ONTOLOGY-DRIVEN 3D RECONSTRUCTION OF ARCHITECTURAL OBJECTS

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Abstract: This paper presents an ontology-driven 3D architectural reconstruction approach based on the survey with a 3D scanner. This solution is powerful in the field of civil engineering projects to save time during the cost process estimation. This time is saved using efficient scanning instruments and a fast reconstruction of a digital mock-up that can be used in specific software. The reconstruction approach considers the three following issues. How to define an ontology to drive the reconstruction process? How to find semantic objects in a cloud of points? How to control an algorithm in order to find all objects in the cloud of points? This paper underlines the solutions found for these questions.

1 INTRODUCTION

In the field of civil engineering projects it is often difficult to update a building. Most of the time, information concerning its design has simply disappeared. Indeed, no process was usually defined to store digital data concerning the design of the architectural project. Such data would be helpful to estimate the update costs. For instance, the security laws evolve and the buildings have to follow them. Consequently, the buildings must be updated too. Also, the building has to be captured “as-built” using expensive geometrical measurements to improve the design and to evaluate the update costs. These measurements have to be done by engineers and comprise several steps like the establishment of a geometrical reference and a local data capture. This process is time consuming, that’s why automatic algorithms are welcome in order to reduce time and cost. In principle, photogrammetry and laser scanning both have the potential for improvements and higher degrees of automatism. In this article we focus on a method based on the laser scanning survey. Digital building plans being defined by the civil engineers with the help of CAD software mostly contain simple geometries. In addition, semantic rules are applied to achieve better design. However, during various processing steps and their inevitable data exchange object information is reduced to a set of vectors using formats like DXF or DWG. As a consequence, semantic information and object structures are lost. Such problems might be avoided with file formats like IFC, defined by the International Alliance for Interoperability. This standard associates a semantic definition to geometrical elements in the field of building projects. Up to now, this standard is used as an exchange format by international leaders of CAD software. This format is of value for "as-built" problems, aiming at the digital reconstruction of real buildings. Consequently, it should be helpful to use the IFC semantic information directly during an “as-built” reconstruction of a building for an automatic reconstruction. In this article we focus on a method not only based on the laser scanning survey and IFC semantics but also introducing an ontology defining the semantic context to simplify the automatic reconstruction.

The following section gives background information on projects that aim to reconstruct a 3D model of a building from survey data. In these projects the semantic information that describes the context of the building takes an important place. Section 3 describes our approach inspired from these projects. Section 4 focuses on this method by explaining all the important parts of the reconstruction process.

2 BACKGROUND

Today, computer-driven evaluation of spatial data sets is limited by the complexity of the objects to be extracted. As a matter of fact it is complicated and time consuming to formulate rules in order to detect and extract objects geometrically correct. It is due to one essential reason that the objects are broken down into many small geometrical pieces. Even if each piece can be treated in an isolated way, it is not possible to treat all data at one time. Therefore, the use of knowledge and its introduction into the process of evaluation is promising for global interrelations. The impact of semantic information on the reconstruction process depends on the structure of the raw data that has to be handled. Therefore, it is necessary to study those structures and reconstruction processes. A short survey is given in the two following subsections. The first subsection is concerned with reconstruction methods based on photogrammetric data and the second considers reconstruction methods based on scanning data. Each method has its own characteristics and advantages but the best choice depends on the material available, the object to be captured, the required precision, and the time available (Grün, 2002), (Bryan, 1999), (Balletti, 2004), (Boehler, 2004).

2.1 Photogrammetry

Reconstruction methods based on photogrammetric data are of two kinds. The semi-automatic methods consist of the interaction with the user during the whole process. The automatic methods consist in the initiation of the process by the user at the beginning so that later the process runs without user interaction. Semi-automatic reconstruction methods can be found in the projects: Realise (Zitova, 2003), TotalCalib (Robert, 1995), (Bougnoux, 1997), (Faugeras, 1997), Marina (Cantzler, 2002), (Nüchter, 2003) and Rekon (Frasson, 1999), (Loscos, 1999), (Poulin, 1998). Automatic reconstruction methods have been developed by Pollefeys et al. (Pollefeys, 2000) and Zisserman et al. (Werner, 2002). They use the projective geometry on non-calibrated images. Pollefeys' system combines various algorithms from computer vision, like projective reconstruction, auto-calibration and depth map estimation. Of special interest for our work was the project Aida (Weik, 1996) because it uses a semantic network to guide the reconstruction. This method opens a new way by using semantic information. The automatic reconstruction remains a difficult task in spite of many years of research (Backer, 1981), (Fleet, 1991), (Grimson, 1981), (Jones, 1992), (Marr, 1979), (McMillan, 1995). The major problems are the impact of the viewpoint onto the appearance of the object in the image. This is due to the changes with respect to geometry, radiometry, occlusions and the lack of texture. Strong variations of the viewpoint may destroy the adjacency relations of points, especially when the object surface shows considerable geometrical variations. This dissimilarity causes confusion in the determination of correspondence and it is worse when partial occlusions result in a disappearance of object parts. In cases of weak texture the algorithms do not have sufficient information to solve the correspondence problem correctly. Usually, this is the reason why the reconstruction fails.

2.2 Scanning

Accurate reconstruction of a surface model from unorganized points of clouds provided by scanning systems are complex and are still not completely solved. Problems arise from the fact that the points are generally not organized, contain noise and do not reflect directly the object characteristics, for example. Computer-based processes of object extraction are therefore limited in their efficiency. F. Remonido gives a good overview of existing algorithms (Remondino, 2003). Close attention is given to the work of Cantzler et al. (Cantzler, 2002) and to the work of Nüchter et al. (Nüchter, 2003) because these projects use semantic information. Planes which are being reconstructed are associated to a semantic interpretation which has to fit to a network model (Grau,1997). A tree of “backtracking” allows to find the best mapping between the scene interpretation and the semantic network model. A coherent labelling exists if all surfaces are labelled.

Compared to photogrammetry, problems seem to be fewer in the field of scanning but an automatic reconstruction is just as impossible as it is within image based techniques. One important reason for this is the complexity of objects in combination with redundancy, incompleteness and noise within the clouds of points. Improvements can be expected when knowledge about the scene is used, as is shown in the work of Cantzler and Nüchter. This is the reason why the nature of the geometrical objects and the existing constraints between them make it possible to support computer based detection.

3 ONTOLOGY-DRIVEN RECONSTRUCTION

As the work presented in the previous section shows, a semantic context may support considerably a 3D reconstruction. This might be helpful for the reconstruction within clouds of points where some elements of the object have already been detected and need to be combined to a final structure. Semantic knowledge is also useful for photogrammetric tasks. 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 the use and the interaction with the data are different. In the following section our vision of the use of semantic definition for 3D reconstruction will be sketched. Our main idea is founded on the duality between context and constraints. It starts from the idea that it is easier to rebuild a scene using available knowledge about the scene's elements. Therefore, in order to define the knowledge about the context, a coarse geometrical and semantic model has to be established. We call this **c**oarse **m**odel "CM" and it is a spatial structure that defines a building and the semantics about the elements that compose the building.

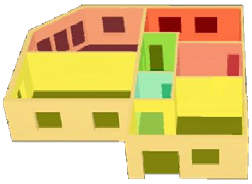


Figure 1: Example of an architectural CM

The "CM" (e.g. fig. 1) defines the rough geometry and the semantics of the building without any real measurement. Such a "CM" will then be updated by means of real measurements representing the building. In order to achieve this, knowledge has to represent the real world by reflecting entities and relations between them. Therefore, knowledge constitutes a model of the world and agents use their knowledge as a model of the world. In addition, to model the semantics of knowledge as well as the structure where this knowledge is stored, it is necessary to reach a higher conceptual level. For that, knowledge representation is independent of knowledge use. Thus, knowledge representation and inferential mechanisms are dissociated (Guarino & al., 1994). On the other hand, domain conceptualization can be performed without ambiguity only if a context of use can be given. In fact, a word or a term can designate two different concepts depending on the particular context of use (Bachimont, 2000). The semantic of knowledge is strongly constrained by the symbolic representation of computers. Therefore N. Guarino (Guarino, 1994) introduced an ontological level between the conceptual level and the epistemological level. The ontological level forms a bridge between interpretative semantics in which users interpret terms and operational semantics in which computers handle symbols (Dechilly, 2000). Some projects presented previously have used a semantic network to model the semantics of a scene. We will use an ontology language for several reasons.

- First, the implementation of an ontology is a mapping stage between the system elements and their ontological "counterparts". Once this mapping has been carried out, the representation of elements in the ontology is regarded as a meta-data diagram. The role of a meta-data diagram is double (Amann, 2003). On the one hand, it represents the knowledge shared on a domain. On the other hand, it plays the role of a database schema which is used for the formulation of requests structured on meta-data or to constitute views.

- Secondly, the ontologies allow to dissociate knowledge representation and inferential mechanisms. We have sketched a generic definition of semantic elements that permit to dynamically add new elements in the ontology without changing the code. Those new elements are also taken automatically into account in the storing process and the inferential mechanisms.

- Thirdly, once the "CM" has been corrected, geometric and semantic information in the ontology can be exported into an IFC file format. So, the 3D model can be used directly in civil engineering processes and CAD software.

4 METHOD DEFINITION

Our method aims at developing a solution to reconstruct automatically a 3D building from a point cloud measured by a 3D scanner. This solution has to consider the three following aspects. How to define a geometric and semantic coarse model? How to find objects in a cloud of points? Which algorithms to use as a propagation method to find all objects in the cloud of points? In our solution the user has to assign the context by defining a coarse model of the building to be reconstructed. Then the user interactively selects a set of points in the cloud that represents a wall. The selection is also mapped to the coarse model by assigning the corresponding wall in the “CM” (e.g. figure 3). Then the user starts the reconstruction algorithm. Within an iterative process the plane representing the wall is found and will be used to correct the model. The process starts with the mapped plane, corrects it, and continues with information in “CM” to detect an adjacent plane by propagation. A final stage should aim at the detection of smaller parts like doors, windows, etc.

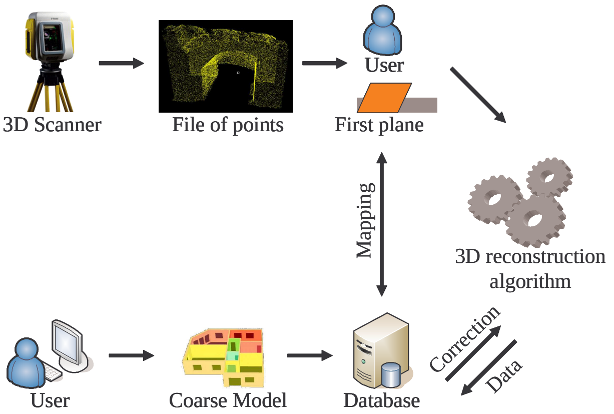
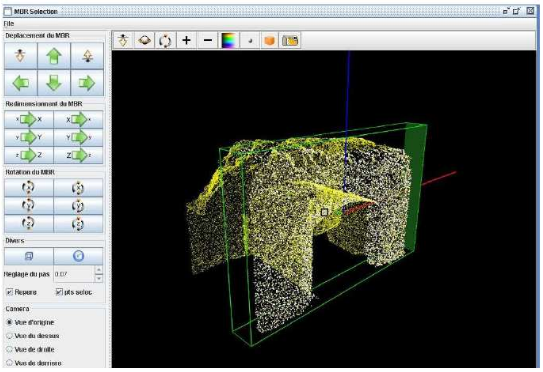


Figure 2: global view of our method

The three following subsections give an overview of our solution to achieve the final goal consisting of the definition of a “CM”, the plane detection that allows to find objects in the cloud of point, the search of objects by propagation permitting the correction of the “CM”.

4.1 Definition of the “CM”

This section describes our method used to define a “CM”. With the application that has been developed (e.g. figure 4) the user can indicate the general geometrical structure of a building like the position and the size. Moreover, the interaction with our application allows to define automatically constraints between elements of the “CM” which are described by the architectural ontology. For instance, a window is a concept that composes the architectural ontology. This window has a constraint which is “the window must be in a wall with a bigger size”. To implement this part we resolved three main issues. First, it was necessary to define the structure of the architectural ontology. Secondly, it was necessary to manage the persistence of data as well. Thirdly, data should be exported into an IFC file format. To resolve the first issue, two ways were available which are the static way and the dynamic way. The static way consists in implementing directly the class necessary to describe the elements that compose a building as well as the relations. Once the necessary elements are defined, the conception of the databases and graphical interfaces can be overtaken. The problem linked to the static way arises when new kinds of objects have to be added to the ontology. As a result, the database and the graphical interface must be adapted. The dynamic way consists in taking into account this issue and in developing a structure that allows to add a new kind of object without changing the structure of the database and the graphical interface. The model defined in this application takes into account this issue and manages the description of the classes and instances from the start.



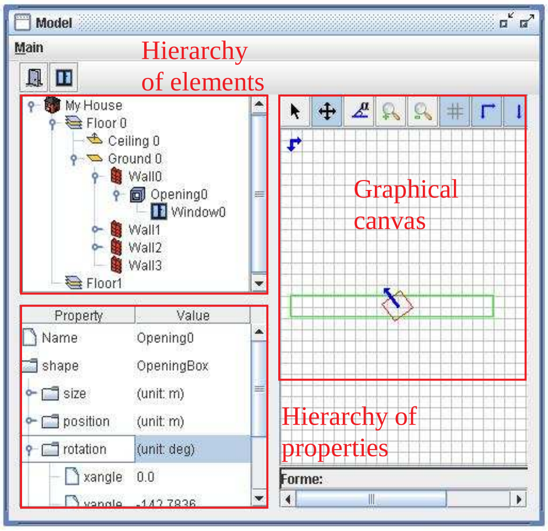
Reglage du pas 0.07

☑ Repere ☑ pts selec

● Vue d'origine
○ Vue du dessus
○ Vue de droite
○ Vue de derriere

Figure 3: Selection of a subcloud of points

Our model is divided into two levels which are the semantic level and the instance level. The semantic level allows to store the description of the ontology classes from a OWL (Web Ontology Language) file. The OWL file is defined with the help of the software Protégé OWL plugin. The instance level allows to store the description of the instances from the classes of the ontology. The storing process and the graphical interface are then not modified when a new class has to be added. Nevertheless, there is still a problem in the management of a dynamic ontology. It is necessary to manage the positioning interactions between elements.



Property	Value
Name	Opening0
shape	OpeningBox
size	(unit: m)
position	(unit: m)
rotation	(unit: deg)
xangle	0.0
yangle	-142.7836

Figure 4: Definition of the “CM”

For instance, if a ground is moved then the elements carried by this ground, like the walls, must undergo a displacement. The solution is to define predefined behaviors and then associate those behaviors of the future elements to the existing behaviors. For example, a new class column has the same behavior as a wall. It is indeed located on the ground and touches the ceiling. Thus, it was necessary to locate the types of behavior according to the possible interactions. A set of behavior was found but only three of them are described here. The ground is rather a horizontally flat element and on this one walls can be deposited. The walls are rather vertical elements. A window is an element in a wall. From those facts the types of elements are the “horizontal elements”, the “vertical elements” and the “vertical subelements”. Concerning the basic constraints, the “horizontal elements” are used as support for the “vertical elements”. So the ”vertical elements” are positioned on the “horizontal elements” and contain the “vertical subelements”. The “vertical subelements” are contained in “vertical elements”. With the help of those predefined behaviors and constraints, it is easy to add a new complex class in the architectural ontology.

Concerning the IFC export, the ontology contains all information about the object that composes the building. The architectural concepts and relations are fully inspired by the IFC standard. So, the objects are exported by our export module with geometrical definition and the relations between them but the constraints are only used for the validation of the “CM”.

4.2 Plan detection and research by propagation

The objects which have to be found in the point cloud are planes. This geometric primitive is the easiest one to search and also the fastest one (Remondino, 2003). During the plane search process, there are several stages that have to be carried out. The first stage is the partitioning of the point cloud. When it is known that a set of points defines only one plane, it is easier to find an equation of the plane that represents this subset. In most cases the point clouds do not model only one plane. To simplify the search of planes in such a cloud it is helpful to initially cut out such a subset of points. After a first segmentation is achieved, one can calculate the plane equation of each subset. But, the equation of a plane is not sufficient for a wall because the extensions are not contained. It is thus necessary to limit the equation of a plane, in order to represent the edges of the wall. The equation of a plane provides the orientation of the wall and the outlines are found in the point cloud.

However, this ideal situation is affected by several real world factors. Like in all physical measurements there will always be noise in such measurements. In addition, the point cloud may contain environmental objects like trees or traffic signs partly hiding the real object. Those objects will add more or less erroneous points that will not represent the building. Moreover, the wall is not an ideal mathematical planar object, leading to a roughness of several millimetres on the surface. Finally, not all the 3d points will be coplanar because only in an ideal model the points can be aligned perfectly.

All these problems must be taken into account in the detection of planes. The noise, the erroneous points and irregularities in the wall are parameters which cannot be modified, and thus it is necessary to manage them in the program. Another important point is that the plane detection algorithm must be automated. The user should not have to interact with the algorithm and only has to judge that the results are correct or not.

The degree of complexity increases enormously, when a simple plane should be detected in a point cloud representing a complex object. This is why the algorithm starts with an adjacency search allowing to group the object into small spatial elements (voxel). All points which are contained in a voxel are considered as a subgroup and a plane is found out in each voxel (e.g. figure 5). Subsequently, the neighbourhood is used to extend the voxel planes. The size of the voxels is an important parameter. If the voxel size is too large then multiple planes can be found in one voxel. Thus, it does not resolve the problem. If the voxel size is too small then it is hard to find a correct plane equation.

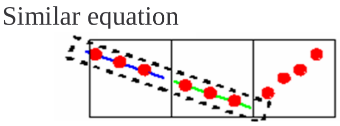


Figure 5: Plane research in voxel space

After initial planes are found, they have to be extended within the point cloud. This is achieved by starting from the plane equation for one voxel and looking at the adjacent voxels if there are points possibly belonging to the same planar surface part. There are several methods to support such a decision. One solution is to calculate a plane for each voxel by means of “least square adjustement”. This is relatively simple to set up, but needs to define a threshold for the different angle of orientation to define the similarity. A better solution starts with the voxel having the best residual error and then it consists in checking the distance to this plane, beginning with the direct neighbours. If the sum of the distance is lower than a certain threshold then the voxels are fused. For the fused group a new equation has to be calculated in order to refine the result.

The plane search by propagation is done in an iterative way. The process starts from a voxel and looks at the neighbours. When the neighbours check the same criteria then the process continues with the "neighbours of the neighbour". Then, all planes that have been found are checked to determine if there are similarities between them. The method based on the angles is also used to avoid useless calculations. If the angle between two planes is higher than 60°, then it is not necessary to try to see whether they can be fused.

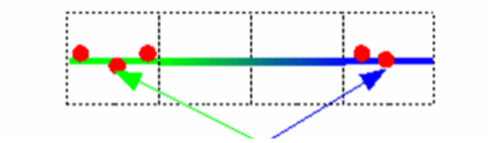


Figure 6: Plane similarity between distant voxels

The plane detection in a point cloud is the most delicate part of the process but needs, in addition, to find the real dimensions of the various elements.

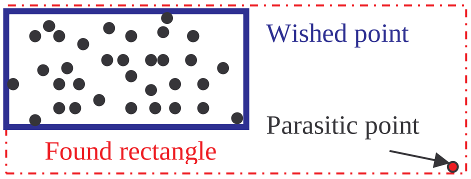


Figure 7: Bounding box and parasitic point

One way to achieve this might calculate a bounding box by taking the extreme values of the points. Some turns of this bounding box with a predefined angle produce acceptable results. In order to find the correct bounding box the characteristics of the delimiting points have to be checked, because single points cannot be regarded as reliable (e.g. figure 7). Only a set of points allows to minimize the errors. The most precise results will be generated by use of the final planes constituting the walls. Assuming the calculations of the equations were done with large sets of points and thus of sufficient accuracy, the edges of the walls can be calculated by intersecting adjacent planes. The result is much more precise and avoids the problem of the parasitic points (e.g. figure 8).

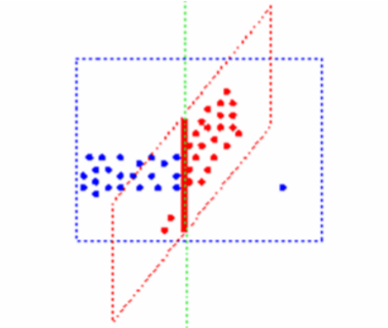


Figure 8: Plane intersection

4.3 Correction of the “CM”

The principle of the project is to use a point cloud coming from a building survey to correct a coarse model that defines the context. Although the improvement of the coarse model is the most interesting result, the initial model - and the knowledge contained therein - is of basic importance for the update process. Therefore, two aspects are of interest in the context of model improvement: first, readjusting the initial wall definition compared to the "CM", and, secondly, the support for the propagation of the plane detection in the whole point cloud.

Repositioning of the initial plane compared to the coarse model

At the beginning, the cloud of points can be positioned in a way completely different compared to the "CM" coordinate system. For the search of the other planes, it is fundamental "to readjust the cloud of points". That readjustment defines an identical framework that accelerates the process. This repositioning takes place during the research of the first plane. Once the readjusted plane has been accomplished, the wall of the "CM" is corrected. The correction of this wall is propagated to the adjacent elements thanks to the constraints defined in "CM".

Research of nearby elements and correction

To propagate the "CM" modification a direction was defined. The propagation is made left towards right then bottom towards top. The "CM" contains information of the neighbourhood. Indeed, the neighbourhood relations are automatically defined during the "CM" definition. To find the bounding box of the second element, the equation of the initial element is used to deduce from "CM" which rotation is defined between the initial element and the second element to be treated. The theoretical equation of the second wall makes it possible to calculate the distance between the second element and each point of the cloud. Thus, by leaving an error margin, we can detect by reading the entire file that contains the points, all the points which are close to this plane. Then, the sub cloud of points undergoes a detection of plane and edges described in the preceding section. Thanks to this information the second element is corrected. Once all the elements from the "CM" are corrected, the sub elements contained in elements of the building must be corrected with the same methods of search of plane and correction.

5 CONCLUSION

This paper presented a solution for the 3D reconstruction driven by an architectural ontology. At this time, most of the huge issues were resolved and the complete process was prototyped. The following issue to be resolved is the use of the other primitives like the cylinder to reconstruct automatically more complex scenes. Furthermore, we are also working on a solution to reuse a partial "CM" that allows to define more easily a complex "CM".

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7 REFERENCES

Amann B., 2003. Du Partage centralisé de ressources Web centralisées à l'échange de documents intensionnels, *Documents de Synthèse, 2003.*

Bachimont B., 2000. Engagement sémantique et engagement ontologique : conception et réalisation d'ontologie en ingénierie des connaissances, *In Charlet J., Zackland M., Kessel G. & Bourigault D., eds., Ingénierie des connaissances : évolution récentes et nouveaux défis, Eyrolles, pages 305-323*.

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

Balletti C. & Mander S., 2004. Contemporary Master's Architecture: New Architectural Heritage, Approaches For Surveying and Representation, *Geo-Imagery Bridging Continents, XXth ISPRS Congress, 12-23 July, Istanbul, Turkey*.

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

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

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

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

Dechilly T. & Bachimont B., 2000. Une ontologie pour éditer des schémas de description audiovisuels, *extension pour l'inférence sur les descriptions, In Actes des journées francophones d'Ingénierie des Connaissances (IC'2000).*

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

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

Frasson M., 1999. Reconstruction interactive de scènes tridimensionnelles à partir d'images, *M.Sc. Thesis, March*.

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

Grimson W. E. L., 1981. From Images to Surfaces., *MIT Press*.

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

Guarino N., 1994, The ontological level, *in R. Casati B. S. & White G., eds, Philosophy and the cognitive sciences, Hölder-Pichler-Tempsky.*

Guarino N., Carrara C., Giaretta P., 1994. An ontologie of meta-level categories, *in J. Doyle F. S & Torano P., eds., Principles of Knowledge representation and Reasonning, Morgan-Kauffman, pages 270-280*.

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

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

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

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

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

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

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

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

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

Remondino F., 2003. 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.*

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

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

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

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