Assisting 3D Modeling from Documents

François Guéna
Atelier de Recherche en Informatique Architecture et Modélisation
Ecole d'Architecture de Paris La Villette
144 avenue de Flandre, 75019 Paris
fguena@paris-lavillette.archi.fr

Abstract. *This paper presents research in computer modeling that ARIAM team of the school of architecture of Paris La Villette has been developing for several years. One of the aims of this research group is to develop computer systems that assist architects in modeling existing buildings or monuments from heterogeneous documents or data as drawings plans, sections, photos, measures taken on site etc.. In spite of advances in computer recognition it's a long way to have a system that could automatically recognize, from any bitmap document or photo, relevant architectural objects and automatically build the model these documents represent. However, if we could define a knowledge base about a particular domain, it would be possible to develop a system that could interpret specific documents that represent some kind of building or monuments. But, even in such limited domain, it is difficult to build an exhaustive knowledge base and user-interactions are generally required. We argue that a user could mark relevant information on the documents and thus facilitate the process of interpreting. The system we propose has three components: a graphical user interaction tool, an analyzer of documents and user interactions, and a generative tool that produces the required model. As an illustration, the paper presents a system we have developed which assists an architect in modeling a 3D mesh of gothic vaults for a finite elements analysis.*

Keywords. *3D modeling; restitution; knowledge base system; meshing; gothic vaults.*

Introduction

The ARIAM team was founded in 1998 when the Heritage Section of the French Ministry of Culture asked us to begin research on the simulation of the behavior of gothic vaults (Chassagnoux et al. 1998). They wondered if it was possible to use computer to help the architects, who are experts in the restoration of historical monuments, in analyzing a gothic structure in order to find the best way to repair or consolidate it. During the first meetings we had with the historical monument architects they told us they would like to have a tool comparable to doctor's stethoscope. That means a tool they could use to give a rapid diagnosis, evaluate the disorder importance and decide if further analyses should be required. We suggested them to use finite elements analysis software packages.

The finite elements analysis method requires the user to build a 3D model of the gothic structure. The 3D model is generally automatically meshed in tetrahedrons and the user has to provide material information for these elements. At last the simulation software can produce several different colored documents explaining the structure behavior.

The finite elements analysis is evidently useful but we think the method usually used by engineers is not suitable for the historical monument architects who wants a fast diagnosis tool. The method requires long and hard work and skills in 3D modeling and meshing. Each part of the structure requires a specific mesh according to the characteristic of the different elements of the gothic architecture; we can't mesh a pillar like a wall or a vault. So we proposed to develop a specific pre-processing system to finite element analysis software packages which would assist the architect to build a 3D model and a mesh from the documents he has about the gothic monument he has to survey. Therefore our problem was a 3D restitution problem.

There is a large demand in digital 3D restitution of buildings or monuments: for cultural heritage preservation, for architects who study the restoration or the rehabilitation of buildings, for researchers in architecture who study the design of past monuments which have completely or partially disappeared etc. However this kind of 3D modeling task may be very hard and time consuming. It depends on the nature of documents and data available. We often need heterogeneous documents: drawings plans, sections, photos, measures taken on the site etc. Such a 3D modeling task consists generally of analyzing the documents to find out which information is relevant and translating it into data that the 3D modeler requires to build a model (i.e. 3D points to define lines, curves, surfaces or solids). Several methods and software packages are available to assist in such a modeling task: vectorization, photogrammetric restitution tools, 3D laser scanning etc. but these tools are not always suitable for every task context and involve laborious user interactions (reorganize vectorized curves, retrieve relevant surfaces in a cloud of points, picking points for photos correlation etc.).

The problems of 3D restitution have instigated several research projects whose aim is to build systems capable of reconstructing 3D models of buildings as automatically as possible.

Some of these researches are focused on document image processing. For example Dosch and Tombre (2000) have proposed a system which combines tiling, segmentation and vectorization methods for analysis of architectural drawings. This system is able to recognize, in an architectural plan, walls, doors, staircases and some other architectural symbols. When these elements have been recognized the system translates them in 3D objects.

Other research is focused on the integration of CAD modeling and photogrammetry techniques. Van Den Heuvel (2000) presents such state-of-the-art methods and trends. Photogrammetry is based on correlations between several projections of the same points of an object measured on several images. Integrate photogrammetry and CAD modeling allow a closer relation between the image measurement and the parameters of the 3D model under restitution. Add constraints reduce the number of images required (Devebec, 1996; Heuvel,1997 ; Huot, 2001).

The Digital 3D scanning devices are means to build 3D models of historic sites (Earl and Aish, 2003). The scanner provides a points cloud from which it is possible to extract planar regions and linear features. As multiple scans are required to acquire an entire monument multiple points clouds have to be registered. Automatic methods have been developed in order to reduce the manual effort associated with registering (Allen et al. 2003).

Although these methods are useful in building restitution we thought they are not well adapted to our problem.

Because the input data are plans of gothic

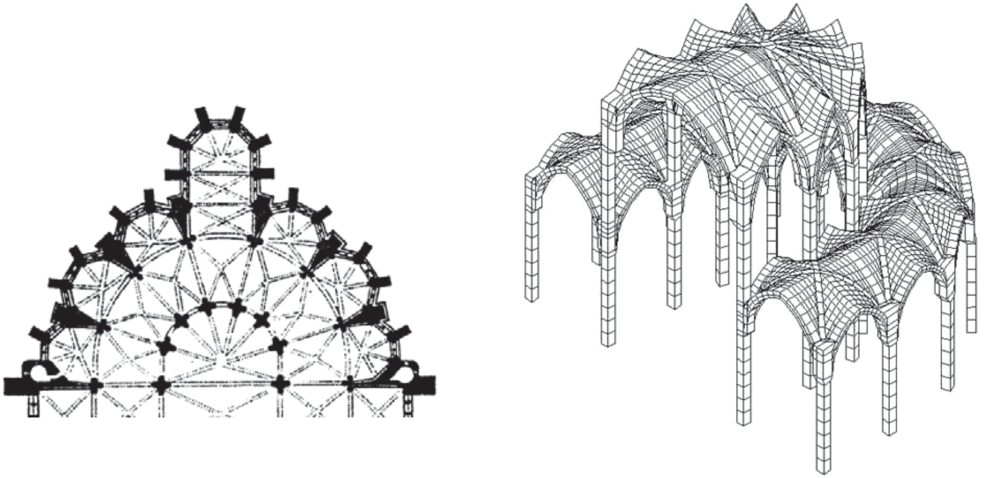

Figure 1. a) raster image of a part of Amiens Cathedral, b) 3D mesh of the choir.

monuments, it seemed a vectorization method for analyzing the documents could be useful. However the behavior of such methods depends on the quality and nature of architectural drawing. The historical monument's documents may be noisy and a pre-processing task may be required. The planar representation of gothic monument has never been normalized. For example the diagonal ribs are represented with two lines and sometimes with a unique line. Finally the design of the gothic monuments has evolved along several centuries and the structures have been repaired from the middle-age until now. So it seemed to be difficult encoding a complete knowledge on the elements the system has to recognize in documents.

Although an architect of historical monuments generally uses plans, he could also take photos of the monument and then use CAD-photogrammetry methods. But the results are best if the entire object to restitute is seen in the images and it is sometimes difficult to do that for a large monument such a gothic structures. The models of buildings the CAD-photogrammetry technics restitute are often made of surfaces or triangular meshes where it is difficult to locate the structural elements. But we needed to distinguish in the model each kind of structural elements in order to build for each of them a specific meshing. The problem is similar with digital 3D scanning. In spite of the interesting experiments made on Beauvais Cathedral (Allen et al., 2003) or on the Sagrada Familia with hybrid measurements (Maher and Burry, 2002), the investigations we can do for these famous monuments are not affordable for a little church in the north of France.

In fact all these methods are obviously useful but they are time and or cost consuming and consequently not adapted to our problem of developing a rapid diagnostic tool: the stethoscope the architect of historical monument desired.

To develop the rapid diagnosis stethoscope required we proposed a method based on the interpretation of simple lines that the user quickly draws over the raster image plan (fig. 1a). As we will see in the next sections of this paper, the lines have to represent the axis of the arches. The system does not analyze the raster image but only these lines. Our assumption is that we can deduce a lot of information about the monument only from this set of lines. A knowledge based system analyzes the set of lines and tries to find out all possible data to deduce the structure and the elements which compose it: the positions of arches, pillars etc., the form of vaults and the relations between these objects. In a manner of speaking we ask the user to show which elements are relevant to analyze in the raster image. From this analysis the system builds an object representation of the gothic structure which is used to build the 3D mesh (fig. 1b)

The next section of the paper presents the architecture of the system. The other following section presents the limitations of the prototype, the extensions we are going to develop and the other related researches of the team.

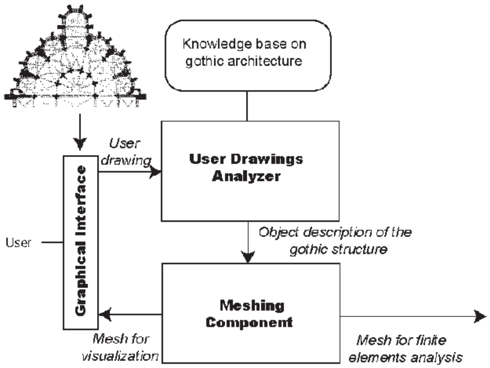

Figure 2. Architecture of the system

Architecture of the system

The system is designed with three major components (fig. 2):

the graphical interface which allows the dialogue between the user and the system,

the analyzer of user drawings which builds gothic structure's representation.

the meshing component which builds the 3D mesh of the gothic structure.

The graphical interface

The graphical interface is developed around AutoCAD. Thus the user and the system have access to all the drawing and visualization command required for input and output. The user activates the _imageattach command to insert the raster image of a plan, he uses the _line command to draw the lines which represent the position of arches' axes. The system activates the _polyface command to present the calculated 3D mesh. New specific commands developed with ObjectARX SDK allow the user to send the set of lines to the analyzer and to ask the system to build the 3D mesh. The next figures present two snapshots of a user drawing session.

The analyzer of user drawing

The analyzer receives as input the unstructured set of lines drawn by the user (fig. 4a). Let us note that this set of lines is regarded as a sketch: lines

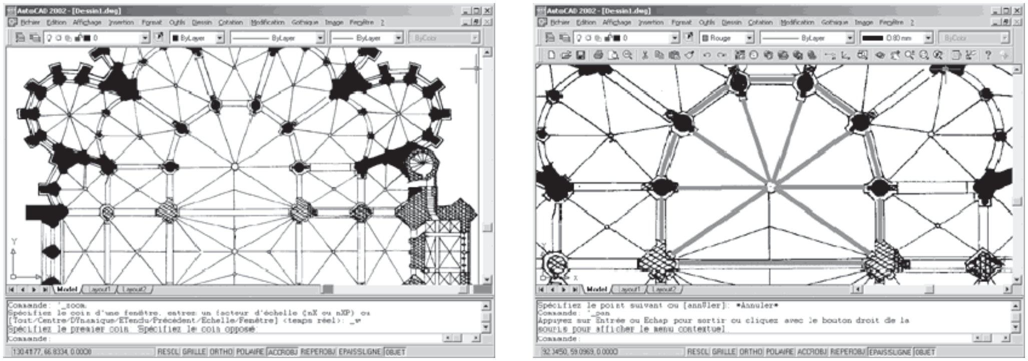

Figure 3. a) raster image, b) user drawing over the raster image.

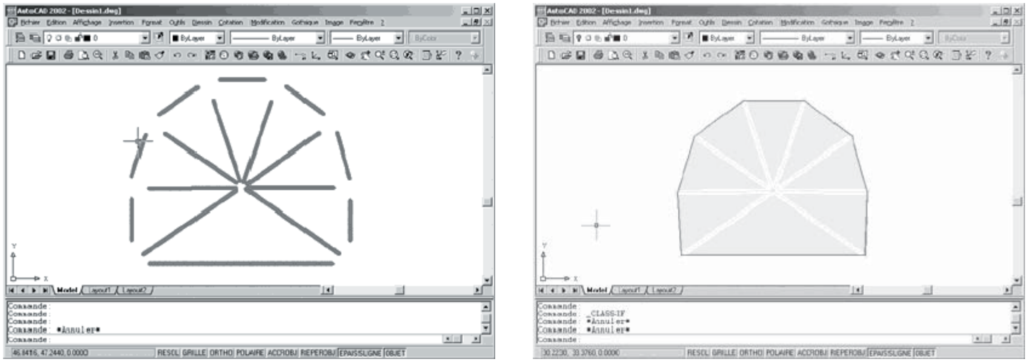

Figure 4. a) user drawing, b) corresponding graph.

are not well connected.

Firstly, the system build a graph from the set of lines (fig. 4b). It computes the intersection points of the lines and makes nodes, arcs and regions.

Then the graph is analyzed with the knowledge base system. The knowledge base system tries to make a correspondence between geometrical elements of the graph and the descriptions of the elements of gothic architecture represented in the knowledge base.

The system has to find which nodes represent a pillar ? which nodes represent a key stone ? which arcs represent an horizontal or vertical arch ? which arcs represent a diagonal rib ? which regions represent a segment-vault ? what subsets of nodes, arcs and regions represent a vault and what kind of vaults are involved ?

Classification reasoning

The knowledge base system uses a classification algorithm: a reasoning mechanism presents in some object-based knowledge representation models (Ducourneau, 1996). This mechanism can be used for analyzing drawings in a CAD context (Guéna, 1997).

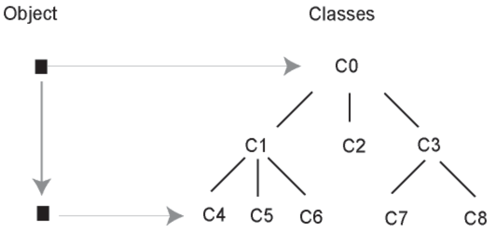

Figure 5. An example of object migration from the root C0 to the leave C4

Classification tries to find the possible classes for an object to migrate from its current class to a lower more specific class. It is based on matching the field values of the object to be classified with the current candidate class description. The class defines a constraint on the possible values for each field (generally a domain for the possible values).

Starting with the current belonging class of the instance the classification mechanism scans all its subclasses and determines, for each of them, if it is possible.

A class is possible if the object satisfies the constraints on all fields that exist in the class.

A class is impossible if at least one constraint is not satisfied by a field value.

When a class reveals itself impossible, all its subclasses are labeled impossible too.

The algorithm reiterates on every possible class and ends after it has reached the leaves of the hierarchy (fig. 5).

The knowledge base

For example the next figure 6 presents a possible hierarchy of classes.

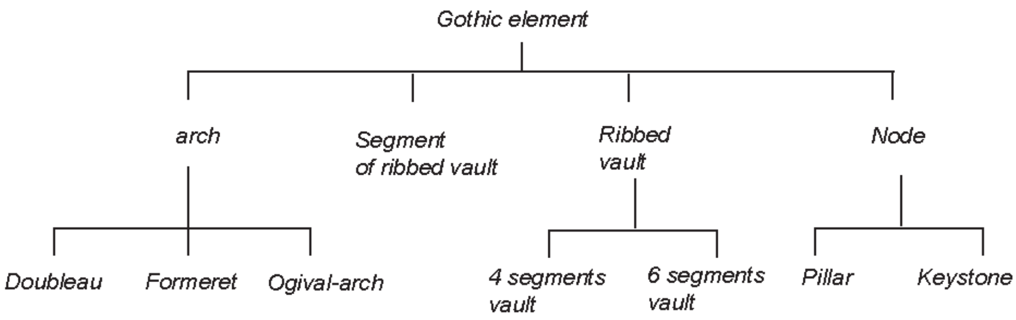

Figure 6. Hierarchy of classes.

The more general class describes properties of any gothic element

Under this class, you find subclasses that are more specific: arch, ribbed vault, structural node.

Then under the arch class we have the ogival-arch class, longitudinal arch class(named “doubleau” in French), vertical arch class (named “formeret” in French).

Under the node class, we have the subclass keystone and the subclass pillar.

The system analyses the graph and tries to attach graph nodes to pillar or keystone classes, graph arcs to ogival-arch class, doubleau class or formeret class. Then it tries to find consistent subgraphs which are then attached to the different classes of vaults.

A classification of node as example

Let’s see a simplified example of classification for nodes

Before classification all node instances a,b,c,d,e,f,g,h,i and j of the graph are attached to the node class. This class defines two properties: the field incidence-number for the number of arcs which are starting from the node and the relation arcs for the corresponding arches. After classification the node instances i belongs to the keystone class because the incidence number value is 4. Likewise the node j belongs to the keystone class because the incidence number value is 6. The nodes a,c,d,e,f and h are attached to the pil-

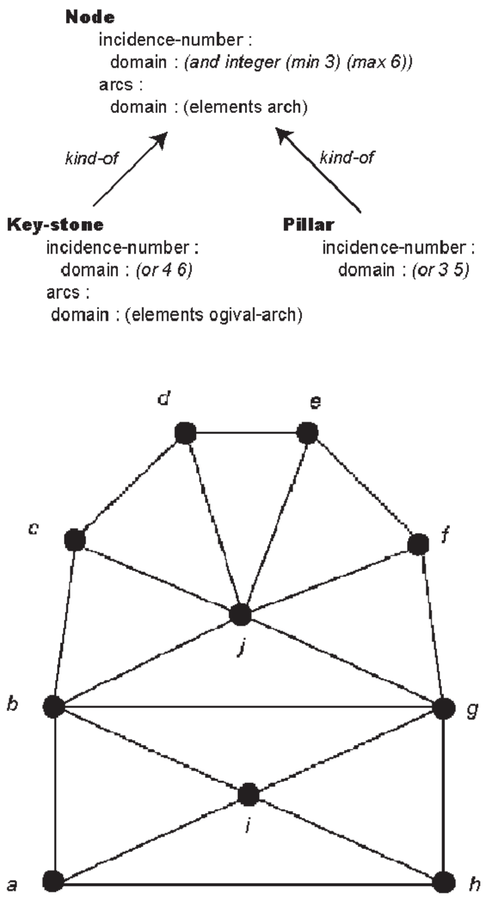

Figure 7. a) a hierarchy for nodes, b) a graph.

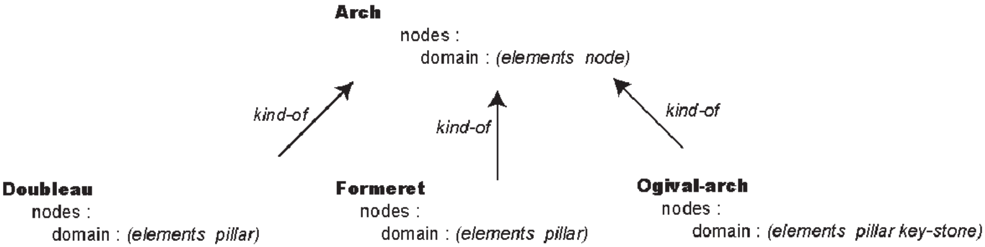

Figure 8. A hierarchy for arches.

lar class because the incidence number value is 3. Finally the nodes b and g are attached to the pillar class too because the incidence number value is 5.

Ambiguities in classification

An important point for our application is that the classification algorithm does not require the knowledge to be exhaustive. We know it is difficult to imagine gathering all cases we could find in a gothic church or monument in a knowledge base. So when an object cannot migrate to a lower class, the system signals the user that it cannot classify this object. The user has to manually attach the object to the right class. But this user action can resolve all other ambiguities automatically by a mechanism of constraints propagation through arcs-nodes relations (fig. 8).

Object representation of the gothic structure

In fact the knowledge based is much more complex and the objects are classified through several hierarchies of classes, one per point of view. We have two point of view : a topological point of view, and a gothic point of view. When the instances are classified in the topological point of view as we have just seen, the instances are also attached to the corresponding classes in gothic point of view.

The classes of the gothic point of view define the fields for the description of the structure, shape, height, thickness of elements and so on. These field values are calculated by the system with methods from information the systems belongs to or with default values. Consequently the first description provided by the system is not precise enough. The user can change those values to adapt the description incrementally. For example the exact height values for key-stones cannot be

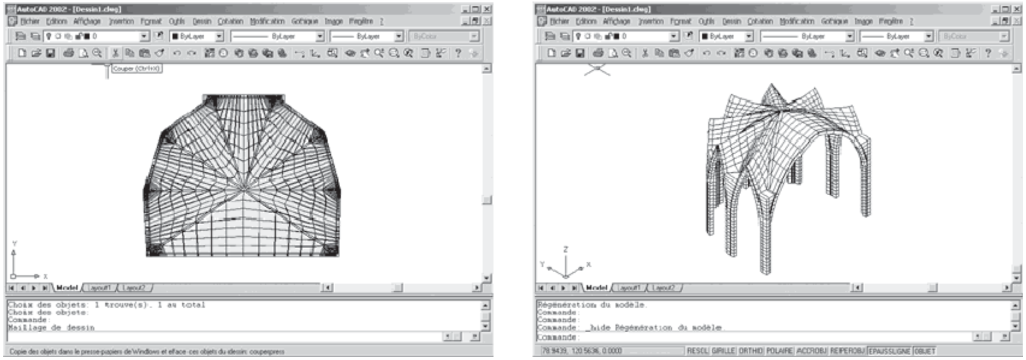

Figure 9: a top view and an axonometric view of a mesh

deduced from the plan. These values are propagated through the parametric object representation of the structure.

In other words a canonical mesh is firstly produced from the knowledge base and then the user has to refine the description of the structure. The cycle is renewed until the user thinks the produced model is close enough to the actual state of the monument (fig. 9).

The analyzer of user drawing is developed in Common Lisp Object System. It communicates with the graphical interface through the ActiveX protocol of the Component Object Model of Windows.

The meshing component

The meshing component uses the description of the structure and returns both a mesh for a visual control and also the meshing data input for the finite elements calculation system. Meshing is not the topic of this paper but briefly a specific meshing is build for each kind of gothic structure element with a specific treatment at the point where arches converge on the top of pillars (Chassagnoux et al. 2000). This component was developed in C++ language.

Limitations, improvements and future works

The system is not currently usable in a professional context. We have just developed a first prototype which has limitations. We have to a improve it in different ways.

Improving the user interface

The way the system offers the user for adapting canonical mesh to the current state of the structure is not smart enough. We have to limited as mush as possible the use of dialogue boxes to change parameter values of gothic elements. In order to facilitate height measurements we intend to develop correlation mechanisms between multiple documents (plan, elevations and sections).

Gothic structure behavior studies

The finite element analysis is apparently useful for understanding behavior of masonries. But limit analysis is another direction to explore (Heyman, 1995). The ARIAM team is engaged in an exchange program with J. Oschendorf (2002) and his team at the Department of Architecture of the MIT. Our aim is to investigate the potential of limited analysis for gothic structures studies.

Application to other simulation

We think it is possible to generalize the architecture of our system in such a way it could be useful for other simulation. The current system comprises three components: a user interface, an analyzer of documents and a generative component which builds a 3D mesh for finite element analysis. But, relative to the sort of 3D model the simulation requires, we could only change generative components.

To assist modeling of other kinds of building we have to change knowledge bases.

Mixing with CAD-based photogrammetry

The ARIAM team is engaged in other research projects. We have been taking part for several years in a research project about free-hand sketch analysis (2D perspective sketches). We have just taken in hand the management of this project started at the “Ecole des Mines de Nantes”. This project is deeply funded on the use of projective geometry constraints and the Grassman-Cayley algebra (the Grasmman-Cayley algebra is not the topic of this paper so, for more information about this project, the reader can have a look to the site www.ariam.archi.fr/gina).

From this project was developed the Marina system for reconstructing 3D models from 2D images (Huot 2001).

Like the system for reconstructing gothic monuments, Marina follows a user-centered process.

The user draws relevant lines over the image and specifies geometric constraints. This information is translated into equation using Grasmman-Cayley algebra and a solver reconstructs the 3D model.

Today our aim is to put together experiences from the “the behavior of gothic vaults project” and the “projective geometry project” in order to develop a hybrid mechanism mixing planar sketch interpretation and perspective sketch interpretation. Thus we could develop a system capable of assisting modeling from heterogeneous documents: drawing plans, sections or photos.

Conclusion

In this paper we have described research in computer modeling currently developed at the school of architecture of Paris La Villette. The systems we are developing are designed for assisting architect in modeling existing buildings or project.

We thing such systems have to be heavily user-centered and capable of understanding simple drawings or free-hand sketches.

The system architecture we propose has three components: a graphical user interaction tool, an knowledge based analyzer of sketches and a generative tool that produces the required model. From this software architecture we can derive several tools for assisting modeling depending on the knowledge base content (i.e. the domain) and the kind of model the generative tool provides (i.e. which process the model is built for).

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