3D INDOOR MODELING OF BUILDINGS BASED ON PHOTOGRAMMETRY AND TOPOLOGIC APPROACHES

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ABSTRACT

Three-dimensional modeling of indoor scenes is interesting for many applications like building representations, indoor facilities and architectural information systems. Modeling is used to document, preserve, restore or rebuild buildings. Properties of objects are characterized by a set of descriptors. In most applications, the model contains only information about the shape and the texture of the object while its topologic and semantic data are not processed. In this paper, we propose a method for the extraction of the information of an indoor scene and its reconstruction by combining geometric and topologic information.
The indoor part is structured in blocks like rooms, corridors, etc. with their own orthogonal coordinate systems. A block is presented in an abstract way using a Data Conceptual Model to identify the entities and the relations to include in the database.
In our approach, geometric and semantic data (which define the entities to be modeled) are extracted simultaneously by using a digital photogrammetry software and an independent Graphical User Interface (GUI). The structuring of geometric, topologic and semantic data is done within the measurement process. MicroStation-J Geographics is used afterwards to complete the database and generate the 3D model automatically. Co-planarity conditions between entities as windows or doors and the compatible walls are taken into account. The blocks are merged by the use of “virtual doors”. These doors are defined in function of the wall thickness and the translation direction according to the local coordinate systems of the blocks.
The final model offers several applications:

? topologic navigation in the models,

? visualization and extraction of the geometric characteristics of given types of entity (areas and perimeters),

? visualization of " the virtual doors ", used to calculate the parameters of the transformation (rotation and translation) between the reference coordinate system and the local systems attached to the different blocks.

? generation of photo-realistic models .

Our prototype has been applied to the modeling of a classroom at ENSAIS and to an Egyptian historical monument (The Wakala of Qaitbay in Cairo)

1. GENERAL INTRODUCTION

Three-dimensional modeling, applied to environments or objects, is used in many fields such as documentation, architecture, virtual imaging (virtual or augmented reality, images compression, etc.) and robotics. Several techniques have been proposed to present the 3D model of an object. This diversity is a function of the destination of the model. In general, the 3D model contains many information about the shape and the texture of objects, but topologic and semantic information are often not taken into account.
3D Modeling of an indoor scene is interesting for many applications like indoor facilities, architectural and monument information systems, where the 3D model of interior parts can be considered as an integral data of the representation. This double modeling is used to document, preserve, restore or rebuild monuments on the assumption of a partial or total destruction.
Studies about this type of modeling are very few and their objectives are varied. In robotics for instance, this modeling is limited to the cartography of interior parts of buildings to simulate and navigate in complex architectural environments. In other approaches, the analysis of architectural plans is used to simulate the indoor environment (Ah-Soon et al., 1998). This modeling requires a heavy processing and may suffer of precision problems (taking into account the data source which is an architectural planning permission).
In (Haggren et al., 1996), a videogrammetry-based 3D modeling procedures for indoor facilities is proposed. This modeling is based on recorded video sequences. The analysis process is inverted in comparison to traditional processes. In fact, when applying this process, a 3D functional model is initially established and measurements of the exact geometry are made afterwards. In this study, merging all the sub-models is based on geodesic measures. Indeed, the establishment of this type of measures is quite difficult and delicate due to the geometric characteristics of the indoor scene. The final result will be a photorealistic model.
Our approach is based on combining geometric, topologic and semantic information. Data structuring represents an automatic and effective solution of merging problem. Indoor parts are structured in two types of blocks: simple and reference blocks. A block is presented by using a Data Conceptual Model and modeling is based upon semantic rules. The semantic attributes and the geometry are extracted simultaneously. Topologic relationships and geometry are used to reconstruct the 3D model of the simple blocks. These 3D models are merged automatically by using the “virtual doors”.

2. INFORMATION HIERARCHY

The diagram, which represents the information as a hierarchy of three levels (geometric, topologic and semantic level) is used frequently to update information systems:

- Geometric level contains spatial data, e. g. coordinates in a given geometric reference. It is the graphic part of the modeling and it defines the position and the shape of the object;
- Topologic level is an intermediate level and defines the relationships between the geometric elements;
- Semantic level defines the objects to be modeled as well as their attributes, according to modeling needs and the available geometric data.

Information hierarchy is one of the key ideas adopted in our prototype for the 3D modeling of an indoor scene. In this prototype, various data structuring is done simultaneously. Data extraction has the two following forms:

- Geometric acquisition: it concerns the Cartesian coordinates, in a given reference frame. They describe the positions of the points measured on the image. The geometric information provides the first essential representation of the block. Required data is extracted by using a digital architectural photogrammetry software package.
- Semantic acquisition: it consists in defining the entities to be modeled and it supposes that the operator has a good knowledge of the object. The semantic acquisition can be realized easily by using the tools integrated in the geometrical acquisition interface itself.

The result is a database that includes the various levels of the representation of the indoor parts. In this database, the topologic information expresses the intrinsic properties of the various elements of a block as well as the interconnections between simple and reference blocks.

3. OUR APPROACH

3.1. Geometric modeling in our prototype

Many approaches for 3D geometric modeling have been developed and the most common are the boundary representation (B-rep) and solid constructive geometry (CSG). Each of them has its applicability, its advantages and disadvantages.

In the interior parts of a building, two types of geometric objects can be distinguished:

- Plane objects such as doors, walls, windows, etc.
- Objects based on simple geometric primitives (cylindrical columns for example).

In our modeling prototype, the surface is the fundamental unit. The surface modeling is based on the use of hollow volumes bounded by their surfaces compared to other methods which handle solid volumes. In fact, the principal entity in an internal environment is the surface: face of wall, face of door, face of window etc. Every entity will be modeled by means of its borders (representation B-rep).Therefore only the points that constitute the outline of a given entity will be measured in the image.

It should be noted that modeling based on the use of simple geometric primitive (CSG) is also possible in our prototype. In fact, the surface-based 3D model generated from the geometric, semantic and topologic data of the object, can be completed by the following geometric primitives: cone, cylinder, prism and sphere.

3.2. Topologic modeling in our prototype

Since topology is a very effective way for data structuring, the use of the topologic modeling in our prototype facilitates data exploitation and avoids the graphic redundancy. Topology is recorded in a way that allows making topologic and geometric requests (perimeter, area, coplanarity relationship between windows, doors and walls). It should be noted that other types of geometric and topologic requests can be conceived for other types of applications.

3.3. Semantic modeling in our prototype

The application of the semantic modeling rules to the 3D modeling of the interior parts of buildings has to take into account the following points:

1. The definition of the model to be set up and semantic properties of the entities. This task is based on the architectural knowledge of the scene and on the scene geometric characteristics.
2. The extracted data depends on the level of details that the modeling has to represent. In our prototype the semantic aspects are taken into consideration during geometric characteristics measurements.
3. The relations between the geometric, topologic and semantic levels define the modeling concepts. The concepts to be modeled are three-dimensional ones. In our approach, the general concept presents the interior part of a building.

3.4. Conceptual Data Model

Conceptual Data Model (CDM) represents the relations between the different modeling levels tackled above. It comprises entities and relationships. Our modeling procedure is based on a semantic approach. Space to be modeled is decomposed into concepts corresponding to a semantic hierarchy. These semantic concepts represent the first family in our CDM. The integration of the 3D geometry requires an effective topologic structuring of the graphic elements. These elements are decomposed into nodes, edges, faces and volumetric bodies. These topologic objects constitute the second family of the DCM entities.

3.5. Algorithms of the 3D modeling

3.5.1. Extraction of the semantic and geometric data and the generation of a partial database

It consists in associating semantic information with geometric data measured by using an unspecified digital architectural photogrammetry software package (our own application of single image modeling, or PhotoModeler, ShapeCapture, etc). The fundamental semantic types are the surfaces that constitute a unit component of the indoor parts (a room or a corridor). In this context, we distinguish the following type of surfaces: WALL, CEILING, GROUND, WINDOW, DOOR, COLUMN.

Thus, when applying this algorithm, the operator measures the geometry of a given surface. Then, he specifies the following information:

1. The semantic type of the surface.
2. The number of the object to be modeled (the unit component).
3. The number of the surface.
4. Numbers of the contour points of this surface, extracted in the same direction.

With regard to the surfaces of type WINDOW and DOOR, other data have to be specified to take account of the co-planarity relationships between these surfaces and the corresponding WALL.

At the end of the geometric and semantic restitution, a partial database is generated. This one is not complete but it contains all data necessary for generating a complete database and reconstructing the 3D model.

Graphical User Interface:

JAVA-based GUI was developed to apply the precedent algorithm. This GUI is independent of any digital photogrammetry system and consists in combining the semantic information and the geometric one where surface constitutes the fundamental unit of modeling. This GUI is easy to use and it allows:

AN AUTOMATIC CONNECTION WITH A DATA BASE FOR READING AND WRITING.

1. An automatic checking of the already taken measurements. Here, the interface gives information about the type of the last restored surface, the number of the last measured point and the number of the object.
2. An extraction of the semantic data and information necessary for the generation of the database.
3. An automatic recovery of points 3D co-ordinate resulting from the use of the digital architectural photogrammetry software package.
4. An automatic generation of a non-complete database. This one will be completed later using a second GUI integrated in the general shape of MicroStation-J & Geographics.

3.5.2. Three-dimensional model generation

After establishing the partial database by using the previous algorithm, a second algorithm whose objective is to generate the 3D model is applied. In fact, the partial database contains only the following tables:

1. The table T_PIECE that contains the modeled component (room, corridor, etc.) identifier and the identifiers of faces which constitute this component.
2. The table T_F_A that contains faces identifiers, faces types and edges identifiers.
3. The table T_ARETE that contains edges identifiers and the corresponding nodes identifiers.
4. The tables T_NODE that contains nodes identifiers with their 3D co-ordinates (X, Y, Z).

We notice the absence of the tables that describe the different types of faces. So, the algorithm consists, at first, in creating these tables automatically. Then, we proceed to the following stages:

1. From table T_PIECE, one extracts the identifiers of the faces that constitute the component, i.e. ID_F.
2. For each identifier, one seeks the corresponding type in the table T_F_A.
3. The identifiers and the types will be gathered in a table called T_FACE.
4. As soon as the table T_FACE is created, the links between the types and the table of various corresponding faces are established owing to the names of these tables, identical to the types ones.
5. At the end of the preceding stage, the tables T_MUR, T_PLAFOND, T_SOL, T_FENETRE, T_INTERCON, will also be filled out by using the link with table T_ARETE. Each one of these tables contains the face identifier and the identifier of edges that belong to this face.
6. In order to take into account the coplanarity relationships between windows or doors surfaces and the corresponding wall surfaces, the GUI gives the possibility of specifying, during data extraction, that one window (or door) belongs to this or that wall.

After completing the database, the generation of the component 3D model is carried out automatically.

It should be noted that before using this GUI, a Geographics project must be configured. In this stage, the user defines the existing categories as well as the features of each category and the tables related to these features. In our application, only one category exists, namely the PIECE. The features correspond to the various types of surfaces and edges.

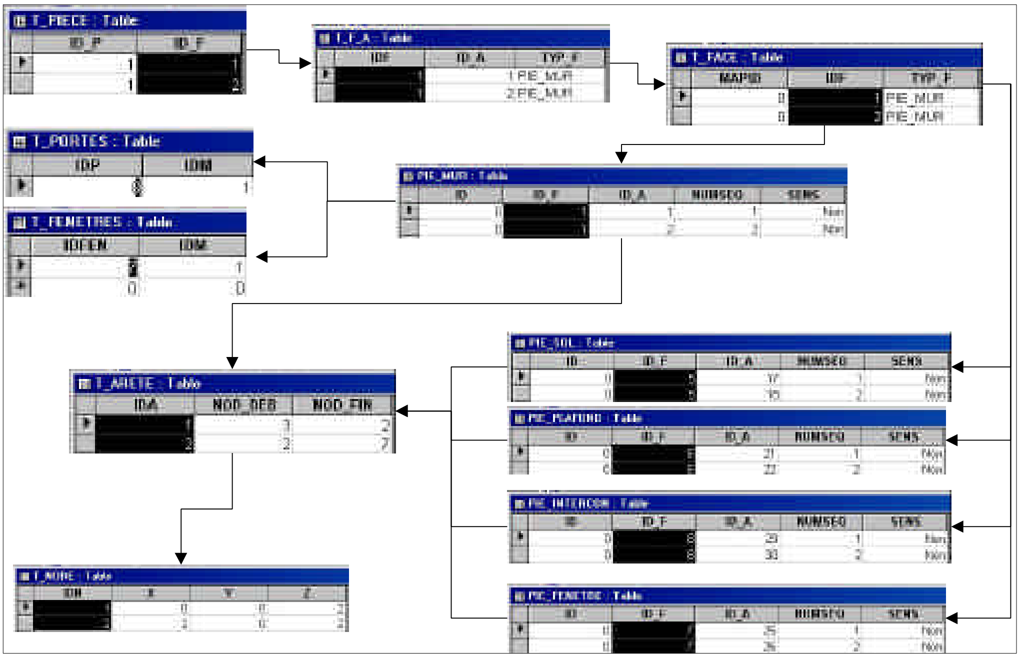


Fig. 1: Relations between the various tables of the data base

A Graphical User Interface (GUI) has been developed and integrated in the general shape of MicroStation-J Geographics:

1. To complete the database and to reconstruct a surface and a VRML models. It also allows to define the textures and to generate a 3D photorealistic model. In order to create a photorealistic model, textures must be prepared from the original image. This stage requires great familiarity with the materials editor of MicroStation-J software package.
2. To interrogate the database. The GUI gives the possibility of questioning the database by using the types of surfaces. In effect, when specifying a surface type, we obtain information about surface identifiers and the total number of the surfaces of this type. Windows and doors faces have coplanarity relationships with the corresponding wall faces. So, the results of the previous query will contain for each of these faces the number of the corresponding wall that includes the window or the door in question;
3. To visualize a given surface and to give its type and principal geometric characteristics (by using surface identifier obtained in the preceding stage);
4. To generate virtual doors which will be used to merge all the blocks.

4. BLOCKS MERGING

This can be done by using “virtual doors”. These doors are defined according to the wall thickness and the translation direction with regard to the local coordinate systems of the blocks. 3D conformal transformation parameters are computed by using the 3D coordinates of a virtual door in a simple component and its homologue in the corresponding reference.

In the following, we propose an algorithm that allows to put all the unite components (of the interior part of a building) in the same geometric reference. This reference is attached to the component of reference which can be defined as the component containing the maximum number of interconnection surfaces (doors, windows, etc.). The relations between a component of the reference and a simple component attached to it can be translations and rotations (3D conformal transformation). The transformation parameters are: a scale factor, three translations and three rotations. We can use the virtual doors to calculate these parameters. In fact, these doors represent the doors of the simple components translated by the value of the corresponding walls thickness. These doors have their corresponding in the reference component defined in the reference coordinates system. Using this idea, the seven parameters of the 3D conformal transformation can be calculated.

Algorithm for blocks merging:

The main stages to follow in order to realize the automatic blocks merging are:

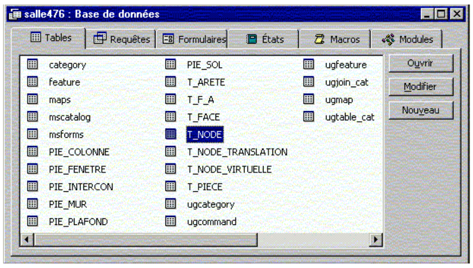
1. Completing the partial database of the simple component;
2. Modeling the simple component in its own coordinates system;
3. Generating the virtual door of this simple component by the use of corresponding wall thickness and the axis of translation. If this thickness is unknown, one supposes it (0.0);
4. Preparing the data automatically;
5. Calculating the 3D conformal transformation and the nodes of the simple component in the reference coordinates system;
6. Integrating the new nodes into the table T_NODE_TRANSLATION;
7. Redrawing the 3D model of the referenced simple component by means of the second interface integrated in the general shape of MicroStation-j Geographics.

5. EXAMPLES

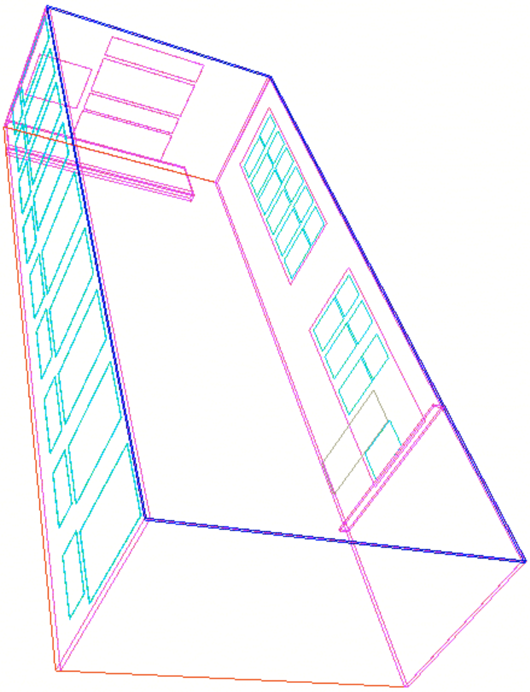
5.1. Classroom at ENSAIS

In order to generate the 3D surface model of this room, 56 surfaces were extracted from (only) two images by using our application for Single Image Modeling. A partial database, which contains the semantic and topologic data of the room, has been established by using our first interface. This database has then been completed by using the second interface integrated in MicroStation-J Geographics. The 3D surface and photorealistic models were finally created.

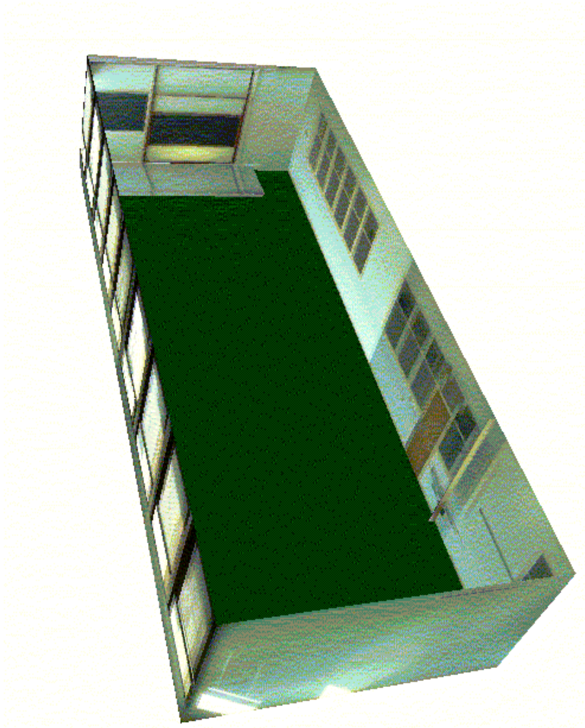
a) Original images (only two)



b) Resulting database



c) Surface Model of the classroom



3D photorealistic model of the classroom

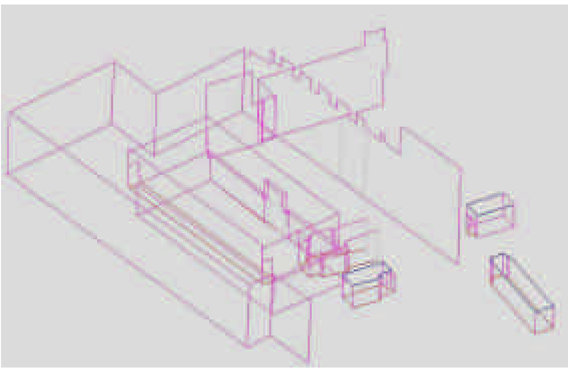
Fig. 2: Steps of 3D Single Image Modeling of a classroom

5.2. Wakala of Qaitbay in Cairo

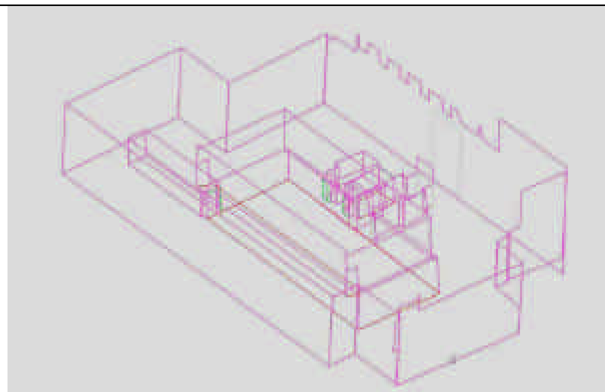
In order to generate the geometric, topological and semantic 3D model of this monument, the following steps have been applied:

- 3D geometry was extracted by using PhotoModeler 4.0.
- Simple components were modeled independently (every component in his own coordinates system).
- Semantic and topologic data were extracted by using the first GUI.
- Geometric, semantic and topologic 3D model of every component was made by using our second GUI.
- Blocks have been merged by using the “virtual doors”.
- The photo-realistic model of the Wakala has been generated by using MicroStation.

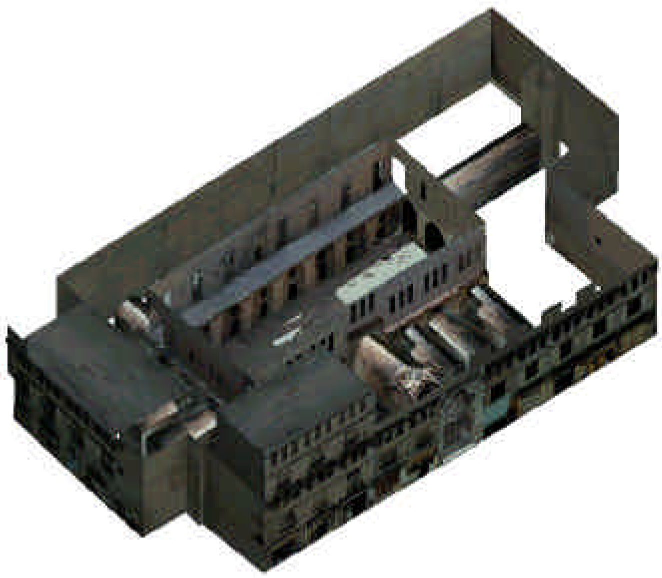
a) Overall view of the documentation of the Wakala of Qaitbay (Cairo, Egypt)



b) 3D models of simple components before merging the blocks



c) 3D model of the monument after merging the blocks



d) 3D photo-realistic model of the monument

Fig. 3: Steps of 3D modeling of the Wakala of Qaitbay (Cairo, Egypt)

6. GENERAL DISCUSSION

The reconstruction of the 3D model is based, in most digital architectural photogrammetry systems, on the generation of a simple wire frame model followed by the generation of surfaces (*façades*). Textures, necessary for the generation of the photo-realistic model, can be added by using the original images. Such photo-realistic models are generally easy to carry out and do not require a professional competence. However, the result is only a "simple geometric model" and no information is available in topologic and semantic levels.

Our prototype represents the modeled information in a hierarchical form and provides a topologic and semantic representation of the object as well as a geometric description. As proposed in any digital architectural photogrammetry (e.g. PhotoModeler or ShapeCapture), our approach produces virtual and photo-realistic models. However, the use of this prototype is reserved to specialists and the procedure of modeling remains complicated compared with other systems of simple geometric and photo-realistic modeling.

7. CONCLUSION AND FUTURE WORKS

Indoor scenes modeling is interesting for many applications like building representations, indoor facilities and architectural information systems. First of all, this paper gives a short overview of current studies about this type of modeling as well as their advantages and disadvantages. Then, information hierarchy, one of the key ideas adopted in our prototype for 3D modeling of an indoor scene, has been tackled. Finally, our prototype for indoor scenes modeling with geometric, topologic and semantic concepts has been presented. Were also detailed: our algorithms and the developed GUI. To be validated, this prototype was applied to different types of objects:

- A classroom at ENSAIS;
- A historic monument in Egypt (the Wakala of Qaitbay in Cairo).

We are planning to integrate this prototype in the package of the Arpenteur software (www.arpenteur.net) with the purpose of carrying out a geometric, topologic and semantic 3D model of building interior parts from a single image.

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