3D GEOMETRIC AND SEMANTIC MODELLING IN HISTORIC SITES

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XVII CIPA International Symposium, October 3-6, 1999, Olinda, Brazil.
WG2 : Cultural Heritage Information Systems

KEY WORDS : documentation, 3D information management, digital stereorestitution, CAD, geometric modelling, semantic modelling

ABSTRACT

The modelling of 3D objects in surveying and particularly of historic monuments is generally mainly based on geometry. We propose in this paper a new approach to the problem of modelling in which the semantic structure combined with the geometry is the root of the 3D model. We decompose the space concerned by the modelling into different "semantic concepts" that include a semantic structure. The semantic structure is the foundation of knowledge and composition rules which can be implemented to help the semi automatic geometric reconstruction of the different objects.

For the modelling of historic monuments located in urban areas, we consider two steps :

- from aerial photographs, we proceed at first the geometric and semantic modelling of the urban objects of the area, including the restitution of the visible parts of the monument plotted in the top view. These objects are directly integrated in a Topographical Information System;
- with the help of architectural photogrammetry, we then define accurately the monument with its geometry and the semantic aspects of its details. The restitution is based on small and medium format photographs acquired on site. These objects are integrated in the Architectural Information System specified for the monument.

We apply this concept to the modelling of the area of Sayeda Zienab in Cairo (Egypt), where the 2 km long Aqueduc El Ghuri constructed in 1311 is located. The data acquisition is realized by using a low cost PC and Windows based system for digital stereophotogrammetry 'TIPHON' developed at ENSAIS-LERGEC, interconnected to the CAD-GIS software package Microstation/Geographics and the ACCESS relational data base.

RESUME

La modélisation des objets topographiques tridimensionnels et plus particulièrement des monuments historiques est généralement basée sur des principes géométriques. Nous proposons dans cet article un nouveau principe dans lequel la structure sémantique associée à la géométrie est la base de la modélisation. L'espace est décomposé en différents ''concepts sémantiques'', chaque concept comprenant une structure sémantique inhérente. Cette structure est à la base de connaissances et de règles de composition qui peuvent être programmées pour aider à la reconstruction géométrique semi-automatique des différents objets.

Pour la modélisation des monuments historiques situés en milieu urbain, nous considérons deux étapes:

- la restitution des photos aériennes, qui nous permet de procéder dans un premier temps à la modélisation géométrique et sémantique des objets urbains du quartier en question, en incluant les parties visibles du monument vu de dessus. Ces objets sont directement intégrés dans un Système d'Information Topographique;
- à l'aide de la photogrammétrie architecturale basée sur des images de petits et moyens formats, nous pouvons ensuite restituer les détails géométriques du monument en considérant ses aspects sémantiques. Les objets restitués sont intégrés dans le Système d'Information Architectural défini pour le monument.

Nous avons appliqué ce concept à la modélisation du quartier de Sayeda Zienab au Caire (Egypte) où se trouve l'aqueduc El Ghuri construit en 1311. L'acquisition des données a été réalisée à l'aide du système de photogrammétrie numérique TIPHON développé au LERGEC-ENSAIS, interfacé avec les logiciels Microstation/Geographics et la base de données relationnelles ACCESS.

ZUSAMMENFASSUNG

Die Modellierung von dreidimensionalen topographischen Objekten und besonders von historische Monumente ist vorwiegend auf geometrische Prinzipien basiert. In diesem Artikel stellen wir eine andere Art von Modellierung vor in der eine semantische Struktur der Geometrie zugegeben ist. Die Objektzone ist in mehrere semantische Konzepte zerteilt, jedes Objektteil enthält eine eigene semantische Struktur. Solch eine Strukturierung erlaubt die Definition von Regeln und von wissensbasierte semi-automatische Rekonstruktionen der Geometrie der Objekten.

Zur Modellierung von historischen Monumente in Stadtlandschaften brauchen wir zwei Arbeitsschritten :

- die Auswertung von Luftbildern. In diesem Schritt wird die semantische und die geometrische Modellierung aus den von oben gesehenen Monumentteile entwickelt. Diese Objektteile werden gleichzeitig in ein topographisches Informationssystem gespeichert;

- mit den Mittel der Architekturphotogrammetrie die sich auf klein Bilder und mittelformat Bilder stützt, können wir dann die geometrische Details des Monumentes auswerten und deren semantische Eigenschaften anhängen. Die gemessenen Objekten sind in das architekturs Informationssystem des Monumentes verwaltet.

Wir haben dieses Konzept zur Modellierung des Sayeda Zienab Viertel in Kairo (Ägypten) in dem sich das Aquädukt El Ghuri (1311) befindet benutzt. Das TIPHON Softwarepaket (LERGEC-ENSAIS) wurde für die Auswertung und Microstation/Geographics mit ACCESS als Datenbank für CAD/GIS System verwendet.

RETURN

1. INTRODUCTION

1.1 General remarks about GIS

Increasing needs to scientifically understand, preserve, protect, and manage historic monuments and archaeological sites, demand new methods of documentation and management with accurate, collective and updated knowledge [Nour El Din, 1997].

Improvements in data acquisition and processing make it possible to create absolute 3D monument models. But handling of 3D data in historical monuments and sites is problematic due to the complexity of the objects geometry, the diversity of attribute information and the large amount of topologic and semantic data.

3D Geographic Information systems help on this systematization. GIS are currently in use in territory and city management, but very often the structure of buildings and monuments is not implemented.

In this paper we propose a new approach to the problem of systematization of 3D geometric and semantic modelling for historic sites and monuments. We decompose the space into different semantic concepts. 3D objects are hierarchically decomposed into basic elements.

This decomposition allows:

- Semi automatic geometric construction of the different objects closely connected to photogrammetric data acquisition;
- An enhanced data model which allows the representation of spatial data hierarchies.

1.2 3D-GIS applied to historic sites in urban areas

Photogrammetry provides advantages for the documentation of heritage buildings and sites. Data acquisition depends at the beginning on the hierarchic decomposition of the monument and the objects located in the area.

We present in the paper the modelling of the area of Sayeda Zienab in Cairo (Egypt), where the 2 km long Aqueduc El Ghuri is located. The first part of this monument (pumping station) was constructed by Sultan Al-Nassir Mohamed in 1311. But the construction was only finished in 1415 (figures 1, 2) by Sultan El-Ghuri to flow water to the citadel some kilometers further.

Figure 1. Engraving of the Aqueduct El Ghuri (1415) in Cairo, view from the Nile.

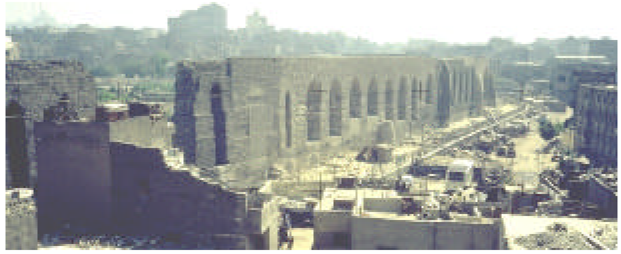

Figure 2. Overall view of the Aqueduct

The paper will discuss the two different steps of modelling:

- from aerial photographs, we proceed at first the geometric and semantic modelling of the urban objects of the area, including the restitution of the visible parts of the monument plotted in the top view. These objects are directly integrated in a Topographical Information System;
- with the help of architectural photogrammetry, we then define accurately the monument with its geometry and the semantic aspects of its details. The restitution of objects is based on small and medium format photographs acquired on site. These objects are integrated in the specific Architectural Information System of the monument.

The change of scale between aerial and terrestrial photographs has to be considered as well as the relations between the Topographical Information System and the Architectural Information System.

2. GLOBAL MODELLING CONCEPTS

2.1 Origin of the modelling concepts

A lot of new applications directly linked with the acquisition, the management, the analysis, the representation of geo-located data have been presented in the last ten years.

It is widely known that in GIS co-exist three levels of information and data processing : the geometric level, the topologic level and the semantic level for the thematic description of the objects.

The measurement techniques are qualified to deal with the geometry. In our application, photogrammetry is the most efficient way to get the geometry of the objects.

Topology is included in the geometry and is strongly dependent on the data structure.

Our application takes also advantage of the semantic and descriptive aspects of the data. In fact, it could be a very efficient aspect in the working out of a global concept for modelling. The whole semantic part is managed in a relational database.

The overlapping of these three concepts is as strong as the complexity of the information is high. And this is particularly verified in the case of 3D objects.

The third dimension is very important in environments where this additional information is in position to improve highly the system efficiency. This is especially verified in urban landscapes where the objects structuring the space have a third dimension, in this

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case a height, as tall as the planimetric dimensions [KOEHL, M., 1999], or when the system has to manage a particular object with great dimensions, which is the case with the Aqueduct El Ghuri in the area of Sayeda Zienab in Cairo (Egypt).

2.2 Data structuring

The basis of such a system is the information that has to be managed. That information contains geometric, topologic and semantic characteristics.
To design such a system it is necessary to start with data acquisition and, in the same time, structure data along with the different approaches.
The developed 3D modelling method comprises in a structuring way the geometric, topologic and semantic definition of the different objects (figure 3). In this case, each principal concept has a structure as a pseudo-hierarchic decomposition [Koehl & Grussenmeyer, 1998].
The object, the major concept, is located on the n-level, intermediate level between a global concept (semantic concept) and a (geometric) point measured by an operator as the data acquisition. Each level contains in a more or less significant way a geometric, topologic or semantic characteristic.

This predefined structure is then used by the operator in its work of data acquisition.
A first step consists in modelling from the geometric point of view: geometric construction rules make it possible to reconstruct the object and to insert it directly in a Topographic Information System or Architectural Information System.
A second step consists in modelling the objects using their semantic aspects which allow to define structural rules for their constitution.

2.3 Method for data acquisition

The principal method used for the fulfillment of a Topographic Information System is the photogrammetric stereorestitution with aerial photographs.
The reconstruction of the objects is based on the measurements done by an operator. The restitution is made with the digital photogrammetric software package TIPHON developed at the ENSAIS-LERGEC [Grussenmeyer & Koehl, 1998].
The reconstruction is completed by using CAD engines in which the 3D tools were optimized to take into account the specifications of the modelling method.
This modus of restitution with aerial photographs enables only to get details of the object which are visible from the top view.

2.4 Extension of the concepts

Other concepts, more abstract, could be integrated in the model. When the scale is modified, the point of view of the photographs is different, the detailing grade is greater. We can then move from a Topographic Information System to an Architectural Information System.

3. 3D TOPOGRAPHIC INFORMATION SYSTEM

3.1 Definition of objects in an historic site

A Topographic Information System is a system which manages and represents data for the description of a part of the earth. In historic sites there are artificial objects with complex architectural features which have

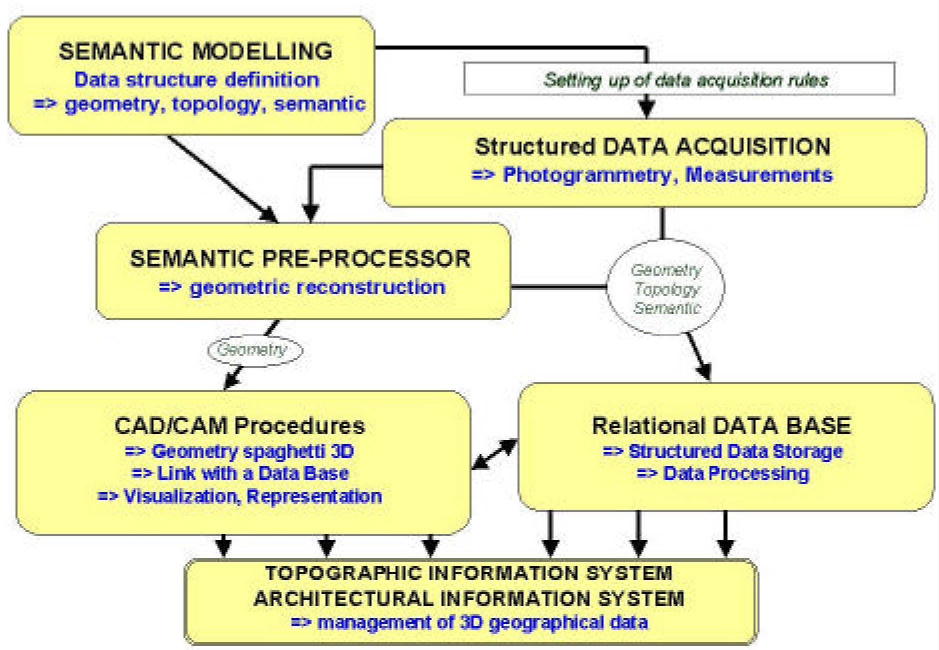

Figure 3. Modelling concept combining geometry, topology and semantic [Koehl, 1999].

to be taken into consideration for geometric representation as well as for thematic structure. In the Sayeda Zienab area used as an example in this paper (figure 4), 9 principal elements classified in 3 categories have been considered for the thematic structuration:

- Category of Digital Terrain Model (DTM), elements used for the definition of the DTM were:
  - Relief
  - Hydrology
  - Roads
- Category of accessories : we consider simply objects usable for 3D visualization:
  - Vegetation
  - Signals
  - Urban furniture
- Category of 3-D complex objects:
  - Monument
  - Building
  - Construction

The method presented uses two majors groups of data:

- DTM and the surface objects: natural features which lie on the surface, e.g. streets, paths, etc.;
- 3D complex geometric objects: the most important objects in the historic sites are the buildings and the monuments.

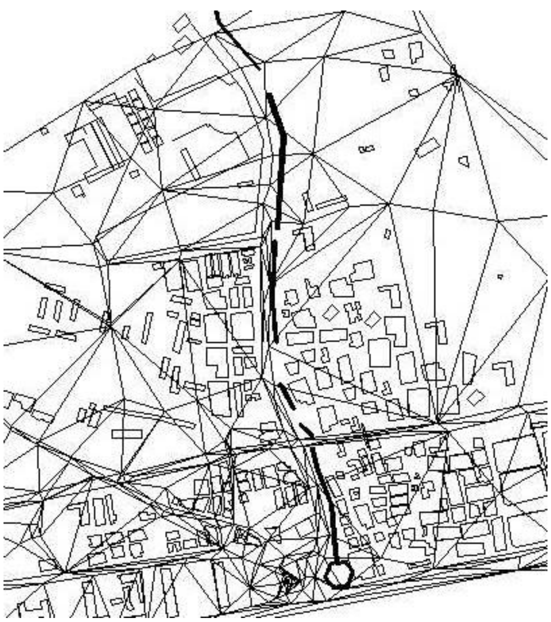

Figure 4. Area of Sayeda Zienab
DTM, buildings and topographic objects, with the DTM built from relief and roads

3.2 The structure of the data set

3.2.1 The structure of the DTM

In a 3D complex geometric model the basic structure is a DTM. Two basic methods can be used for representation of the DTM:

- regular grid
- Triangular Irregular Network (TIN)

The TIN gives the best presentation of the relief in case of rough terrain like the Sayeda Zienab area. The points co-ordinates are obtained from the stereomodel or measured in the field by geodetic means. The triangulation is done in the Microstation CAD system. This DTM is the ground surface onto which all the complex 3D objects are projected.

3.2.2 The 3-D complex objects

The most important complex objects are the buildings and the monument itself. The buildings are described using faces. In our application, the shape of the building will be reduced to a simple 3D bloc. It means that the rooftops are considered flat, the faces can be deducted from the housetops by a vertical projection of their shape onto the DTM. A 3D building generator has been developed to apply the following procedure :

1- Measurements of roofbuildings as lines and polygons feature from the aerial photographs
2- The outline corner points of the roof are extracted and projected perpendicularly onto the DTM (figure 5). The *façades* of the building are in generally not visible in the photos.
3- The generation of the *façades* is achieved automatically through a Graphical User Interface (GUI) inside the Microstation-J environment.

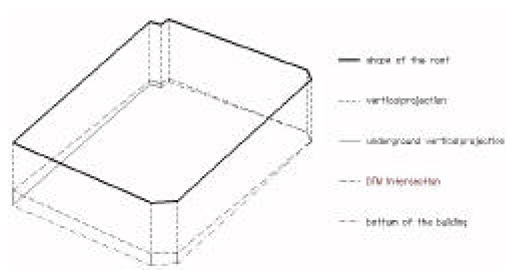

Figure 5. A reconstructed building

3.3 3D data acquisition

The data acquisition of the site objects is obtained using both aerial photographs and geodetic surveying techniques. Photogrammetric processing of aerial images produce the main graphical information. One single couple of 1/10000 photographs taken by a Zeiss RMK TOP camera covers the area of our study. About twenty ground points were measured in the field by using both total-station and GPS. The stereoplotting is done by digital photogrammetric software TIPHON (figure 6). The photogrammetric tools are coupled with a CAD system to acquire interactively the visible parts of the objects and to achieve the reconstruction by using 3D-CAD tools and 3D model generation application. The CAD software used as the graphical engine of the application is Microstation/J. The GIS software is Microstation Geographics/J also proposed by Bentley and running within Microstation. The database management system used is Microsoft Access.

Figure 6. TIPHON software package for digital photogrammetry

3.4 Automated generation of the buildings

Generating 3D description of buildings from aerial photographs involves two major components:

- photogrammetric measurements to produce a DTM and the roof of the buildings;
- automated structuring.

Using the Java tools, an integrated interface has been developed (figure 7). It uses the GUI components of AWT, Swing and Borland packages.
The GUI is divided into four main parts, as follows: DTM, Building generation, Results and Database Integration.

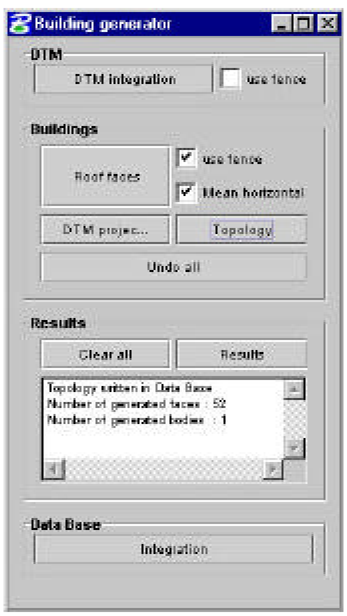

Figure 7. Application's GUI (Building generator)

3.5 The topologic modelling

In the general case the topologic modelling concerns the objects of the DTM category (Relief, hydrology, roads) and the category of the 3D complex objects (Buildings, monuments, constructions). The specific elements of the topology are nodes, arcs, faces and loops for the first categories and are completed with the bodies which concern the second categories. In our project (figure 8), the topologic modelling is only made of objects with a real third dimension. Each 3D complex objects are automatically codified and topologicaly decomposed into two-dimensional elements (roof, faces, etc.). These elements can themselves be decomposed into one-dimensional objects (the edge which are linear elements), at last each linear element is defined by a beginning and an end nodes which are 0-D objects. This topologic decomposition offers the possibility of creating a table containing the topologic structure of 3D complex objects.

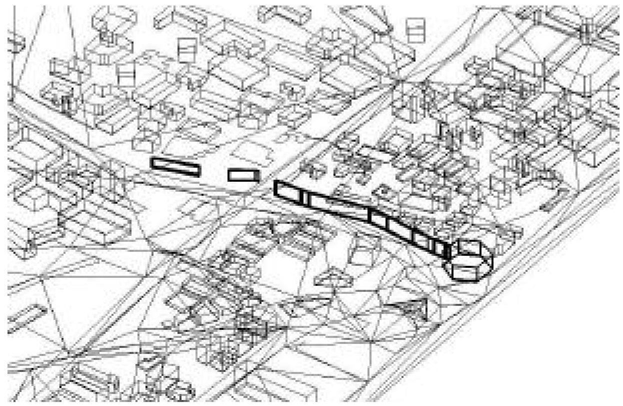

Figure 8. 3D view of part of the area

3.6 The Thematic Modelling

The thematic structure allows to complete the definition of the topographic objects with a thematic description. In Sayeda Zienab area the thematic modelling is implemented by using the relational database. The different type of objects are classified in predominant thematic classes. The structure of this thematic classes is a hierarchical structure and each thematic class includes the methods that allows the

- data acquisition
- update of the data
- querying and editing of the description data

The generic shapes are structured as aggregation of objects which have themselves a thematic signification. Each object in a thematic class is constituted of object components that inherit the main properties of the mother thematic class and that have themselves a structure of a thematic class. In this way, it is possible to go from a thematic class to all thematic classes of the object components.

4. FROM TOPOGRAPHIC INFORMATION SYSTEM TO ARCHITECTURAL INFORMATION SYSTEM

Until now we have mainly presented the results given by aerial photogrammetry. The second step of our modelling method is the integration of geometric and semantic details of the monument available by architectural photogrammetry.
The complexity of historic monuments requires special and adapted methods for their measurement survey.

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For the documentation of the monument, it is important to create architectural drawings of the *façades* and measure every visible details in the monument. Working with large scale architectural photogrammetry allows to provide architects with the essential data sets for a detailed documentation of the building.
The scale factor plays a very important role in the geographic information system. The change of the scale between the different types of data (figure 9) may cause changes in the field of application and transformations of the type of information system. In our project, the big difference between the scale of aerial and terrestrial photographs has to be considered as well as the relations between the Topographical Information System of the area and the Architectural Information System of the monument. The number of details required and the type of thematic classes are the bases of the Information System.

3D Data Acquisition	3D Modelling	Type of System
Aerial photogrammetry Image scale (1/10000)	3D geometric, topologic and semantic modelling of area	3D Topographical Information System (TIS)
Architectural photogrammetry Image scale (1/100 –1/500) Small and medium format	Accurate definition of the monument with geometry, topologic and semantic aspects of its details.	3D Architectural Information System (AIS)

Figure 9. Change of scale between TIS and AIS

5. ARCHITECTURAL INFORMATION SYSTEM

5.1 Definition and field of application

An Architectural Information System is a system which includes concepts of acquisition, data processing and methods of 3D modelling usable to manage, display and analyze highly accurate data with geometric, topologic, and semantic details.
This type of Geographic Information System applied to a monument has a lot of thematic fields of application :

- Civil engineering:
  - Collecting the different materials that make up the building (stone, ceramic, metal, wood pieces, glasses, mortar, etc.);
  - Characterizing them in detail by their physical, chemical, mechanical variables;
  - Determining the damage they have suffered through the years due to external action.
- Archaeological research:
  - The synchronic dating of the analyzed constructed parts;
  - The better understanding of why and how the building has reached us in this way;
  - The reading of the constructive parameters and the registration of the constructive phases.
- Analyze of the state:
  - Study of the previous use of the building;
  - The possible solution in the future;
  - The restoration project of the building;
  - Re-use of the building in better conservation condition.

These large amount of data has to be organized and integrated in the Information System. We try to apply the concept presented in §3 to the monument by geometric, topologic and semantic definition of its objects.

5.2 3D data acquisition

El-Ghuri's aqueduct is an impressive monument (about 2 kilometres long and 20 meters high at some parts). Site photography was obtained using approx. 600

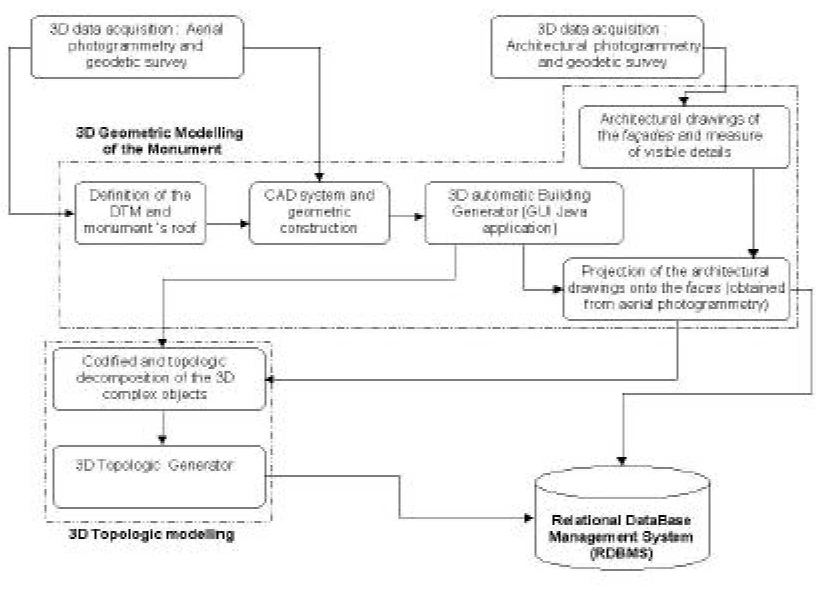

Figure 12. Steps of the geometric and topologic modelling

photographs. They were taken with semi-metric and metric cameras: Wild P32 (6cm*9cm), Pentax 67 metric (70mm*60mm), Rolleimetric 35 (24mm*36mm). The control points (approx. 200) and topographic map of the area were realized by using geodetic techniques, in the same co-ordinate system used for aerial photographs.

Figure 10. Rolleimetric35 image (Aqueduct El Ghuri)

5.3 3D geometric and topologic modelling

The 3D modelling of the Aqueduct was realized with photogrammetry tools [Nour El Din, Koehl, Grussenmeyer, 1999]. The plotting of about 40000 square meters of *façades* (figure 11) was made with ZEISS P33 stereoplotters. The digital photogrammetric software TIPHON was also used. After the definition of an adapted structure of the data sets, all plotted elements are integrated in the CAD software Microstation. A special problem is raised when using very large scale images (terrestrial) because many details are available from such images.

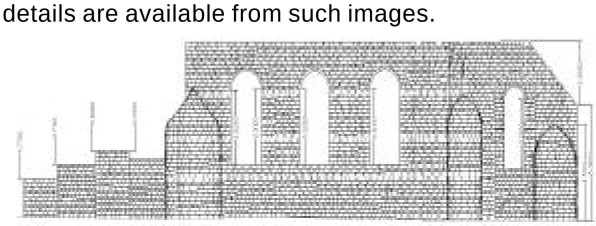

Figure 11. Example of photogrammetric restitution.

After the generation of a 3D model of the aqueduct from the aerial photographs (see §3 for the projection of the aqueduct's roof on the DTM), we consider the details for each *façade* (face) obtained by architectural photogrammetry stereorestitution.
For the restitution of the aqueduct we have two different cases depending on the area around the monument:

- The North *façade* of the aqueduct was completely photographed, and the stereorestitution was done using Zeiss P33 stereo-plotters
- For the South *façade* several problems occurred because buildings are very close to the monument. It was often impossible to take photos nearly perpendicular to the *façades* and to use stereophotogrammetry. We used digital rectification methods (Rollei MSR software) and the TIPHON software.

For the modelling, the monument is our major concept and is located in the n-level which has a structure as a pseudo-hierarchic decomposition. At first level of the concept there is the 3D complex form of the whole monument. At another level it could be the walls or the windows, at the last level we have the points (nodes) measured by architectural photogrammetry in x,y,z (geometric concept). In this way, each complex object can itself be a composition of complex objects (to codify and decompose topologically into 2D elements like faces, etc.). These elements can themselves be decomposed of one-dimension objects (the edges which are linear elements), at last each linear element is defined by a node as a 0-D object (figure 13). Generating and structuring the objects can be automated by a kind of object generator (like the building generator in §3.4).

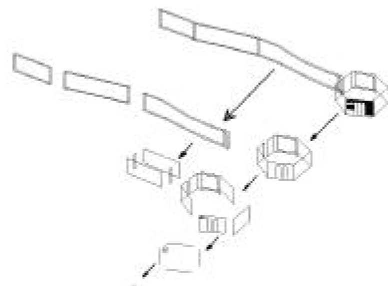

Figure 13. The hierarchical structure (aqueduct)

The integration between architectural photogrammetry and the Microstation Geographics/J software from Bentley is the platform on which the Architectural Information System is built by integrating the thematic and descriptive data to the 3D geometric model of the monument.

5.4 Thematic Modelling

With the very large amount of details, the production of the thematic structure becomes highly complicated as they are in 3D models, where topologies are infinitely more complicated. The thematic modelling is organized in the relational database management system like in the TIS. This thematic structure covers the different connections of the decomposition for the elements drawn by photogrammetric restitution. The relational database management system keeps the relational integrity of the database, and this will allow a continuous updating of the contents.

6. CONCLUSION

The proposed method for 3D geometric and semantic modelling of sites and monuments is linked to photogrammetric restitution in order to automate the reconstruction of objects corresponding to a semantic concept. The Topographical Information System (obtained by aerial photogrammetry of an area) and the Architectural Information System (obtained by terrestrial photogrammetry of the monument) is created by this first step and then completed with the semantic details.
The combination of aerial and architectural photogrammetry raises the scale difference between the images and the level of details available. For the test area of Sayeda Zienab located around the aqueduct El Ghuri in Cairo (Egypt), the tools developed for the

RETURN

generation of objects of the Topographical Information System are operational. These tools are adaptable:

- to more complex roof shapes for example (depending on the buildings of the area)
- to monuments to be modelled by terrestrial stereorestitution in the Architectural Information System.

The development of different 'objects generators' based on global modelling concepts (combining geometry, topology and semantic) is bound to take more and more importance and to reach new fields of application. These systems are full of advantages for setting up 3D Information Systems, especially those dedicated to historic sites and monuments.

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