENSING, 76, pp. 64-75.

Lerma, J.L., Navarro, S., Cabrelles, M., Villaverde, V. (2010), Terrestrial laser scanning and close range photogrammetry for 3D archaeological documentation: the Upper Palaeolithic Cave of Parpalló as a case study, in JOURNAL OF ARCHAEOLOGICAL SCIENCE, 37, 3, pp. 499-507.

Lerma, José Luis (2010), Heritage recording using image-based techniques, Heritage in the Digital Era (Ioannides, M., Alonzo, A., Georgopoulos, A., Kalisperis, L., Brown, A., Pitzalis, D., Eds.), Multi-Science Publishing, pp. 83-93.

Letellier, Robin, Schmid, Werner, LeBlanc, François (2007), Recording, documentation, and information management for the conservation of heritage places: guiding principles, The Getty Conservation Institute, Los Angeles.

Moreels, P., Perona, P., (2007), Evaluation of Features Detectors and Descriptors based on 3D Objects, in INTERNATIONAL JOURNAL OF COMPUTER VISION, 73(3), pp. 263–284.

Pierrot Deseilligny, M., Clery, I. (2011), APERO, an Open Source Bundle Adjustment Software for Automatic Calibration and Orientation of a Set of Images, in INTERNATIONAL ARCHIVES OF PHOTOGRAMMETRY, REMOTE SENSING AND SPATIAL INFORMATION SCIENCES, 38(5/W16), Trento, Italy (on CD-ROM).

Pollefeys, M., Koch, R., Van Gool, L. (1999), Self-calibration and metric reconstruction in spite of varying and unknown internal camera parameters, in INTERNATIONAL JOURNAL OF COMPUTER VISION, 32(1), pp. 7-25.

Remondino, F, Del Pizzo, S., Kersten, Th., Troisi, S., 2012. Low-cost and open-source solutions for automated image orientation – a critical overview, in LECTURE NOTES IN COMPUTER SCIENCE 7616, Springer-Verlag, Berlin Heidelberg, pp. 40-54.

Remondino, Fabio, El-Hakim, S. (2006), Image-based 3D modelling: a review, in THE PHOTOGRAMMETRIC RECORD, Blackwell Publishing Ltd., 21(115), pp. 269-291.

Remondino, Fabio, Ressl, Camillo (2006), Overview and experiences in automated markerless image orientation, in INTERNATIONAL ARCHIVES OF PHOTOGRAMMETRY, REMOTE SENSING AND SPATIAL INFORMATION SCIENCES, 37(B5-1), pp. 199-206.

Slama, C.C., Henriksen, S.W., Theurer, C. (1980), Manual of Photogrammetry. 4th. Edition, American Society of Photogrammetry, Falls Church Virginia, EEUU, 1056 pp.

Waldhäusl, Peter, Ogleby, Cliff (1994), 3x3-Rules for simple photogrammetric documentation of architecture, INTERNATIONAL ARCHIVES OF PHOTOGRAMMETRY AND REMOTE SENSING, vol. 30, part 5, pp. 426-429.


ACKNOWLEDGEMENTS

The authors would like to thank the support provided by the Spanish Ministry of Science and Innovation to the project HAR2010-18620.

.