

HISTORICAL DOCUMENTATION OF ROCK CHURCHES IN THE “SASSI” OF MATERA WITH TERRESTRIAL LASER DATA IN A 3D GIS

M. Caprioli, B. Figorito, A. Scognamiglio, E. Tarantino

Polytechnic University of Bari -Italy

e-mail: m.caprioli@poliba.it; benedetto1980@libero.it; a.scognamiglio@poliba.it; e.tarantino@poliba.it

Keywords: Laser data, CAD, 3D GIS, Multipatch, Cultural Heritage.

ABSTRACT

With this study the Laser data acquisition and handling applied on a suggestive Italian Architectural Heritage was executed, in order to allow next complex spatial processing in 3D GIS visualization environments for the management and divulgation of information on Cultural Heritage.

The site test is represented by the “Convicinio of S. Antonio” (XII-XIII centuries), that is one of the Churches carved into the rocks of the “Sassi”, the very ancient quarters of the Matera city.

The Laser data of the above Churches were produced by means of the innovative technologies of the terrestrial Laser Scanner *Leica HDS 3000*, that it is able to extract in a fast way the third dimension of objects and makes high-definition field data capture easy and efficient.

Particular attention was made on the potentiality of the CAD-GIS tandem using the *feature type Multipatch* with different softwares. The *Multipatch* permits to encapsulate complex objects in a compact way and to add also *textures* on surfaces, providing a real 3D objects visualization. Such technique is not still used because commercial GIS softwares have not specific tools to create *3D feature Multipatch*.

The 3D objects made with integrated procedures were next processed with GIS tools, verifying the effective possibility of executing three-dimensional thematic queries of complex georeferenced Laser data.

1. INTRODUCTION

The 3D spatial information is considered as great aid for protection and maintenance of Cultural Heritages. For some application fields the simple 3D data visualization is required, but the effective possibility to manage 3D complex objects can improve and speed up knowledge and analysis connected to a next conservative intervention.

GIS technology can satisfy such requirements because it is a fundamental tool of graphical and alphanumeric architectural data documentation and management. The use of third dimension can enrich such archives with “navigable” and consultable information, derived in a very simple way, in order to obtain also measures on the deepness or thickness of Cultural Heritages .

Actually, the above representations only permit the user to view map layers as a single entity rather than being able to visualize the layers as a combined overlay representation and as individual entities in the same way that is possible with 2D GIS (Brooks et al., 2005).

The last generation CAD softwares have improved the editing and the photorealistic visualization of objects for mechanics and industrial fields, whereas GIS softwares, with the use of georeferenced points, lines and polygons, have emphatically developed tools for spatial analysis of objects. So far, with visualization tools based on simple extrusions, both the technologies doesn't permit structuring of 3D topological models and visualization with thematic queries of complex entities.

In literature there are substantially *object oriented* and *topology oriented* models. In the first one, addressed to visualization, topology and spatial relations are derived from the object structure, while in the second one, connected to analysis, relations are explicitly defined between one object and its neighbours (Zlatanova et al., 2002).

All the 3D vectors data models share the set of geometric primitives, structured in different way for every specific application (Abdul-Rahman, 2000; Coors, 2003; Molenaar, 1998; Pilouk, 1996; , Zlatanova, 2000).

The common components of any model are points, lines and solids.

The point is the most diffused in GIS environment, even if in real world there are a few entities that have not area or volume. The point is easily visualized in a three-dimensional space and is the basis for many spatial representations.

The line is a set of points connected as single one-dimensional primitive and, as the points, it is an abstraction of real objects. In the 3D space the lines are used to schematise for example cables, pipes, linear elements, without visualization of the height and the diameter or the thickness of objects.

The polygon defines a surface with common attributes and it is a two-dimensional primitive constituted by one or more closed lines. It is used to represent planes, surfaces or all entities that have a two-dimensional extension without thickness. Polygons are utilized also to create 2,5 D data: the TIN is the classical example of a polygons collection with a surface and without thickness, but with a variable height.

The solid is a primitive constituted by a set of closed polygonal faces. This is the true 3D primitive that could represent all the entities if it was easier implemented in GIS software. The definition of the order of border points in a solid is very complex and hard to implement in a geodatabase.

The hybrid mode for 3D representations, through the union of a 2D surface with a 3D ring (border of an object), is not suitable to conventional data processing of the next generation GIS (Ammoscato et al., 2006). On the contrary, a model strongly oriented to representation of three-dimensional objects in urban contexts is the *CityGML*, widely investigated by public and private research groups (Kolbe, 2005). This cartographic model uses five levels of detail to represent objects and permits the

insertion of texture, by using 3D virtual models aimed to sophisticated analyses in different application fields as simulations, urban data mining, facility management and also thematic complex queries. Moreover, it is implemented as application scheme for the international standard *Geography Markup Language 3 (GML3)*. Nowadays, the implementation costs of *CityGML*, even if they guarantees the creation of a real 3D GIS, are still expensive for an immediate applicability.

The *GML3* could represent one of the most innovative prospects towards the integration of complex and georeferenced geometries, but the instructions suggested by the *Open Geospatial Consortium (OGC)*, in order to define the structure of the information, the metadata, the types of geographical objects, the geometric and topological relations of the entities, are hardly implemented in practical applications because of their complexity.

In the light of the Italian and international experiences in 3D GIS context, this work proposes the evaluation of the capability of CAD software to manipulate three-dimensional Laser data and the properties of the *Multipatch feature type* in *shapefile* format to represent complex objects in GIS environment.

The 3D objects obtained with different procedures was next visualized with 3D GIS tools to verify the effective execution of thematic queries for the management and divulgation of information on Cultural Heritage.

2. DATA AND METHODS

2.1 The test site

The “Sassi” (stones) are a quarter of the Matera city, completely excavated in calcareous rocks. They constitute a primordial inhabited system clung along the slope of the “Gravina”, a deep valley with natural and rare characteristics.

In this place, populated from immemorial time, it's easy to recall the history of Man going to the paleolithic age, in the neolithic villages and the vast urban areas of the “Civita” and “Sassi”.

The architectural structure of this site is made of excavated caverns and constructions built with debris or tuff, that were derived from the rock excavation and next used to make and extend the place in front of the caves. In this way, marvellous examples of architecture, strictly connected between interior and external environments, arose from natural rocks..

In the last decade Unesco enlisted them in the World Heritage and more then 120 rock churches are considered one of the best representation of Architectural works of a certain complexity. The Byzantine frescos of such historical sites are in a good state of conservation, if we consider that they preserved their magnificence over the centuries without any preservation intervention.

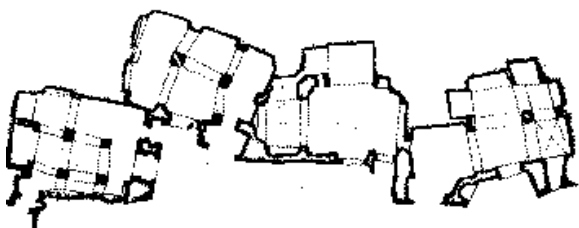


Figure 1. Plan of the rock churches of “Convicinio di S. Antonio” (XII-XIII centuries) in the “Sassi” of Matera city.

The test site selected for our study is the “Convicinio di S. Antonio” (XII-XIII centuries), that is a religious structure composed by three churches connected among them and carved into the rocks (Figures 1 and 2) with significant frescos and decorations.



Figure 2. Image of one of the nave of the “Convicinio di S. Antonio” churches

2.2 The Laser survey

The Laser survey was carried out with the aid of technology of the terrestrial Laser Scanner *Leica HDS 3000*, that it is able to extract in a fast way the third dimension of objects and makes high-definition field data capture easy and efficient.

Cyclone provided by *Leica Geosystem* was the processing software used for this study and considered most appropriate to manage a great amount of data of complex objects.

The system was set on high resolution grids (5 mm) and 90° as scanning angle for the historical details, while lower resolution and 360° as scanning angle for the completion areas and the whole coverage of the heritage were next scheduled (Figure 3).

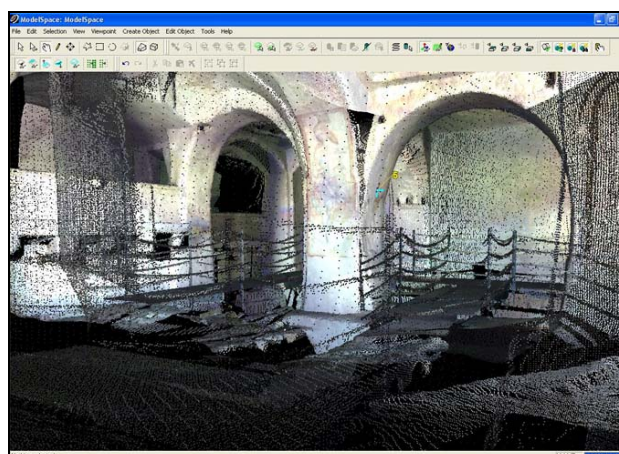


Figure 3. Laser acquisition with RGB data

After the preprocessing phase, all the scanings were aligned for the registration, each with its own reference system, assigning a new and unique one to each (reference frame). This operation was based on recognition of the control points materialized from natural and reflecting targets, surveyed with conventional topographic instruments.

Then the integration by identifying the overlap areas between the different scannings was executed, evaluating the confidence values calculated during the phases of pre-processing and which precedes triangulation (Balletti et al., 2005).

In the triangulation phase, every scanning was first transformed into initial low-resolution meshes and then refined until reaching a definite accuracy.

The great dimension of files derived from processing did not permit the creation of a single file with all the sections; however, since all are in the same global reference system, we worked on small groups of sections (Figure 4).

Once the detailed editing on each section was complete, the significant sections were imported into a new file for creation of the final model.

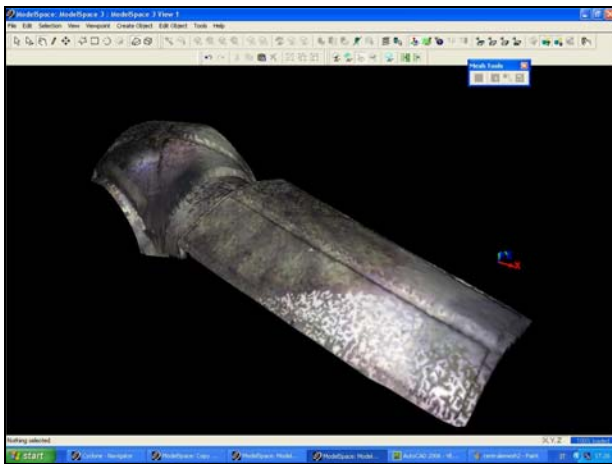


Figure 4. Data processing of single sections: the central roof nave of the rock churches of “*Convicinio di S. Antonio*”.

2.3 The Multipatch procedure for three-dimensional objects construction

The *Multipatch* is constituted of a combination of three-dimensional surfaces, similar to conventional objects (as points, lines, polygons) on *shapefile* format and alphanumeric attributes. Such objects can be encapsulated in a compact way and provide a real 3D visualization, by adding also textures on surfaces (Armit, 1971). This procedure is not yet utilized among GIS community because commercial softwares have not specific tools with spatial operators. The current version of *ArcGis-ArcInfo 9.2* had timidly introduced only a few functions for the editing of the *Multipatch*, without permitting the real development of feature type. Moreover, modern photogrammetric plotting, only using 3D points and polylines for object description, still does not permit the easy direct comprehension of 3D reality, except for a consequent time expensive editing work.

In order to build the *shapefiles* with *Multipatch* features type, in the second phase of the methodology we benefited from the efficient conversion facilities supported by *CAD2Shape*. The combined use of such tools with CAD softwares has many advantages and could have a rapid growth among GIS community, because basic cartographic data is prevalently spread in *.dwg* or *.dxf* formats.

The processing times of the *features* depend on level of details of objects to be represented for a peculiar application field (Caprioli et al., 2007).

In our case the complexity of the investigated entities had conducted to the subdivision of the entire heritage by using more *Multipatches* features, by executing the manual segmentation of homogeneous architectural elements (central, right and left front roofs, etc.). In this way the intrinsic limits of CAD softwares were overcome. Such instruments are still unable to manage a great amount of Laser data, producing mesh surfaces with no more of 32000 polygons, and make random subdivisions of objects with consequent useless editing processing.

The final product was a geo-database constituted of single 3D architectural units, further upgradeable with georeferenced thematic contents, in order to execute also complete spatial analysis in 3D visualization environments.

Figure 5 points out the univocal representation of every object with relative thematic information derived in 3D interactive visualizations by means of GIS query tools.

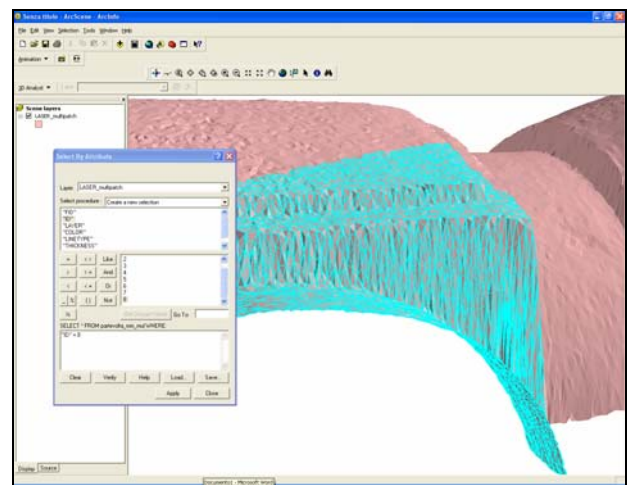


Figure 5. Alphanumeric information derived from 3D visualization on every *Multipatch* object

2.4 Conclusion

In this work the potentiality of integrated use of CAD-GIS tandem using the *feature type Multipatch* was evaluated.

One of our key objectives in testing of procedures was to propose to GIS community the interactive querying capabilities inside of 3D visualization and navigation systems, in order to use them for decision making and spatial data analysis in Cultural Heritage context.

The implemented features have the advantage to be simple and immediately usable in current GIS softwares and, as tested in other studies, they could efficiently allow the retrieval and the reuse of digital cartographic archives as basic data for many application fields. The possibility of inserting textures and images on *Multipatch* objects will make such procedures interesting also for photo-realistic rendering of complex objects.

Same critical elements in case of the implementation of a 3D GIS for architectural heritages were found. The main tested problem consists in increase of computational times of current PC on a 3D model derived from Laser scanning. Such aspect certainly will be overcome by the future advances in computer science.

Next, the other important aspect encountered in this study is the limits of current commercial GIS softwares and just in this

context many significant improvements could be made, producing new or in rewritten codex algorithms.

The diffusion of *Multipatch* objects will depend on commercial choices of CAD and GIS softwares and on the development of new 3D spatial operators, compatible with Laser data.

This work can be considered as a first step towards the use of terrestrial Laser data for the documentation and management of Cultural Heritages in a complete 3D GIS environment.

The effectiveness of the method in our case was however attained with time expensive apportioning work of a complex architectural structure, as the "Convicinio di S. Antonio" Churches. The single simplified objects consequently can be better studied and managed for further aims in different application fields of heritage conservation.

Molenaar M., 1998. An Introduction to the Theory of Spatial Objects Modelling, Taylor & Francis, London, pp. 1411–1420.

Pilouk M., 1996. Topologic data structure for a 3D GIS, PhD thesis, ITC.

Zlatanova S., 2000. 3D GIS for urban development, PhD thesis, ITC, The Netherlands, 222 p.

Zlatanova S., Rahman, A.A., Pilouk, M., 2002. Trends in 3D GIS development, Journal of Geospatial Engineering, 2, pp. 1-10.

AKNOLEGMENT

The authors are grateful for the precious collaboration to Gianni Abate and Michele Rubidio, land-surveyors of Leica Geosystem (Italy), and to Massimiliano Burgi, architect of Matera city.

REFERENCES

Ammoscato A., Corsale R., Scianna A., 2006. Cartografia Numerica Tridimensionale per GIS e WEB-GIS: verso la fruizione virtuale, Proceedings of SIFET Conference, 14 - 17 June 2006, Taranto, Italy, (unpaginated CD-ROM).

Abdul-Rahman 2000. A., The design and implementation of two and three-dimensional triangular irregular network (TIN) based GIS, PhD thesis, University of Glasgow, Scotland, United Kingdom, p.250.

Armit A., 1971. Multipatch and MultiObject Design Systems, Proceedings of the Royal Society London, Vol. A 321 p. 235.

Balletti, C., Guerra, F., Gerbaudi, F., 2005. The Survey of the wooden Structure of the roof of Palazzo Ducale in Venice. IAPRS, Vol. XXXIV, Part 5/W12, pp.49-53.

Caprioli, M., Figorito, B., Scognamiglio, A., Tarantino, E., 2007. Implementing the Features 3D Multipatch for the Management of Territorial Infrastructures, WIT Transaction on Ecology and Environment, pp. 853-860.

Brooks, S. and Whalley, J. L., 2005. A 2D/3D Hybrid Geographical Information System, Proceedings of ACM GRAPHITE, Dunedin, December 2005, (unpaginated CD-ROM).

Coors V., 2003. 3D GIS in Networking environments, Computer, Environment and Urban Systems, 27 (4), pp. 345–357.

ESRI Inc, 1998. Shapefile Technical Description An ESRI White Paper p.20-24,
<http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf>.

Kolbe H., Gröger G., Plümer L., 2005. CityGML- Interoperable Access to 3D City Models, Proceedings of "International Symposium on Geoinformation for Disaster Management", 21-23 March 2005, Delft, Netherlands (unpaginated CD-ROM).