URBAN LASERMETRY. PROBLEMS AND RESULTS FOR SURVEYING URBAN HISTORICAL CENTRES: SOME PILOT CASES OF SPANISH PLAZA MAYOR

J.I.SanJosé[a], J.Finat[b], J.J.Fernández-Martin[a], J. Martínez[a], L.M.Fuentes[b], M.Gonzalo[b]
[a]LFA-DAVAP, ETS Arquitectura, Univ. de Valladolid, 47014 Valladolid, Spain
jesussanjose@usuarios.retecal.es, juanjo@ega.uva.es, jmr@ega.uva.es
[b]MoBiVA-DAVAP Group, Lab. 2.2, R+D Building, M.Delibes Campus, 47011 Valladolid, Spain
jfinat@agt.uva.es, lfuentes@opt.uva.es, marga@infor.uva.es.

KEY WORDS: Laser scanning, Close-range photogrammetry, Cultural Heritage, Surveying, Recognition.

ABSTRACT

Laser recording applied to urban centres provides a key tool for surveying and recovering the global geometry of historical centres. The application of laser devices provides three-dimensional models including architectonic and urban parameters, which are meaningful for buildings and urban typologies~~,~~ and morphological analysis relative to the shape and dimension of public spaces. In this work we have developed a ground-based static laser-based methodology for robust and accurate 3D urban modelling of historical centres, based on coarse discrete 3D models from which we generate robust piecewise-linear and accurate piecewise-smooth models. Our main contribution~~s~~ are related locally with the compatibility between syntactic architectural elements and their semantic insertion in urban tissue and, globally, with the management of very large data and the semi-automatic identification of structural elements involving the urban and architectural morphology. The feedback between both local and global aspects is solved by designing a specific symbolic representation given by a topological graph, which is automatically generated from a lecture of planar cartographic representation. The graph provides a support for a memory management of high complexity. We have applied this approach for a laser surveying based on an ILRIS 3D (Optech) of large urban environments with historical contents, helping to understand the articulation of central urban spaces six centuries ago. Nevertheless the strong differences, it is possible to identify common syntactic elements helping to understand the articulation between urban spaces and to interpret urban environments with similar functionalities.

1. INTRODUCTION AND BACKGROUND

A general goal for architectural and urban surveying is to provide assistance for architectural restoration and urban conservation policies. More recently, there exists an increasing interest in divulgation purposes for increasing the knowledge and sensibility in regard to Cultural Heritage and promoting citizen participation in conservation tasks [CIPA 2003]. Usual approaches have been developed on 2D support involving cartography or plane photogrammetry. Traditional surveying methods based on total station require high human expertise with very intensive manual work, being very time-consuming in both, capture and processing stages. The incorporation of remote sensing, computer vision [Hartley and Zisserman, 2000], and laser scanners to digital photogrammetry [ASPRS 2004] provides accurate 3d results in a quicker and simpler way, by increasing the productivity according with professional requirements, and by satisfying the more immediate need for displaying results on a common 3D support.

Three-dimensional models of large scenarios in urban centres provide powerful support for visualizing and understanding of large urban environments. The pioneering work by [Debevec et al 1996] developed a methodology based in Computer Vision and Computer Graphics for semi-automatic 3D reconstruction of isolated buildings from a low number of views. It is necessary to decrease manual intervention without sacrificing accuracy. Recent developments along last ten years display a large diversity of approaches for achieving this goal depending on the theoretical framework, available tools and the reach of proposals [Hansen and Johnson, 2005]

The incorporation of terrestrial laser scanning for surveying tasks allows super-imposing very precise 3D information on usual cartographic representations and validating old models which can be superimposed to laser-scanning approaches [ASPRS 2004]. Nowadays, it is clear that the architectural surveying of large urban environments [Shiode 2001] requires the design of a multi-scale and multi-level support, capable of incorporating the knowledge of different experts.

Figure 1: Display of cartographic and 3D information

A *multi-scale* support is need for supporting cartographic, urban and architectural data structures, involving *syntactic analysis* relative to morphological aspects. *Multi-level* support includes the management of data structures, including primitives and metadata for the contextualization of contents in the *semantic analysis*. The articulation between both syntactic and semantic levels is a challenge which involves the automatic extraction of *structural elements* for the syntactic level, and a meaningful grouping for their architectural and urban interpretation.

Structural elements are stratified following an increasing complexity level with several layers. So, after information processing, three kinds of primitives will be obtained:

a) Geometric primitives (perspective lines, vanishing points, dominant planes, polylines, e.g.) for piecewise linear approach.
b) Architectural primitives (windows, doors, columns, entablatures, balconies, ornamental elements, etc) which are meaningful for the architectural morphology and style.

c) Urban primitives (streets, squares, city districts) for the global aspects concerning to localization of buildings, their insertion and interpretation in urban tissue.

All of them pre-configure several layers for Digital Information Systems adapted to Cultural Heritage sensitive to the representation scale. Syntactic elements acquire a precise meaning by means of their semantic interpretation in terms of a) perspective models for geometric primitives, b) identification of incidences, interventions or pathologies (deformations, cracks, etc) for architectural primitives and c) cultural heritage (artistic or historical itineraries) for urban primitives. The incorporation of IST technologies as assistant to the semantic analysis involves the semi-automatic acquisition and processing of relevant information arising from old and recent information sources.

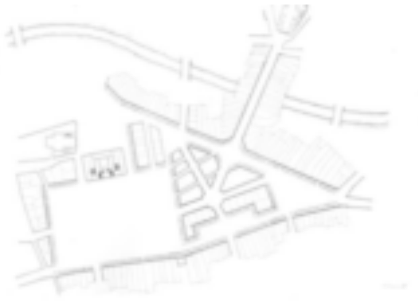

Figure 2: Ideal reconstruction of the environment of Plaza Mayor of Valladolid around the 15th century

The design of data structures for the information management includes metadata for contextualizing and managing cultural heritage contents, with a view for the assistance in architectural conservation, restoration and urban planning. The computer management is performed in symbolic terms from a graph with links to vector (geometric, architectural) information and raster (cartographic, historic, urban) information.

The work is outlined as follows. The second paragraph shows some related approaches for surveying large-scale urban environments. Next, a hybrid methodology for spatial-based urban modelling is developed. This hybrid methodology is applied in the fourth paragraph to the information acquisition and processing of digital information relative to the historical centre of Soria, Valladolid, and some small villages of Palencia. Repetitive elements in historical places simplify the syntactic analysis which is semi-automatically performed in section 5 by means of a selective search of intermediate primitives. We finish with a discussion of results and some conclusions.

2. RELATED APPROACHES FOR SURVEYING LARGE-SCALE URBAN ENVIRONMENTS

In this work, we address to the applications of Computer Vision, and laser-based photogrammetry to urban environments. Some computer vision base approaches with recent important contributions are [Emem and Batuk, 2004], [Otani et al, 2004] , and [Kada et al, 2003] for the incorporation of real-time visualizations of large urban environments. Computer vision approaches for *dense* 3D reconstructions from 2d images use some additional constraints relative to the scene, the camera or the motion. Typical additional constraints involve the surface continuity for geometric features in dense depth estimation [M.Pollefeys et al, 2000], the estimation of extrinsic parameters of the camera [Sato et al, 2002] and the continuity of optical flow between views or scans taken with small baseline [Barron et al, 1994].

An alternative approach can be developed directly from 3D information. Some voxel-based approaches to Reconstruction in Computer Vision with visibility constraints provide a representation based in visual hulls arising from volumetric segmentation. Planar segmentation contained in 2D views is linked to the identification of well-defined geometric features or colour/texture. The main attribute for geometry is the global coherence, whereas for colour/texture is the local consistency. However, volumetric segmentation is linked to a cascade of constraints linked to meaningful discontinuities in proximity, depth and orientation. The display of the whole information in discrete clouds of 3D points, wired or “transparent” representations is very difficult to interpret due to the information overlapping in several depth planes. Thus, it is required some kind of volumetric display linked to visibility constraints in urban scenes.

A typical strategy for a low number of primitives is based in *octrees*. An *octree* is given by a tree where each node represents an orthogonal octant, and each edge represents a subdivision of the original octant in eight octants according to recursive decomposition in 3D cells given as intersections of three orthogonal half-spaces. Octants are recursively subdivided till some meaningful element is found in sweeping. Traditional management of voxels by using octrees has a prohibitive computational cost. Thus, some reduction to meaningful voxels is necessary [Seitz and Dyer, 1999]. First criteria for reduction are linked to visibility in 3D space. Finer criteria for reduction are linked to the occupancy and colour. In our case, colour is replaced by the intensity of the grey scale linked to scan files. Radiometric properties are difficult to interpret in spatial information; thus, grouping criteria is based on geometric properties linked to scan files. Ideally, each scan can be imagined as a cone over a PL or a PS-surface corresponding to the external boundary of the object. Intersection of cones has a high computational cost and they are sensitive to noise or partial occlusions. To avoid them, some strategies based on energy functions can be developed [Snow et al, 2000]. However, the choice for the best energy function is not clear, and furthermore, the geometry disappears; hence, the capability for developing a stylistic taxonomy for buildings in urban environments is lost.

Figure 3: A partial view of the 3D model for the Plaza Mayor of Valladolid after merging several scans in false colour

3. A HYBRID METHODOLOGY FOR SPATIAL URBAN MODELLING

Laser devices provide dense and accurate information with a low processing time. A precise and robust large-scale surveying of urban areas is possible thanks to the low time for information acquisition and processing. A Cultural Heritage Information System (CHIS) able of integrating image ranging and laser scanning approaches for surveying is under development. In the meantime, some morphological and thematic studies are undertaken for the assistance in architectural restoration or urban management policies.

The articulation between semantic and syntactic approaches is developed by means of a multilevel symbolic representation of the urban framework and the underlying architectural typology based on 3D laser scanning. An extreme example is shown concerning to a textured visualization of a façade of the Plaza Mayor of Valladolid (Spain) and a dramatic reduction, where only two pencils of the coarsest perspective lines are displayed.

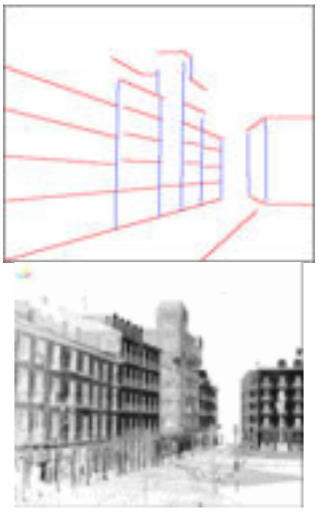

Figure 4: Textured display and wild reduction of a façade of the Plaza Mayor of Valladolid

Architectural layers of the hierarchised model are characterised by the presence of several strategies of complementary character which are labelled as:

- Multiscale/multirresolution capture with two levels of detail (LoD) in our case, including surveying with variable resolution (range scanning approach)
- Automatic identification of geometric incidence / adjacency conditions for structural elements appearing in views (image based approach).
- Semi-automatic extraction of perspective models (perspective lines, vanishing points, etc) including frontal, lateral and skew views (bundles adjustment)
- Adaptive management of static/dynamic visualization tools (isosurfaces/flows) with different LoD (rendering tools in computer graphics).

The output of fine information processing must be an accurate photorealistic visualization for surveying, inspection and tracking of architectural and urban information. This goal involves the relationship between local and global aspects. Computer Vision provides tools for developing these relations based on texture and geometry of 2D views:

1) The final result of geometric-based approach must provide a global model able of articulating in urban units the multiplicity of architectural shapes and the optimal geometric management of such information. Some problems to be solved with geometric-based models are
    - Estimation of metric information for perspective lines and dominant planes.
    - Automatic grouping of bundles of 3D lines in perspective models and automatic identification of dominant planes.
    - Optimization of local morphological models based on a feedback between metric and perspective models by combining probabilistic and functional optimisation criteria associated to different data structures.
2) The main problems for texture-based models are the fusion and reduction of information. To achieve it, we shall adopt a double strategy based on adaptive optimization and a selective reduction. Starting point is given by partial clouds of 3D points corrupted by noise and incomplete information.

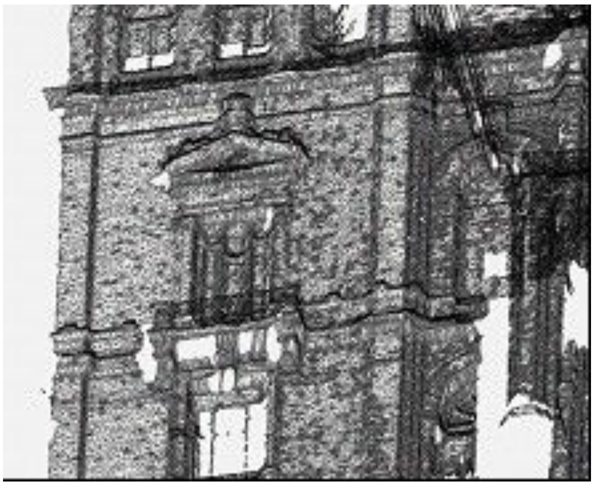

Figure 5: Incomplete and striated information linked to balconies and ornamental details in the façade of the City Hall

Superimposing of partial views generate a global discrete model containing information about the local structural PL-elements (dominant planes, e.g.) and their incidence/adjacency conditions. Some meaningful issues for linking local to global aspects concern to:

a) The decomposition of the global discrete model obtained after merging the scans, which involves the following steps: selective reduction of clouds of points, simplification of meshes, fitting to standard architectural primitives and management of textured surfaces obtained from high resolution views.
b) Processing of dense information with different densities depending on the compatibility between the image ranging (2D and radiometric information) and range scanning information.
c) The interaction capability by means of friendly user interfaces for the computer management of data structures with architectural and urban contents.

First point is already developed in other related papers [Finat et al, 2005]. Thus, we pay attention to second and third aspects.

4. PROCESSING OF DIFFERENT DENSITIES

Large urban environments are benefited from a low-level global capture, to which finer information relative to particular buildings can be inserted in a second stage. This methodology can be illustrated with some examples of Paredes de Nava, a small Castilian village with noticeable renaissance influences in several buildings.

General scans of the village are taken from a distance larger than 200 meters, and with a spot at most of 10 cm. A total number of 247 scans with 35.3 millions of points (after merging and optimising) have been captured. The information management of superimposed structures for the global model requires a memory distribution, which is being currently developed. A coarse and easy to hand model is generated for virtual navigation and comparison with available urban cartographic information.

Figure 6: Partial view of the 3D model of Paredes de Nava (Palencia) taken with ILRIS 3D for coarse urban surveying

The next step consists of surveying specific buildings with a much smaller spot (typically between 1 and 2 cm). From these data it is possible to obtain metric information, visualize non-occluded plants from any viewpoint, to obtain frontal views and to give maps of sections with a step selected by user.

Figure 7: Metric information, longitudinal and transversal sections of scanned buildings for fine architectural surveying.

In the same way, a global model for the surveying of the whole street allows the evaluation of the current state of buildings, and provides an assistant for conservation or restoration tasks. Furthermore, longitudinal and transversal sections can support additional elements arising from usual urban surveying.

Orthogonality relations between elements of façades simplify the search of a subdivision of the scanned 3D scene from discontinuities. Buildings and façades are automatically identified from discontinuities in relative depth and relative orientation of triangles. Grouping clouds of points around dominant planes is performed by means of a voting scheme. More explicitly, for each triplet of non-collinear near points with similar radiometric properties a candidate plane is selected. The minimization of distances for near points with respect to the candidate plane gives a locally winner plane. Obviously, this process can not be performed for every triplet. An adaptation of RANSAC (Random Sampling Consensus) algorithm for sampled triplets of non-collinear points and a propagation algorithm on near vertices gives a quicker convergence for each winner plan. Subdivisions are performed with respect to “jumps” in relative depth, and relative orientation for near points in each scanner file. In this way, a 3D global information for urban lasermetry is obtained from a relatively low number of scans.

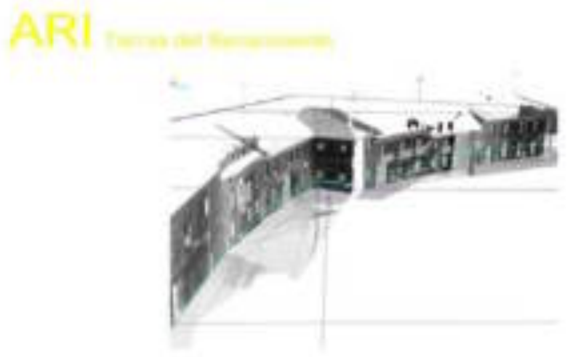

Figure 8: Façade of a street with planimetric information for validation and automatic adjustment of urban 3D cartography

5. COMPUTER MANAGEMENT OF DATA STRUCTURES LINKED TO LARGE URBAN AREAS

Computer management of data structures follows the classical approach depending on vector and raster information. Raster information is organized as a typical Geographic Information System and managed as hypertext including metadata, but adapted to Cultural Heritage contents; this modulus is currently in development and facilitates 3d information retrieval in an interactive way. Vector component includes topographic, metric, localization and radiometric information relative to buildings and urban environments. The connection between both of them is planned in terms of multidimensional relational large databases with advanced visualization tools. Currently, we are developing some tools for automatic query and interactive exploration in data structures based in two basic symbolic representations. Elementary pieces of symbolic representations are given by two *graphs* associated to structural elements for buildings and the current urban cartography, which are represented as G_A (architectural graph) and G_U (urban graph), respectively.

The architectural graph G_A is based on a triangulation adapted to a re-sampling of the discrete cloud of 3D points. Given a building B with a cloud C_B, a direct management of architectural primitives requires an identification of subjacent geometric primitives. To achieve it, it is necessary the design and implementation of algorithms for objects grouping according meaningful discontinuities in relative proximity, depth and orientation for discrete clouds of 3D points. A first step is the construction of a coarse triangulation T_C linked to successive decimations of the cloud of points, being the number of iterations for decimations decided by user. The identification of geometric primitives (dominant planes or quadratic components) of the building B is performed by grouping normal vectors to triangles of T_C verifying simple constraints (parallelism, orthogonality, incidence on a point or a line, etc).

The next step consists in computing edges (visible or occluded) corresponding to the intersection of the identified geometric primitives which generate a second layer L_A of candidates for supporting architectural primitives. The supervised interpretation of architectural primitives in terms of geometric primitives requires the design of an expert system with learning capabilities, which is currently in development. A very large number of software tools in Computational Geometry [Berg et al, 2001] for the management of geometric information are based in graphs. The Computational Geometry Algorithms Library (CGAL) provides an open source kernel and libraries in C++ with typical (evaluation, measuring, e.g.) applications and interfaces for visualization and other support facilities. Management and display of these tools is based on different types of graphs. Currently, a similar methodology is being developed for integrating C++ and OpenGL-based real-time visualization of large urban zones in Open Scene Graph [Kada, Roettger, Weiss, Ertl and Fritsch, 2004]

In our case, symbolic representations for the urban graph G_U are obtained as a skeleton linking the re-sampled discrete clouds of architectural graphs G_A corresponding to buildings in the surveyed urban zone. A planar representation of the urban graph can be automatically obtained by means of an identification of a skeleton given by median axis superimposed to the cartographic information (if available) or of planar information obtained by projection of discrete clouds of 3d points on some dominant plane of the 3d model. In the second case, our strategy consists of several steps: a) generation of dxf files from txt files, b) export to dwg files from each dxf file, c) thinning of 3d walls appearing in dxf file, d) computation of median axis for each street, e) connection between median axis for obtaining a global skeleton. Each skeleton simplifies the information management, and the formulation of elementary transformations for updating structural modifications involving the update of architectural surveying and/or urban planning.

Nodes of the urban graph G_U correspond to cross-roads or squares, whereas edges of G_U correspond to streets connecting them. Grouping and unfolding are the basic operations for contracting or expanding the urban graph G_U depending on the identification of common characteristics for urban units. Nodes of G_U can be interpreted as the sites for a constrained skeleton whose edges can not traverse the obstacles; constraints are linked to the “obstacles” corresponding to the façades of buldings B_i. A connection between both graphs is generated by duality, in a similar way to the duality between Voronoi diagrams and Delaunay triangulations. Let us remark that the triangulation is not necessarily a Delaunay triangulation linked to the original discrete cloud, because it is adapted to the identified boundaries of buildings. In particular, edges or facets connecting vertices belonging to different dominant planes are deleted. A friendly user interface for visualizing this symbolic representation in a similar way to [Seitz and Dyer, 1999] is currently under development.

6. DISCUSSION

The proposed methodology has followed an iterated acquisition of a large number of scans to different resolution (35 for the Plaza Mayor of Valladolid, e.g.). Most scans are taken from the ground, but some of them have been taken from high (more than 60 m for some general views of Paredes de Nava). Accuracy depends on the overlapping areas, and some problems have required a post-processing work. Merging and construction have been performed without additional topographic information.

Original resulting model (without reduction) arising from merging scans captured with Optech ILRIS 3D, has more than 4 millions of triangles. Thus, the computer management of this model does present a high complexity, which suggests generate simplified models at least for dynamic visualization. The larger estimated error in the global coarse model is less than 5 cm. Nevertheless this coarse error, it is possible a real-time management of the volumetry of the model corresponding to the whole square.

We have generated panoramic views from several high resolution images. Currently, we are working on a Computer Vision model able of inserting high resolution views on 3D models linked to dense clouds of points which have been originally captured by laser scan. A lot of work remains to be done. It is necessary to develop expert systems for semi-automatic objects recognition oriented towards architectural and urban primitives. This development will require a narrower cooperation between experts in Cultural Heritage and experts in software development.

In the near future, a flexible support is required for modifying or adapting contents in a remote way. This issue concerns the capability of providing a support for remote modification of 3D information by means of multi-platform browsers. Java applets provide this capability, but they have a static character and lack of required accuracy which is need for professional applications. Currently, we are developing a XML dynamic model which can be updated in a remote way from different browsers.

7. CONCLUSIONS

Nevertheless the partial character of the current research, obtained results are very promising. Laser based surveying provides a 3D support where traditional techniques can be incorporated. Global merging does not fill all the details for professional requirements, and must be completed with contributions of another research fields and applications. Global models provide assistance tools for restoration and conservation planning, and for divulgation purposes for architectural and urban management in Cultural Heritage.

A lot of work remains to be done concerning to the integration of modelling and software tools, and the development of information systems for Cultural Heritage. This work is a challenge for the next future and requires the cooperation of multidisciplinary teams with a wide variety of expertise.

REFERENCES

References from Journals:

Barron, J.L., Fleet, D.J. and Beauchemin, S.S.: “*Performance of optical flow techniques*”, Intl, J. of Computer Vision, 12 (1), 43-77, 1994.99999

Shiode, N.: “*3D urban models: recent developments in the digital modelling of urban environments in three dimensions*”, GeoJournal 52 (3), 263-269, 2001.

Sato, T., Kanbara, M., and Yokoya, N.: “*Dense 3D Reconstruction of an outdoor scene by hundred-baseline stereo using a hand-held video camera*”, Intl J. of Computer Vision 47 (1/2/3), 119-129, 2002.

Seitz, S, and Dyer, C.: “*Photorealistic scene reconstruction by voxel coloring*“, Intl J. of Computer Vision, 35 (2), 151-173, 1999.

References from Books:

ASPRS, 2004: *Manual of Photogrammetry*. 5th Edition.

Hansen, C.D. and Johnson, C.R., eds: “*The Visualization*

Handbook", Elsevier, 2005.

Hartley, R. and Zisserman, A.: *Multiple View Geometry in Computer Vision*, Cambridge University Press, 2000.

Berg, M.; Van Kreveld, M.; Overmars, M.; and O. Schwarzkopf, 1997. *Computational Geometry. Algorithms and Applications*, Springer-Verlag.

References from Other Literature:

CIPA 2003: *New Perspectives to Save Cultural Heritage*, XIXth International Symposium (Antalya, 2003).

Debevec, P, Taylor, C.J., and Malik, J.: *Modeling and rendering architecture from photographs*, Proc of the ACM SIGGRAPH, 1996.

Emem, O, and Batuk, F.: *Generating precise accurate 3D city models using photogrammetric data*, XXXV Proc. ISPRS Istambul, July 2004, 431-436.

Finat J.; Fernández-Martín, J.J..; Fuentes, L.; Gonzalo, M.; Martínez-Rubio, J. and SanJose, J.I.: *Ordering criteria and information fusion in 3d laser surveying of small urban spaces*, ISPRS, Mestre, 2005.

Kada, M; Roettger, S; Weiss, K; Ertl, T; Fritsch, D.: *Real-time Visualization of Urban Landscapes using Open-Source Software*, Proc. ACRS '03, 2003.

Otani, H., Aoki, H., Yamada, M., ItoT., Kochi N.: "*3D measuring systems*", XXXV Proc. ISPRS Istambul, July 2004, 165-170.

Pollefeys, M., Koch, R., Vergauwen, M., Deknuydt A.A., and Gool, L.J.V.: *Three-dimensional scene reconstruction from images*, Proc. SPIE, 3958, 215-226, 2000.

ACKNOWLEDGEMENTS

The acquisition of time-of-flight laser ILRIS 3D (Optech) has been supported by EU research funds (FEDER), by the Spanish Ministry of Science and Technology, and regional institutions (JCYL) in the Project DELTAVHEC (Dispositivos para el Escaneo Láser Tridimensional, Adquisición y Visualización de la Herencia Cultural), Research Group Responsible, Prof. Javier Finat.

This work has been partially financed by the Spanish Ministry of Culture, CICYT Research Project MAPA (Modelos y Algoritmos para visualización del Patrimonio Arquitectónico) Research Group Responsible Prof. Juan José Fernández Martin)
.