3D Reconstruction based on Semantic Information for Architectural Applications

Christophe Cruz[1], Frank Boochs[2], Christophe Nicolle[1]

1

Laboratoire LE2I
UMR CNRS 5158
Université de Bourgogne
BP 47870
9 Allée Alain Savary
21078 Dijon Cedex – France
cruz@khali.u-bourgogne.fr

2

i3mainz – Institut für Raumbezogene´Informations- und Messtechnik
Fachhochschule Mainz,
Holzstrasse 36
55116 Mainz - Germany
boochs@geoinform.fh-mainz.de

0. ABSTRACT

This paper presents the results of a feasibility study concerning the use of semantic information for the simplification of 3D reconstruction for architectural objects using data from in- and outside of a digitised building. The paper gives an overview to actual techniques for the spatial digitisation of buildings and their 3D reconstruction and shows a way to use semantic information for improvements. The approach of this paper is new, because it uses a semantic characteristics for the geometrical correction of spatial models derived from scanned or photogrammetric data.

1. INTRODUCTION

A civil engineering project is made up of various steps allowing to validate different stages of development for a building. For example, we have to distinguish different design, engineering and construction phases until the building is completed and delivered to the owner. Unfortunately the finally built object is not necessarily precisely geometrically documented allowing to evaluate possible deviations between planning and real object. Furthermore it is often difficult to restore or modify a building, because information concerning its design simply has been disappeared. Such data would, for example, help to estimate the costs of the work having to be done. If the object is unknown, it has to be captured "as-built" using extensive geometrical measurements. These measurements have to be done by engineers and comprise several steps like establishment of a geometrical reference and a local data capture, serving as base for the final evaluation process realised by specialists. The whole process is very time consuming, why it would help to extend the use of automatic algorithms in order to reduce time and costs. In principle photogrammetry and laser scanning both have the potential for improvements and higher degrees of automatism and this article tries to show some ideas how to realise this.

First, the problem will be defined in relation to the need of the architecture. Then an overview to the actual state of art is given followed by the outline of a new concept. Finally, a conclusion terminates the paper.

2. VALUE OF SEMANTICS FOR THE RECONSTRUCTION OF OBJCECTS

Digital plans of an object defined by the civil engineers mostly contain simple geometries, stored in CAD software packages. In addition, semantic rules are applied to achieve better design. However, during data exchange information is reduced to sets of vectors with formats like DXF or DWG, resulting in a loss of semantic information, and the destruction of the object structure. Such problems disappear with formats like IFC[1], defined by the International Alliance for Interoperability[2]. The IFC format is a model associating semantics to the geometrical 2D/3D elements forming a building. Up to now, this standard is not used as base for the major CAD software packages, but it is at least supported as exchange format. In addition, IFC is also used for building management projects [48].

This format could be of value for "as-built" problems, aiming at the determination of the actual structure of objects, because such a reconstruction has not only geometrical but also semantic aspects, which could be supported directly by this format. The possibility to incorporate semantic information could furthermore simplify the process of reconstruction, because it might be used for modelling purposes. But – and this leads to a problem not being solved up to now - why not using semantic information directly during a computer based evaluation, because it allows to support algorithms for a faster and more efficient extraction of objects?

Today, computer based evaluation of spatial data sets is limited by the complexity of the objects to be extracted and the manifold possibilities how the real object is expressed within the data, what makes it very complicate and extensive to formulate rules having to be applied to the data in order to detect and extract objects geometrically correct. One essential reason for these problems comes from the fact, that objects are broken down into many small geometrical pieces, which are treated isolated not using possible local interrelations. So, existing knowledge allowing a human interpreter to solve even disordered situations in image based or spatial data sets is simply ignored. Therefore conceptions using such a knowledge and introducing it into the process of evaluation are promising and should be more powerful than existing ones.

[1] IFC : Industrial Foundation Classes (c.f. IAI Web Site)
[2] IAI : http://www.iai-international.org

3. CONVENTIONAL SOLUTIONS

The impact of semantic data on the process of reconstruction depends on the structure of the raw data to be handled. Therefore, it is necessary to study the steps of the whole process and to analyse methods and data used. This will be done in this chapter, starting with photogrammetry, followed by laser scanning and finally looking to the steps of data processing.

3.1. DATA ACQUISITION

The methods for reconstruction are founded on digital data of an existing object. This data may consist of a 3D point cloud approximating the surface, sometimes coupled with the light intensity of each point or of structural data like points and edges in digital images accompanied with the grey or colour values representing the surface reflectance from the actual point of view. Each method has it's characteristics and advantages and the best choice depends on the material available, the object to be captured, the required precision, and the time available at the object [1, 2, 3, 4].

3.1.1. Digital photogrammetry

Image based data capture is founded on measurements carried out from one or several photographs taken from various positions. These photographs are digital images coming from a CCD camera, can be conventional digitized images or are produced by any other detector. The data used from the images are 2D co-ordinates describing image rays to 3D points on the object surface. From these rays the geometry of the object can be derived using monoscopic or stereoscopic techniques and by means of multi-images concepts.

In monoscopic photogrammetry numerical corrections may be applied to the images [2, 5] or the images are completely recticified as known from aerial applications [6]. The main difference of these set ups can be seen in the amount of knowledge or constraints applied to the object in order to treat the image geometrically correct.

Stereoscopic photogrammetry uses two images, allows to generate the spatial shape of an object without any preconditions and is based on the intersection of two correspondung rays. The only problem is the process to find the correspondence of two rays, in computer vison called "stereoscopic fusion". Traditional methods are founded on calibrated[3] metric images with known exterior[4] orientation parameters and basic knowledge to the object mostly expressed in some reference points. The real activity needed for the evaluation process is the detection of homologeous image rays, what is equivalent to the

---

[3] The intrinsic parameters of the camera are the focal distance or the opening angle, pixel size, the position of the optical center, etc. These parameters are specific to each camera.

[4] The extrinsic parameters are the position of the camera, the test card (point aimed) and rolling (orientation of the apparatus compared to the center of aiming). These parameters are specific to each image.

mapping of a cloud of points in one image to the corresponding points in the other one [7, 8, 9, 10, 11, 12, 13, 14].

Multi-image concepts use sets of images taken from different view points showing each part of the object in at least two images. The more images contribute to an object point the higher is the geometric quality and the more complete is the coverage of the object surface with image data from different view points. Objects with a considerable spatial extent furthermore allow to calibrate cameras on the fly and therefore facilitate to use non-metric cameras.

3.1.2. Scanning

Scanning systems are mostly founded on laser beams moving around and touching the object surface at numerous positions. Such systems are useful for complex surfaces needing many discrete points for a satisfying description. Latest commercial systems provide measuring speeds of thousands of points per second accompanied with an accuray of some millimeter per point. For architectural applications this is a largely sufficient precision.

As drawback can be seen, that architectural surfaces have a simple geometrical structure only needing very few characteristic points. But scanner produce thousands of points resulting in a terrible oversampling, even with the risk, that the characteristic points are not contained in the data set. The situation could be perceived to have thousends of undesired points without those really needed, why the extraction of the object geometry must result in an interpolation process [15, 4].

3.2. 3D Reconstruction

3.2.1. Techniques in photogrammetry

Within photogrammetry three classes of methods have to be distinguished: manual methods, semi-automatic methods and automatic methods. Manual methods are completely based on user interaction allowing to extract scene elements, which then are converted into 3D models by means of a software package. For semi-automatic methods the user initializes the process by some manual measurements based on which an algorithm tries to extract other elements. Automatic methods are processes without the need of any kind of user intervention.

Manual methods have been established long time ago and are available in form of high end commercial c.f. Leica®[5] or low cost software Dista[6]. The process of reconstruction is rather long and tiresome. However, the morphological and geometrical precision achieved is very high, supposed that the images have an appropriate resolution, that a metric camera is used and that the geometrical configuration is sufficient. Time consuming evaluation processes can be simplified using software as developed within research programs like Facade

---

[5] Leica® : http://www.leica-geosystems.com/
[6] Dista : http://www.i3mainz.fh-mainz.de/projekte/dista.html

[16], meanwhile being commercially available in software packages (Canoma[7] and RealViz's ImageModeler[8]). Facade allows to place 3D parametric primitives onto the images and tries to find correspondences of edges in the images an thus simplifies the modelling step. However, the user is limited to the primitives offered by the system what restricts the flexibility.

Semi-automatic methods use projective, affine, and Euclidean geometries [7] for the definition of constraints. The projects Realise [18] and TotalCalib [19, 20, 21] mainly use epipolar geometry [22] to support the mapping. TotalCalib in opposite to Realise uses calibrated images and geometrical constraints such as parallelism, coplanarity, intersection, etc. TotalCalib reduces user interaction to the introduction of points and of polygons. For the first points the correspondence is carried out by the user. After a certain progress, the system is able to find corresponding points automatically using the projection defined by the points manually measured and by means of local discontinuities in the image. The projective relation of the images is computed with about thirty points using a non-linear method [23].

Main focus of Realise is the integration of vision tools into the calculation of geometrical relations. So, epipolar lines are superimposed to all images during point selection, helping to support the process of selection and reducing errors. However, the manual interaction still remains considerable.

This will be further reduced by approaches as used in Marina [24, 25] and Rekon [26, 27, 28]. Also based on projective geometry, these projects don't use epipolar geometry and don't require calibrated images. Instead, an iterative process tries to establish and refine geometrical constraints. If the model does not correspond to the expectations the constraints can be refined. These constraints are used by an engine called "Gina" in the Marina project and by a convergence engine in the Rekon project. For data collection the user may draw directly onto the images, specifies what has to be reconstructed and formulates geometrical constraints to be respected by the model. This information is translated in the Grassman-Cayley algebra before it is treated formally. The formalism used in Marina allows to apply geometrical reasoning which is not sensitive to the numerical precision. The Rekon system substitutes the intrinsic and extrinsic parameters by an approximation matrix of the perspective projection or the series of transformations that have led to the image. Once the two views are calibrated the 3D geometry of the drawn primitives is directly generated. A convergence engine alternates between each iteration by trying to improve matrices and the 3D model.

---

7 Canoma® : http://www.canoma.com/

8 RealViz's ImageModeler ® : http://www.realviz.com/products/im/

Automatic methods use various approaches but all are based on image segmentation techniques to extract features. The methods of Pollefeys et al. [29] and Zisserman et al. [30] use the projective geometry on not calibrated images. Pollefeys method divides the task of 3D modelling into several steps. The system combines various algorithms from computer vision, like projective reconstruction, auto-calibration and depth map estimation. The disparity calculation between point pairs makes it possible to get a depth map. Then, the depth map is transformed into a volume model composed of voxels. The surface estimation between the outer surface voxels and the interior surface voxels makes it possible to combine inner and outer object parts. The method developed is effective and obtains good results. The approach of A. Zisserman et al. is inspired by Façade and proceeds in two steps. First, a coarse surface model of the building is carried out. Then the coarse model guides the search of details (windows and doors) and refines the surface model. The reconstruction uses the detection of "vanishing points", line correspondence, and the estimation of points and homologous lines. Vanishing points are necessary for the detection of planar primitives with the help of the plane-sweeping method. This method has strong constraints as it contains three perpendicular dominant directions.

Of special interest is the project Aida [31], because it uses a semantic network to guide the reconstruction. Aida uses epipolar geometries and calibrated images. The process of pattern recognition is supported by a bank of constraints. As the images are used together with their orientation values the epipolar geometry is known, simplifying the calculation of the disparity map from which the depth information is derived. The depth maps are used for the processes of segmentation, which is based on region growing and groups 3D points into geometrical elements like planes, for example. The knowledge of the scene is modelled with a network forming a model. To describe the objects and their relations an independent language is defined. This language is inspired by the network syntax of ERNEST [32]. During the phase of interpretation, a semantic value is assigned to each primitive resulting in a semantic network. This network is an instance of the model. At the end, when all primitives are labelled, the assigned semantics is correct. That means that all primitives check the geometric and semantic constraints. Thus, the semantic information allows to guide then the process of reconstruction.

However, the problem of automatic object reconstruction remains a task difficult to realise in spite of many years of research [8, 9, 10, 11, 12, 13]. The major problems are the impact of the viewpoint onto the appearance of the object, resulting in changes with respect to geometry and radiometry and, in addition, existence of occlusions and the lack of texture. Strong variations in the viewpoint may destroy the adjacency relations of points, especially when the object surface shows considerable geometrical variations. This dissimilarity causes a confusion within correspondence determination and is even worse, when partial occlusions result in a disappearance of object parts. In cases of weak texture the algorithms don’t have sufficient information to correctly solve the correspondence problem, why the base for 3D modelling erases and the reconstruction fails.

3.2.2. Techniques based on scanned data

Accurate reconstruction of a surface model from unorganised point clouds provided by a scanning systems is complex and not yet solved completely. Problems arise from the fact, that the points are generally not organised, have noise and don’t directly reflect the structural characteristics of the object. Computer based processes of object extraction are therefore limited in their efficiency. F. Remonido gives an overview to existing algorithms [33].

The surface reconstruction from point clouds is composed of several phases [33]. First, during a pre-processing step, the clouds are cleaned and fused to large point distributions, if multiple views are available. Then the topology is determined allowing to triangulate the points in order to get a closed surface. Finally, during a post-processing, the data is completed and refined to get an acceptable and useful model.

Several software packages like Geomagic Studio®, Cyclone®, AutoCAD® or 3D Max® Studio, etc. allow to evaluate the data in order to extract the desired surface model. According to the functionality of the package, a reconstruction will be guided purely manually or might be supported by the software. Support could originate from functions allowing to place primitives into the point cloud, what simplifies the process of modelling and speeds up the evaluation.

Commercial software is founded on more or less extensive user interaction, why several research projects aim to find solutions for an automatic processing of the data. This is the more simple the less complex the geometry of an object is structured. So, in case of modern architectural surfaces, which are mostly composed of simple geometrical elements like planes, the problem has a reduced complexity. However, the reconstruction of buildings needs to have data sets covering the whole building. So, various views onto the object have to be available in order to avoid occlusions hiding some parts of the surface. These various point clouds have to be merged, what might be simplified by use of mobile robots, for example. Although robots limit the capability of scanning systems, several projects have shown how to find automatic solutions using autonomous mobile robots travelling around in the environment [34, 35, 36, 37, 38, 39].

Point clouds from different view points are fused either by an Iterative Closest Point determination (ICP) [40] or by total error minimisation [41]. Algorithms for surface extraction are based either on “region growing” concepts [34], on RANSAC [36] or on “Expectation Maximization” [37]. Nüchter [35] uses a mixture of region growing and ICP.

Close attention is given to the work of Cantzler et al. [36] and to the work of Nüchter et al. [35]. These projects use semantic information coupled to a scene. Planes found in the phase of reconstruction are introduced into a semantic interpretation, which has to fit to a network model [42]. A tree of “backtracking” allows to find best mapping between the interpretation of the scene and the semantic network model. A coherent labelling exists, if all surfaces are labelled. Relations between the nodes of the semantic network are used to define geometrical constraints between labelled surfaces. The model used and the relations between the elements of the model define the knowledge of a typical architectural scene. The interpretation of the scene then forms a semantic network, which is an instance of the architectural model. As inaccuracies within measurements affect the 3D model, the semantic interpretation makes it possible to refine and improve the model. In particular, the planes are adjusted in order to correspond to the geometrical and semantic constraints.

So, with respect to scanning, problems are fewer as in photogrammetry. But an automatic reconstruction is just as impossible as within image based techniques. One important reason is the complexity of an object in combination with redundancy, incompleteness and noise within the point clouds. Improvements can be expected, when knowledge about the scene is used, as the work of Cantzler and Nüchter have shown. The nature of the geometrical objects and the existing constraints between them makes it possible to support a computer based detection.

4. SEMANTIC-BASED 3D RECONSTRUCTION

As the preceding approaches have shown, a semantic context may support a reconstruction considerably. This might be helpful for the reconstruction within 3D point clouds, when only the elements of the object have to be detected and will be combined to the final object structure. But certainly, semantic knowledge is useful for photogrammetric tasks, too. This might either help to group 2D points in the images or to form the spatial structure, when several images are available. The semantic structure of the spatial object model is the same, only use and interaction with the data are different, but should generally improve existing techniques. In the following, some thoughts to a semantic guided conception will be sketched.

4.1. HYPOTHESIS

The idea is founded on the duality between context and constraints. It starts from the thought, that it is easier to rebuild a scene, if a priori knowledge to elements in a scene exists and will be used. At first, a coarse geometrical and semantic model called "CM" has to be established. Such a CM corresponds to the spatial structure of a building and is an instance of semantic network defined by the user. This instance defines the rough geometry and the semantics of the building without any real measurement. For example, a coarse model may define the number of stages, the type of roof, the configuration of the walls, the number of rooms per stage, the number of windows and doors per wall. Figure 1 shows a CM being defined by an interface allowing to determine a building and his elements. Once this CM is expressed, images and point clouds may be used as entry parameters for the process of data collection trying to correct the CM. Within an iterative process the elements found are used to refine the model. This process may start at external surface parts, continues in the interior environment and ends by merging interior and exterior surface elements. The final stage should aim at the detection of smaller parts like doors, windows, etc.

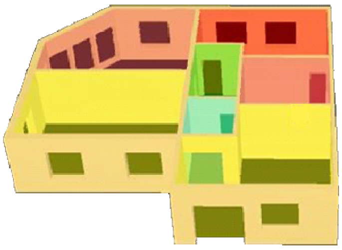

Figure 1 : Example of an architectural CM

4.2. Solution

A possible solution has to consider aspects like

1. How to define a coarse geometrical and semantic model
2. How to fuse the interior and exterior data of a building
3. How to correct a geometrical model (GM)

-1. For a CM geometrical, topological, and semantic constraints have to be defined. This information forms the knowledge base used to model the scene. To pass from a declarative model to a geometrical model, a process of modelling must be applied. Declarative modelling is widely used, when virtual scenes have to be automatically generated from a list of properties or constraints. To solve certain problems of generation, declarative modelling also uses techniques of constraint satisfaction [43, 44, 47, 49]. We propose to generate a semantic network using constraints on the geometrical model based on object geometry and semantics.

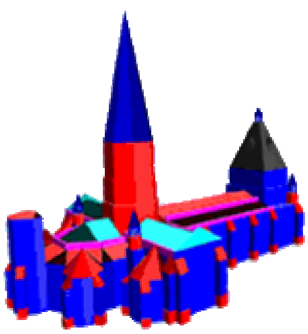

Figure 2 : Geometrical Model generated from a declarative modeler (W. Ruchaud)

-2. The fusion of the external and internal data coming from photogrammetric and/or scanning techniques cannot be achieved without a common object model. However, fusion must not be based on the final model. It might be founded on an intermediate model like a volumetric one. Nüchter [35], for example, uses an octal tree to eliminate measurement errors and to refine the data before surface reconstruction and labelling. An octal tree or octree is a refinement of a voxellisation with a hierarchical structure and elements getting increasingly smaller according to the level of the tree.

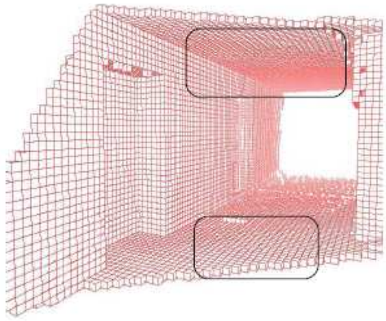

Figure 3 : Arbre octal (A. Nüchter)

Pollefeys et al. [29] merge the depth maps into a volumetric model composed of voxels. The interrelation between voxels at the border of the internal and external surface parts allows to combine different surface regions.

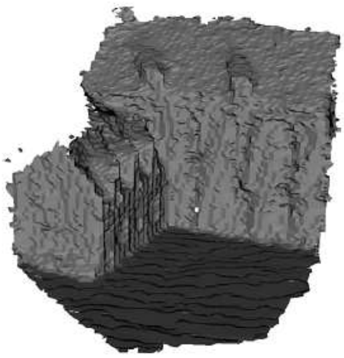

Figure 4 : Computer surface from voxels (M. Pollefeys)

So, a volumetric model (VM) might help to combine data from different surface parts and/or collection techniques and could be used as pivot model before surface reconstruction and labelling start.

-3. The process of transition from a volumetric to a correct semantic model has to be guided by correspondences between their parts. That means to find volumetric elements which fit to constraints defined in the CM. This might be simplified by labels belonging to the voxels which are used to define their nature and formulate their topologic relations to other elements. These relations express a semantic network which can be checked by the CM. From the beginning the VM will not correspond widely to the CM but by an iterative grouping it will be possible to refine semantic information and to find matches to the geometry. If there are no matches found, the constraints in the CM might be reduced in order to simplify the model.

4.3. System Architecture

The solution proposed consists of three principal steps. First, the user defines geometric, topologic, semantic and correction constraints for the GM that he will derive from the knowledge base. Module 1) preserves all knowledge of the reconstruction projects, i.e. semantic networks. Module 2) formulates the à priori model which has to be validated by module 3) or 5) after correction and for later reuse. The second process is the process of declarations, where the CM is declared as well as the scanning and the photogrammetric data.

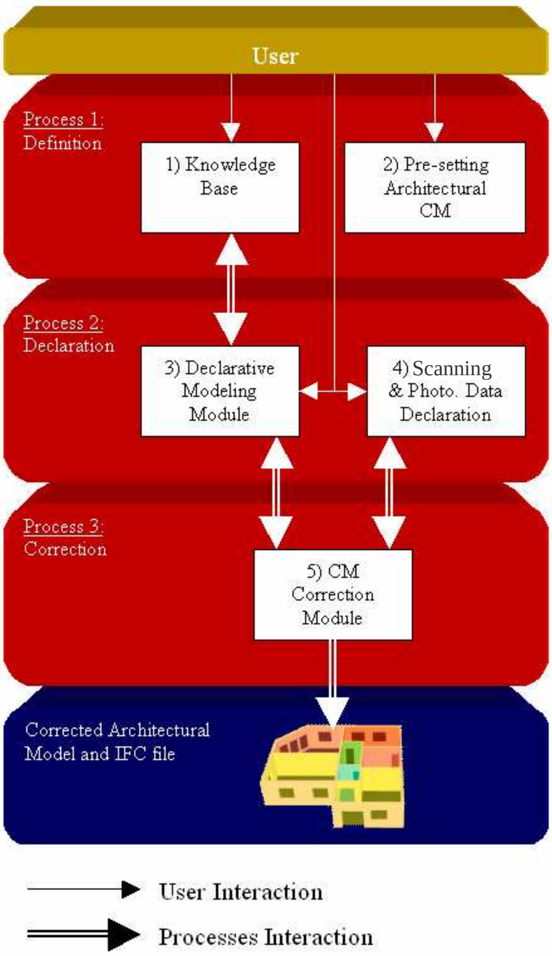

Figure 5: General architecture

This data belongs to the iterative process “declaration/correction”. The third process realises a correction. Then, real measurements are extracted from point clouds or images in order to check the correction constraints. If all correction constraints are validated the model is updated and a IFC file is generated. Otherwise the incomplete model is handed over to the process of declaration to redefine the correction constraints or the measurements necessary. Thus, the solution is an iterative correction until all constraints are checked finally validated by the user.

The user has an important role in the selections to be made and in the actions to be done. This role is important, because only the user knows the potential structure of the object and what kind of model can be established. Therefore, the process of reconstruction only can be automated and supported if the use takes the right decisions.

5. CONCLUSION

This paper presents an extended set up used for an automated reconstruction of objects in the field of as-built photogrammetry and laser scanning. It is obvious, that due to the complexity of a reconstruction process, knowledge of several disciplines is required. On the other hand each discipline such as industrial metrology, computer graphics, knowledge management and computer vision has solutions, which could constructively interact in order to make progress towards a final solution.

In the next stage a prototype will be generated allowing to correct a simple CM using geometrical information. By this, it will be possible to estimate the feasibility of the project. If the result is positive, an application defined according to an industrial framework will be realised. The knowledge base as well as the à priori model for the semantic network will then be refined with respect to the needs of the engineers during the process of reconstruction.

6. REFERENCES

[01] A. Grün, S. Bär, et S. Beutner, ”Signals in the Sand - 3D Recording and Visualization of the Nasca Geoglyphs”, *PFG (Photogrammetrie, Fernerkundung, Geoinformation)*, No. 6/2000. pp. 385-398, 2002.

[02] P.G. Bryan, I. Corner, & D. Stevens, “Digital Rectification Techniques for Architectural and Archaeological”, *Presentation. Photogrammetric Record*, 16(93): 399-415, April 1999.

[03] C. Balletti, & S. Mander, ”Contemporary Master’s Architecture: New Architectural Heritage, Approaches For Surveying and Representation”, *Geo-*

Imagery Bridging Continents, XXth ISPRS Congress, 12-23 July, Istanbul, Turkey, 2004.

[04] W. Boehler & al., “The potential of non-contact close range laser scanners for cultural heritage recording”, *Actes du XVIII Symposium International CIPA*, Postdam, Allemagne, 2004.

[05] G. Heinz, “Combination of Photogrammetry and Easy-to-use Non-Metric Methods for The Documentation of Archeological Excavation”, *Commission V Symposium; Close-Range Imaging*, Long-Range Vision - Corfu, Greece, 2002.

[06] P. Reiss, “Production of Digital Orthophotos and Orthophotomaps”, *at the Bavarian Land Survey Office*, Munich, 1997.

[07] B. Zitova & J. Flusser, “Image registration methods: A survey”, *Image and Vision*, Computing 21, 977–1000, 2003.

[08] H. H. Backer & T. O. Binford. "Depth from edge and intensity based stereo". In Proceedinds of the seventh IJCAI, Vancouver, BC, pages 631-636, 1981.

[09] D. J. Fleet, A. D. Jepson, & M. R. M. Jenkin, “Phase-Based Disparity measurement.”, *CVGIP : Image Understanding*, 53(2):198-210, 1991.

[10] W. E. L. Grimson, “From Images to Surfaces.”, *MIT Press*, 1981.

[11] D. Jones & J. Malik, “Computational Framework for determining stereo correspondence from a set of linear spatial filters.”, *Image and Vision Computing*, 10(10):699-708, December 1992.

[12] D. Marr & T. Poggio, “A computational theory of human stereo vision”. *Proceedings of the Royal Society of London*, 204:301-328, 1979.

[13] L. McMillan & G. Bishop, “Plenoptic modeling : An image-based rendering system.”, *In SIGGRAPH '95*, 1995.

[14] L. Vinet, “Segmentation et mise en correspondance de régions de paires d'images stéréoscopiques.”, *Thèse de l'université de Paris IX Dauphine*, 2 Juillet 1991.

[15] C. Fröhlich, M. Mettenleiter & Zoller+Fröhlich GmbH, “Terrestrial Laser-Scanning - New Perspectives in 3D-Surveying”, *Proceedings of the ISPRS working group VIII/2, Laser-Scanners for Forest and Landscape Assessment*, Freiburg, Germany 03-06 October, 2004.

[16] Paul E. Debevec. “Modeling and Rendering Architecture from Photographs.”, *PhD thesis, University of California at Berkeley*, December 1996.

[17] P. Etyngier, “Introduction intuitive à la géométrie projective”, *Tutorial Version 1.0*, Ecole Supérieure d’Informatique - Electronique – Automatique, juin 2003.

[18] F.Leymarie & al., “REALISE: Reconstruction of Reality from Images Sequences”, *Proc. of IEEE «International Conference on Image Processing» (ICIP'96)*, Vol.III, pp.651-654, P.Delogne ed., Lausanne, Switzerland, Sept. 1996.

[19] L. Robert. “Camera calibration without feature extraction.”, *Computer Vision, Graphics, and Image Processing*, 63(2) :314–325, March 1995. also INRIA Technical Report 2204.

[20] S. Bougnoux & L. Robert. “TotalCalib: a fast and reliable system for off-line calibration of images sequences.”, In *Proceedings of International Conference on Computer Vision and Pattern Recognition*, 1997. The Demo Session.

[21] O. Faugeras, S. Laveau, L. Robert, G. Csurka, C. Zeller, C. Gauclin, & I. Zoghlami. “3-d reconstruction of urban scenes from image sequences”. *CVGIP : Image Understanding*, 1997.

[22] R.I. Hartley & A. Zisserman, “Multiple View Geometry in Computer Vision”, *second edition, Cambridge University Press*, 2004.

[23] Z. Zhang, R. Deriche, O. Faugeras, & Q.-T. Luong. “A robust technique for matching two uncalibrated images through the recovery of the unknown epipolar geometry.”, *Artificial Intelligence Journal*, 78 :87–119, October, 1995.

[24] P. M. Kuzo, “Des contraintes projectives en modélisation tridimensionnelle interactive”, *Thèse de doctorat, Ecole des Mines de Nantes – Université de Nantes*, novembre 1999.

[25] S. Huot & C. Colin. “MArINa : reconstruction de bâtiments 3D à partir d'images.”, *Colloque Modélisation Multimodale appliquée à la reconstruction d'environnements architecturaux et urbains*, Bordeaux, France, 2002.

[26] M. Frasson, “Reconstruction interactive de scènes tridimensionnelles à partir d'images ”, *M.Sc. Thesis*, March 1999.

[27] C. Loscos, M. Frasson, G. Drettakis, B. Walter, X. Granier, & P. Poulin, “Interactive Virtual Relighting and Remodeling of Real Scenes”, *Proc. Eurographics Workshop on Rendering 99*, June 1999.

[28] P. Poulin, M. Ouimet, & M. Frasson, “Interactively Modeling with Photogrammetry”, *Proc. Eurographics Workshop on Rendering 98*, June 1998.

[29] M. Pollefeys, R. Koch, M. Vergauwen & L. Van Gool. “Automated reconstruction of 3D scenes from sequences of images”, *ISPRS Journal Of Photogrammetry And Remote Sensing* (55)4, pp. 251-267, 2000.

[30] T. Werner, & A. Zisserman, “New Techniques for Automated Architecture Reconstruction from Photographs”, *Proc. 7th European Conference on Computer Vision*, Copenhagen, Denmark, 2002.

[31] S. Weik & O. Grau. “Recovering 3-D Object Geometry using a Generic Constraint Description”. *In ISPRS96 - 18th Congress of the International Society for Photogrammetry and Remote Sensing*, juillet, Vienne 1996.

[32] H. Niemann, G. Sagerer, S. Schröder & F. Kummert, ”ERNEST: A Semantic Network System for Pattern Understanding”, *IEEE Trans. on Pattern Analysis and Machine Intelligence*, Vol. 12, No. 9, pp. 883–905, Sept. 1990.

[33] F. Remondino, “From point cloud to surface: the modeling and visualization problem”, *Proc. Int. Worksh. Visualization and Animation of Reality-Based 3D Models*, Int. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences XXXIV-5/W10, Feb 2003

[34] D. Hähnel, W. Burgard, & S. Thrun, “Learning Compact 3D Models of Indoor and Outdoor Environments with a Mobile Robot”, *Robotics and Autonomous Systems*, 44 (1), pp. 15-27, 2003.

[35] A. Nüchter, H. Surmann, & J. Hertzberg , “Automatic Model Refinement for 3D Reconstruction with Mobile Robots”, Fraunhofer Institute for Autonomous Intelligent Systems (AIS) Schloss Birlinghoven, D-53754 Sankt Augustin, Germany, 2003.

[36] H. Cantzler, R. B. Fisher & M. Devy, “Quality enhancement of reconstructed 3D models using coplanarity and constraints”, *Proc. Annual German Symposium for Pattern Recognition (DAGM02, Zurich)*, pp 34-41, 2002.

[37] Y. Liu, R. Emery, D. Chakrabarti, W. Burgard & S. Thrun, “Using EM to Learn 3D Models of Indoor Environments with Mobile Robots”, *Proceedings of the Eighteenth International Conference on Machine Learning*, 329 – 336, 2001.

[38] A. Georgiev & P. K. Allen, “Localization Methods for a Mobile Robot in Urban Environments”, *IEEE Transactions on Robotics*, vol. 20, pp 851-864, October, 2004.

[39] V. Sequeira, K. C. Ng, E. Wolfart, J.G.M Gonçalves, & D.C. Hogg. “Automated Reconstruction of 3D Models from Real Environment”, *ISPRS Journal of Photogrammetry and Remote Sensing*, Elsevier, To appear 1999.

[40] P.J. Besl & N.D McKay, "A Method for Registration of 3D Shapes", *Proc. of IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 14, No. 2, pp.239-256, 1992

[41] K. Pulli. “Multiview registration for large data sets”. *In Proc. 2nd Int. Conf. on 3D Digital Imaging and Modeling* (3DIM), pages 160-168, 1999.

[42] O. Grau. “A Scene Analysis System for the Generation of 3-D Models”, *3dim*, p. 221, First 1997.

[43] G. Kwaiter , V. Gaildrat & R. Caubet, “Modelling with Constraints: A Bibliographical Survey”, *Proceedings of the International Conference on Information Visualisation*, p.211, July 29-31, 1998.

[44] O. Le Roux , V. Gaildrat & R. Caubet, “Constraint satisfaction techniques for the generation phase in declarative modeling”, *Geometric modeling: techniques, applications, systems and tools*, Kluwer Academic Publishers, Norwell, MA, 2004

[45] N. Ayache, “ Vision stéréoscopique et perception multisensorielle.”, *Inter éditions science informatique*, 1989.

[46] A. Fuchs, J.P. Perrin & P. Grussenmeyer, “Confrontation de la lasergrammétrie aux techniques de relevé conventionnelles et développement d’outils numériques pour la restitution architecturale”, *Télédétection et photogrammétrie pour le développement en milieu urbain*, Marne-la-Vallée (France), 26 - 28 novembre, 2003

[47] I. Ravani, D. Makris, G. Miaoulis, P. Constantinides, A. Petridis & D. Plemenos, “Implementation of Architecture-oriented Knowledge Framework in MultiCAD Declarative Scene Modeling System”, *in BCI, 1st Balkan Conference in Informatics*, Greece, 2003.

[48] R. Vanlande, C. Cruz, C. Nicolle, “Managing IFC files in civil engineering projects” , *ACM CIKM’03*, New Orelans, Lousianne, USA, 3-8 November 2003.

[49] W. Ruchaud, D.Plemonos, “Improvement techniques for geometric constraint solving in declarative modelling.”, *International Conference 3IA'2003*, Limoges (France), May 14-15, 2003