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## MODELLING HISTORIC SITES AND MONUMENTS IN 3D HERITAGE INFORMATION SYSTEMS BY COMBINING AERIAL AND ARCHITECTURAL PHOTOGRAMMETRY

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TC V-8 Site recording and modelling  
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**KEY-WORDS:** Architecture, CAD, Database, Modelling, Spatial database, Topology, Urban objects

### ABSTRACT

The modelling of 3D objects in surveying and particularly of historic monuments is generally mainly based on geometry. Our aim is to extend the modelling approach of 3D complex geometric monuments by integrating the semantic structure in combination with geometry. We propose a method for 3D geometric, topologic and semantic modelling of sites and monuments which is linking aerial and architectural photogrammetric restitution. The elements to be modeled are decomposed into different "semantic concepts" that include a semantic structure. One of the objectives is to automate the reconstruction of objects corresponding to semantic concepts. The Topographical Information System of the area (obtained by aerial photogrammetry) and the Architectural Information System of the monument (obtained by terrestrial photogrammetry), is created by this first step and then completed with the semantic details. The data acquisition is realized by using a low cost PC and Windows based system for digital stereophotogrammetry "TIPHON" developed at ENSAIS-LERGECE, interconnected to the CAD-GIS software package Microstation/Geographics and the ACCESS relational database. Our method has been tested on two projects :

- the first one is in Cairo (Egypt) in the Sayeda Zienab area around the aqueduct El Ghuri;
- the second one is located in Strasbourg and applied to buildings constructed at the end of the last century (zoological museum).

The tools developed for the generation of objects in the Topographical Information System are adaptable :

- to different kinds of roof shapes (depending on the buildings of the area);
- to monuments to be modelled by terrestrial restitution and integrated in the Architectural Information System.

### RESUME

La modélisation tridimensionnelle des objets topographiques et plus particulièrement des monuments historiques est généralement basée sur la géométrie. Notre but est d'étendre la modélisation géométrique des monuments 3D complexes en intégrant la structure sémantique associée à la géométrie. Nous proposons une méthode pour la modélisation géométrique, topologique et sémantique tridimensionnelle des sites et des monuments, associée à la restitution photogrammétrique aérienne et architecturale. Chacun des éléments à modéliser est décomposé en différents " concepts sémantiques " incluant une structure sémantique. Un des objectifs est d'automatiser la reconstruction des objets correspondant aux différents concepts sémantiques. Les Systèmes d'Information Topographique (obtenu par photogrammetrie aérienne d'une zone) et les Systèmes d'Information Architectural (obtenu par photogrammetrie terrestre du monument) sont créés par cette première étape, puis complétés par les détails sémantiques. L'acquisition des données a été réalisée à l'aide du système de photogrammétrie numérique TIPHON développé au LERGECE-ENSAIS, interfacé avec les logiciels Microstation/Geographics et la base de données relationnelles ACCESS. Pour tester notre méthode, nous avons travaillé sur deux projets:

- le premier est au Caire (Egypte) dans le quartier de Sayeda Zienab autour de l'aqueduc EL Ghuri;
- le second est situé à Strasbourg et appliqué aux bâtiments construits à la fin du siècle dernier.

Les outils développés pour la génération des objets du système d'information topographique sont adaptables:

- aux différentes formes de toit (selon les bâtiments d'une zone considérée) ;
- aux monuments modélisés par photogrammétrie terrestre pour leur intégration dans le Système d'Information Architectural.

### 1. INTRODUCTION

The increasing needs of an accurate and updated knowledge of monuments and historical sites demand an especial information system. The Architectural Information System (AIS) helps in this systemization and includes concepts of acquisition, data processing and modelling usable to manage, update and analyse large amount of geometric, topologic and semantic data. This type of Geographic Information System applied to a monument has a lot of thematic fields of

application in civil engineering, Archaeological research, to analyze the state of the monument and the urbanization of the historical site. We propose a method for 3D geometric, topologic and semantic modelling of sites and monuments which is based on aerial and architectural photogrammetric restitution. For the modelling of buildings and historic monuments located in urban areas, we consider two steps :

- from aerial photographs, we proceed at first the geometric and semantic modelling of the 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 Topographic 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.

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 (Grussenmeyer et al., 1999). This paper is focused only on the data structuring and modelling in the Architectural Information System.

## 2. GENERAL CONCEPT

The semantic and descriptive aspect of the data is also exploited, whereas it is too often neglected in the different existing concepts because it is directly depending on the choices of management defined by the users. Indeed, it can be a very significant aspect for the development of a global concept of modelling. The architectural objects concerned by the modelling are decomposed into different semantic concepts. In this paper, our major concept is the monument which has a pseudo-hierarchic decomposition structure. The 3D complex form of the whole monument is the first level of the concept (figure 1). At another level are the walls or the windows, at the last level we have the points (nodes) measured by architectural photogrammetry in x,y,z (geometric concept). With these very large amount of details, the production of the thematic structure becomes highly complicated as they are in 3D models. This thematic structure covers the different connections of the decomposition for the elements drawn by photogrammetric restitution. The thematic modelling is organized in the relational database management system. The relational database management system keeps the relational integrity of the database, and this will allows a continuous update of the contents.

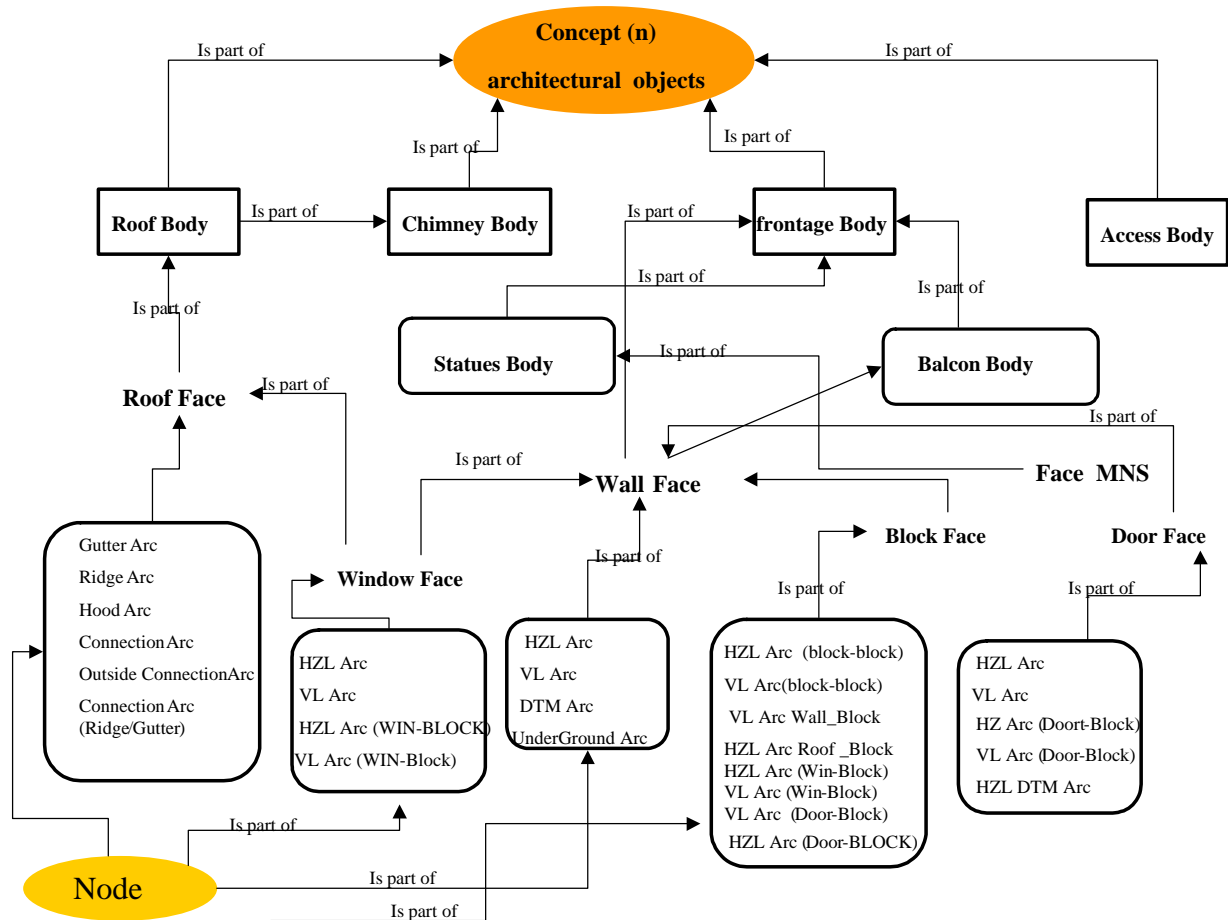


Figure 1 : Pseudo-hierarchic structure of architectural objects

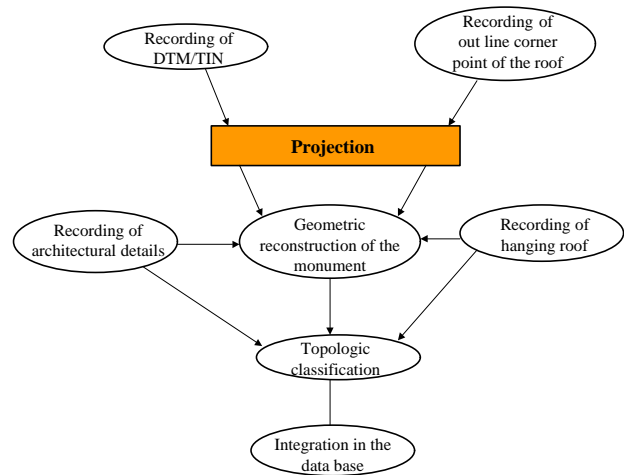
## 2.1. Data structuring

The information about the monument is structured into three major levels: geometric, topologic and semantic. The lowest level is the geometric level. It aims to represent information about position, shape and size of the object. In our application, photogrammetry is the most efficient way to get the geometry of the object. The second level is the topologic level which is included in the geometry and strongly dependent on the data structure. The type of the object is defined on the first level (semantic level), this data structure consists in modelling the objects using their semantic aspect. 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 (Koehl, 1999).

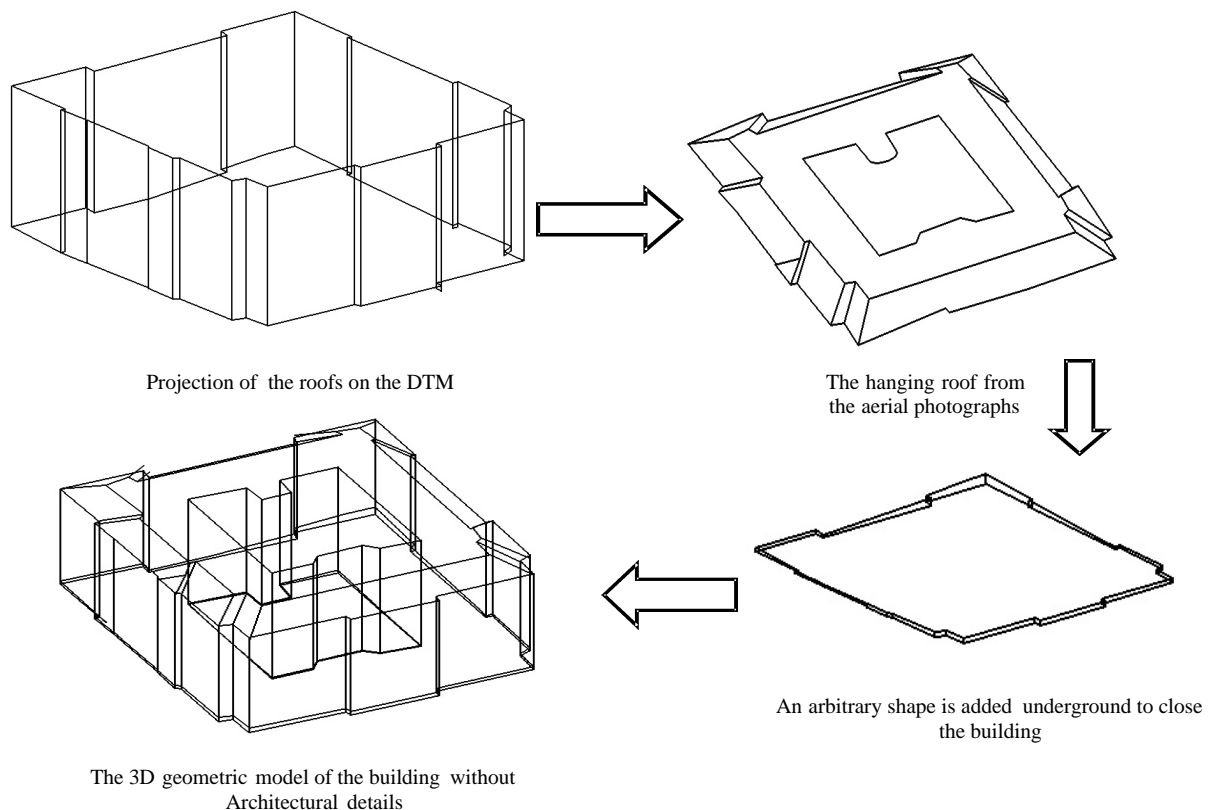
## 2.2. Presentation of the modelling method

The procedure is based on the architectural and aerial photogrammetric data acquisition, and involves several steps (figure2) :

1. We assume at first that the buildings have only vertical walls without windows and doors and without hanging roof;
2. The outline corner points of the roof are then extracted and projected perpendicularly onto the DTM;
3. An arbitrary shape is added underground to close the building. This shape is simply a copy of the roof shape corresponding to the lower projected point;
4. The hanging roof is added and automatically codified and integrated in the information system (figure 3);
5. The architectural details are integrated to different faces of the building and automatically codified and completed the different details of the monument faces.



**Figure 2** : Steps of geometric and topologic modelling

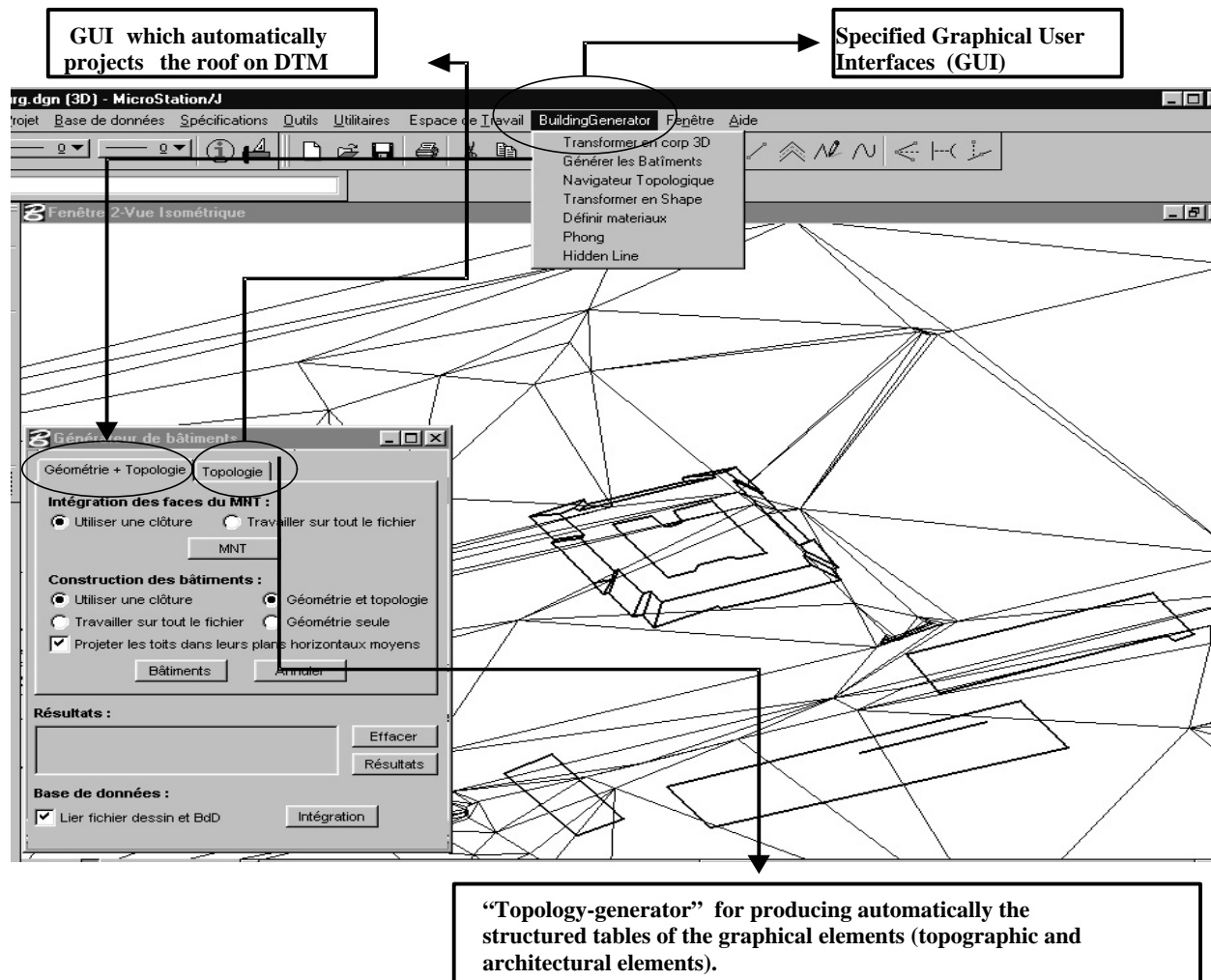


**Figure 3** : The main steps for the 3D geometric modelling of the building

### 2.3. Prototype for the Modelling of 3D objects

One of our objectives is to automate the reconstruction of objects corresponding to semantic concepts. Specified Graphical User Interfaces (GUI) have been developed and integrated in the general shape of Microstation-J tool boxes (Figure 4). These tools are mainly:

- A “building-generator” which automatically completes the shape of the building by projecting the roof on DTM;
- A “generator of architectural details ” which automatically completes the different details of the monument’s faces;
- A “Topology-generator” for producing automatically the structured tables of the graphical elements (topographic and architectural elements) in the CAD environment.



**Figure 4 :** Application's GUI (Generators of Building and Architectural Details)

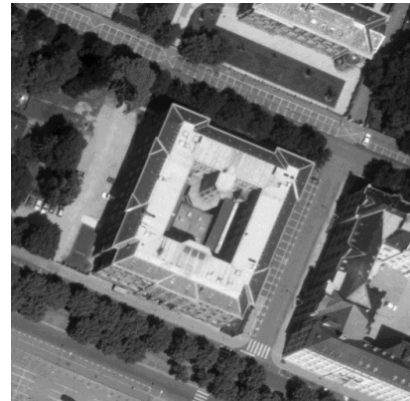
The data acquisition is realized by using a low cost PC and Windows based system for digital stereophotogrammetry 'TIPHON' developed at ENSAIS-LERGE. The photogrammetric tools are coupled with a CAD system to achieve the reconstruction by using 3D-CAD tools and 3D model generation application. The DTM points and the outline of the roof building is obtained using both aerial photographs and geodetic data. The 3D acquisition of the monument faces and details was realized by architectural photogrammetry (based on small and medium format photographs acquired on the site). The CAD software used as the graphical engine of the application is Microstation/J. The GIS software is Microstation Geographics/J and running within Microstation. The database management system used is Microsoft Access. After the generation of the 3D model of the monument from the aerial photograph, we consider the details for each façade obtained by architectural photogrammetry stereorestitution, and all this large amount of data has to be automatically organised, codified topologically and integrated in the information system as described above.

The method has been tested on two projects :

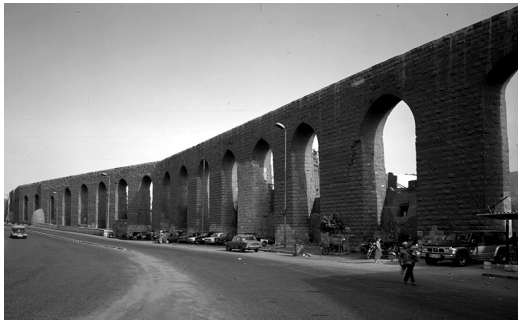
- the first one is in Cairo (Egypt) in the Sayeda Zienab area around the aqueduct El Ghuri (figures 5a, 5c,9 and 10);
- the second one is located in Strasbourg and applied to buildings constructed at the end of the last century (figures 5b, 5d and 8).



**Figure 5a:** Aerial view of the Aqueduct area (Cairo, Egypt)



**Figure 5b:** Aerial view of the Zoological Museum (Strasbourg, France)



**Figure 5c:** Overview of the aqueduct El Ghuri



**Figure 5d :** The zoological museum

### 3. DATA PROCESSING

Three major groups of data are used:

- DTM and 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;
- Architectural details.

Processing of different types of data involve several steps, which finally leads to the construction of a 3D topologic model to be integrated in the database. The procedure depends on the different categories to be processed (DTM, Building, Roof, windows, etc.), and on the feature of each category (façade of DTM, wall, etc.). Our prototype system allows simple coding of semantic information by numbering of building or type of surface and line objects, to be recorded when the procedure starts.

#### 3.1. Digital terrain model (DTM)

The DTM is one of the main components of the system. It is used to define and build the ground terrain surface , and also to form and build complex surface shapes. The points co-ordinates are obtained from the stereomodel or measured in the field by geodetic means.

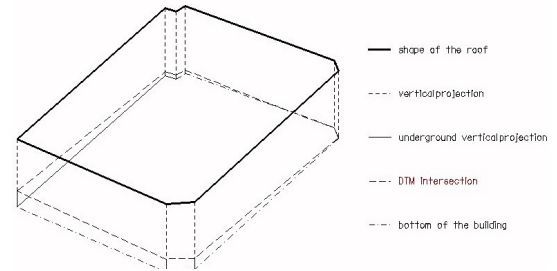
The processing of the DTM data involves two main steps :

- Temporary recording for the DTM faces;
- Topological decomposition to: node, edge and face.

### 3.2. Building

The main steps of the algorithm for constructing 3D geometric model of the building are (figure 6) :

1. The roof edges elements are looked for and written in the temporary structure. All closed string of roof edges are considered as roof faces. If the user chooses this option, the graphical elements of each face can be redrawn in an average height plan. At this step, the DTM and roof faces are known, so the projection of the roofs on the DTM is possible;
2. Then, using the previously recorded structure, the traces of the roof edges projected vertically on the DTM faces are computed and drawn in the DGN model. The vertical wall edges and the "bottom" face are drawn. While these elements are being drawn, they are also given a GeoGraphics feature. These features will be used in the next step;
3. After drawing the buildings, they are structured and written in the arrays. The topology of each complete building is now available. The results can be displayed and checked by the user before being written in the database.

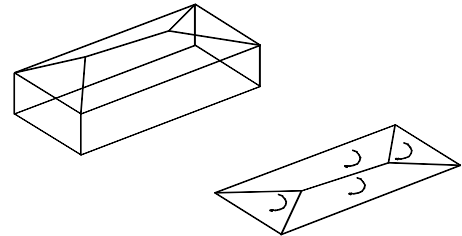


**Figure 6 :** Building construction

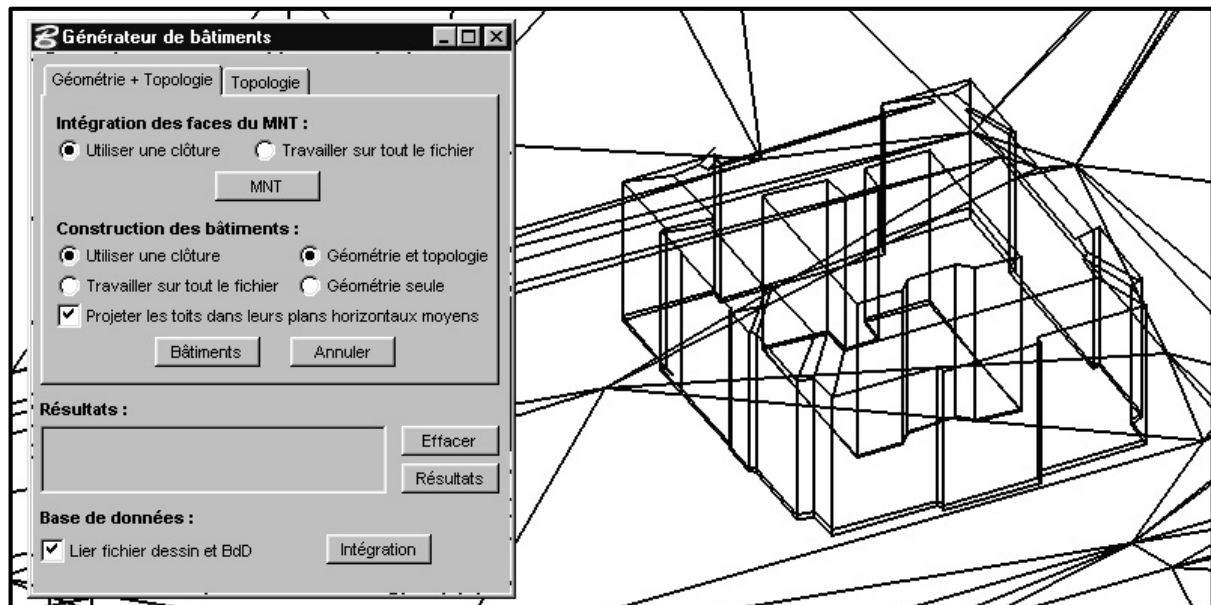
### 3.3. Hanging roof (non-flat roof)

For the non-flat roofs (figure 7) , the idea developed in our prototype is to :

- Establish the semantic properties of the roof based on the form of the hanging roof;
- Project all the roof data onto horizontal plane;
- Construct the faces as closed polygons;
- Construct the topology among the geometric primitives (nodes, arcs and faces) and semantics properties of the roof.



**Figure 7:** the hanging roof construction



**Figure 8:** 3D Modelling of the Zoological Museum of Strasbourg (DTM, buildings) with the DTM built from relief and roads



### 3.4. Architectural entities

For the architectural details, the data must be compatible with the level of detail aimed for the modelling. Aerial photogrammetry will be replaced by terrestrial photogrammetry. Processing of different types of architectural data involve following steps (figure 9) :

- Analysis of architectural characteristics of the monument;
- Definition of semantic properties of objects based on historical, archaeological, and geometrical properties of the monument;
- Automatic creation of different levels of detail for fast 3D modelling of the complex objects;
- GUI for automatic codified and topologic modelling of all the details and materials of the monument.

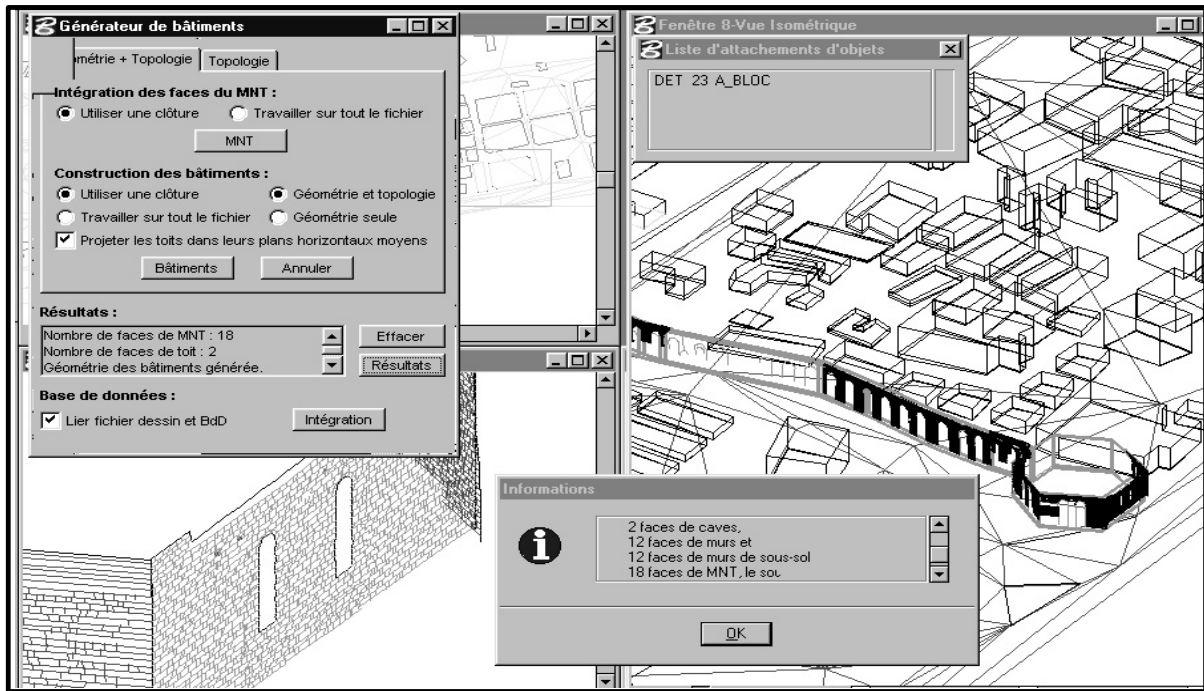


Figure 9 : 3D Modelling for the monument and part of the Aqueduct area

## 4. 3D TOPOLOGIC STRUCTURE AND DATABASE UPDATING

Beside the automatic generation of the monument and its architectural entities, the application is also bound to structure the graphical elements (figure 10). This structure splits each object into different elements of smaller topological dimension. A monument, which is a 3-D object is composed of 2-D elements (roof, walls, windows, blocks), these elements can themselves be made of one-dimension objects, the edges, which are linear elements. At least, each linear element is defined by beginning and end nodes (0-D object). This "tree" of relations is stored in a database. The topology based data is automatically written to a relational database. The thematic structure allows to complete the definition of the monument with a thematic description. The structure of this thematic structure is a hierarchical structure and includes the methods that allows :

- Data acquisition;
- Update of data;
- Querying and editing of descriptive data;

The data structure is based on basic primitives nodes, arcs, and faces. Semantic information about points, lines, surfaces and bodies objects can be stored in it. A set of relational tables is the result of the processing described above (figure 11).

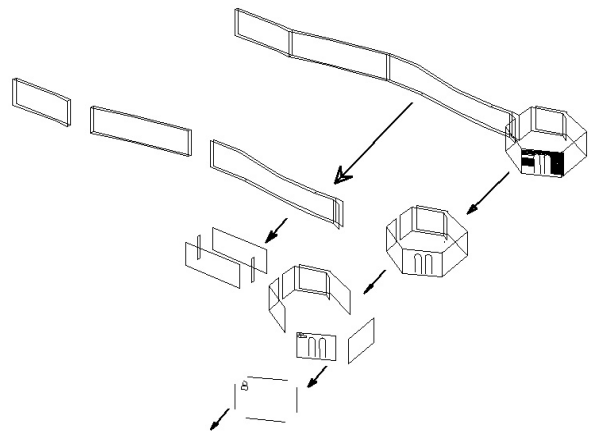


Figure 10 : The hierarchical structure of the aqueduct EL Ghuri (Cairo, Egypt)



ID_F	ID_A	NUMSEQ	SENS	attributs
1	4	4	Oui	
1	5	5	Oui	
1	6	6	Oui	
15	30	1	Oui	
15	31	2	Oui	
15	32	3	Oui	
15	33	4	Oui	
15	34	5	Oui	
15	35	6	Oui	
15	36	7	Oui	
15	37	8	Oui	
33	69	1	Oui	
33	70	2	Oui	

**Figure 11 :** Tables in the relational database (Microsoft Access), as part of the modelling concept

## 5. CONCLUSION

The structure of objects in architecture is complex and based on a hierarchy between the complex objects and their components. This hierarchy was also found between the thematic data that are associated with these objects. The thematic structure allows to complete the definition of the architectural objects with a thematic description. These complementary descriptions are recorded into fields in a relational database. Specific tools for data acquisition and handling are needed. The development of different ‘objects generators’ based on global modelling concepts (combining geometry, topology and semantic) are full of advantages for the development of 3D Information Systems dedicated to historic sites and monuments. The aerial and terrestrial photogrammetry appear as a valuable data acquisition technique for these purposes. Monuments with various types of roof shapes and architectural details can be reconstructed. This method enables also to fulfil the topologic and semantic descriptions of an object in the same time as the definition of the construction rules to benefit from the topologic and semantic models from the beginning.

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