GENERATION OF ARCHITECTURAL PARAMETRIC COMPONENTS

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Cultural heritage 3D modeling

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Abstract. This paper deals with 3D modeling of complex architectural elements for virtual 3D scene reconstruction based on images or point clouds. It presents a new method at the opposite of classical photogrammetry and lasergrammetry techniques: parametric components are created and then adapted to the measured data. We have conceived and developed a parametric shape generator tool for virtual 3D reconstruction of cultural heritage monuments. We present the geometrical study on the cupola shapes with all their diversity. It is illustrated with the Suleymaniyé Mosque in Turkey. The results are promising. The modeling time is greatly reduced.

Keywords: 3D modeling, architectural component, parametric modeling, cultural heritage.

Résumé. *Cet article traite de la modélisation 3D d'éléments architecturaux complexes pour la reconstruction virtuelle de monuments historiques à partir de photographies et de nuages de points. Nous présentons une méthode à l'opposé des techniques de photogrammétrie et lasergrammétrie : les composants paramétrés sont d'abord créés puis adaptés aux données mesurées. Nous présentons l'exemple des coupoles et de leur étude géométrique et plus spécifiquement la Mosquée Suleymaniyé en Turquie. Les résultats sont prometteurs et les temps de modélisation sont grandement réduits.*

Mots-clé*: Modélisation 3D, composants architecturaux, modélisation paramétrique, Monuments historiques.*

1. Introduction

The evolution of the data acquisition techniques produces today accurate 3D data sets. This leads to many requests for 3D models for various applications (scientific and architectural studies, virtual visit for a better understanding of the monument and so on). However the modeling task is still time consuming whatever the method employed (CAD, photogrammetry or laser scanning tools), because architectural elements have complex geometry. Furthermore the geometry of an element varies with space and historic period. Automating the modeling of the most common components could ease this 3D work and produce accurate, consistent and re-usable models. Based upon compound rules of architectural elements but also upon data sources such as 2D plans, photographs and 3D laser scanning, we have conceived and developed a tool for virtual 3D reconstruction of cultural heritage monuments. On the contrary of image-based and point cloud tools which model element by element from the measured data, we propose a new method at the opposite: parametric components (unique or compound elements) are first created and then adapted to the measured data. Our method allows a quick modeling and accurate adjustments. In a previous paper, it was just the beginning of the project; the mehod was had not been validated on complex models such as the one presented here (Chevrier 2008a).

After a presentation of various ways to acquire 3D models and related works (part 2), part 3 explains the principles and advantages of our method. Part 4 explains the study of architectural elements and the example of the cupola. The composition of complex scenes from basic elements is then described in the fifth part. Part 6 explains how one can adjust the 3D model to the measured data. Part 7 explains the implementation of the project. Some results are exposed in part 8 with the Suleymaniyé Mosque in Istambul and, finally, we conclude and present the future work in part 9.

2. Various ways to acquire 3D models and related works

Various methods exist to acquire the 3D model of existing monuments. 2D architectural plans with a CAD tool is the most widely used but is a time-consuming method. Other techniques are now utilized.

Photogrammetry techniques (photomodeler, Debevec et al. 1996; El Hakim et al. 2002) allow building main parts of a building rapidly. For detailed and complex objects (volutes, vaults) a great number of pictures and/or corresponding points are required, increasing the modeling time. Mueller et al (2007) have conceived a method for a quick reconstruction of façades from upright pictures. Horizontal and vertical straight lines are computed for the creation of simple shape (box) elements. The user enter the depth position of the elements. However their method is suitable for simple modern façades of buildings but is not adaptable to complex architectural ancient and classical façades. Lasergrammetry techniques (Trimble, Remondino, 2003) produce point clouds with very high precision. However the modeling task is tedious and only geometrical simple objects can be automatically created (sphere, cube, plan, cylinder). Boulassal et al. (2007) retrieve lines of façades in laser point clouds and can therefore dimension the openings and the walls. However tests were made on quite simple façades (not classical façades with columns, pediments, balconies and so on). Either image based and point cloud based modeling allows building the visible captured parts of the objects. There are always invisible parts in complex shapes. Furthermore, if we have to model the inside and the outside parts of a building, this is quite difficult to automatically match data because of the few redundant data.

Finally parametric objects are now available in libraries for specific fields (steel structure, boiler making industry, mechanics…) but no architectural libraries exist. Modeling from architectural rules (for example old treaties for ancient and classic style) (DeLuca 2007, Fuchs 2006) appears to be a promising field of research. However, only moulding objects are considered. No libraries of parametric architectural components exist.

We study the most common components to propose a 3D library of architectural parametric objects to reduce the modeling time and produce accurate, consistent and re-usable models. Our tool (plug-ins for Maya) could be a great help for architectural and virtual designers. Its usefulness is various: quick but detailed 3D modeling for movie or game scenery, accurate modeling for archaeological aims, 3D as-built model for a monument lighting simulation purpose, working out new configurations from existing architectural elements...

3. Principles of the method

Architectural components (vault, door, window, column, and so on) are first theoretically studied for various styles (classic, Gothic, Asian styles) from bibliography and from existing monuments. Each component is then described with a minimal set of parameters (part 4). These parameters allow writing a 3D building method to create the virtual shape of the architectural element. Instances of architectural components are described with their own values of parameters in a file library. When the user chooses an object predefined in this library, it is created in real time with the values of the parameters read in the file (Figure 1). Several examples are given in Figure 2. Parameters can then be adjusted to adapt the shape to the various practical situations. Deformation parameters allow adjustments to deformed shapes (trapeze instead of rectangle). Then, the Maya modeller functions allow adapting perfect mathematical models to imperfect shapes: surfaces can be eroded, a dome may not be a perfect semi-sphere. Maya deformers and sculpt geometry tools can be used to adjust the shape. Sculpted elements modelled with meshes can be inserted in the scene description file library.

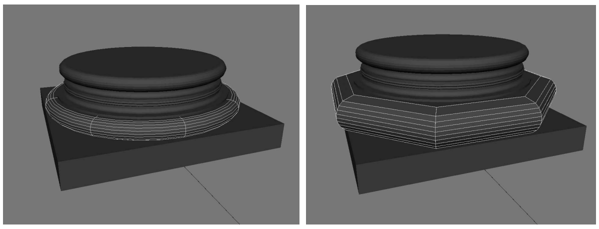

Figure 1. Modifications of parameters on a Corinthian basis of column: the second moulding parameters have been modified between the first and the second image. The new height value translates automatically the following mouldings upwards.

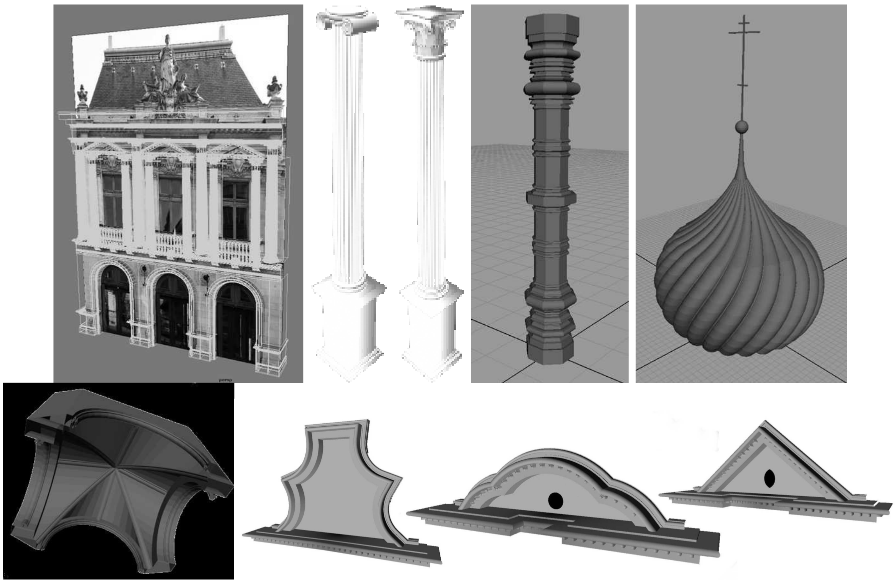

Figure 2. Façade of an auditorium in Nancy, ancient style columns, Khmer column, orthodox roof, gothic vault and various pediments.

4. Study of architectural elements

The study of each architectural element allows us to define the dimensions and the various shapes according the period and the space. This step is important because good parameters and building methods depend on it. It must cover at best all the existing cases and allow us to keep only the minimal number of parameters enabling the object modeling. For some kinds of cupolas for instance, only one parameter is required: all the other dimensions can be deduced and the computation can be carried out following geometrical rules. The height, the pendentive arch shapes are deduced from the square side dimension. Ancient and classic styles are principally based on mouldings, each moulding having a shape (cavetto, circle...) that requires several parameters (height, sort, radius, offset centre…). Dimensions are given proportionally to a module (Vitruve 1996, Palladio 1965). The mouldings are then revolved to form columns (radius and sweep angles) or extruded to create entablures (direction and length). Supplementary parameters are required to model specific characteristics (hood moulding, fluting…). Lots of compound elements are also based on moulding (doors, windows, pediments...)(Figure 2). From the study of each of these elements, a set of parameters and moulding profiles enable them to be described.

In this part we take the example of the cupola to explain our reasoning process. This study takes place in two steps:
- The **first** step is the creation of a typological organigram of the cupola through a historical analysis of the various building systems in the East and the West (Roman, Byzantine, Islamic and Romanesque), and through a geometrical analysis of the various transition solutions between the squared plan and the cupola circle. For this we have studied geometrical layouts, plans and analyses of architecture theoreticians (Eugène Viollet-le-Duc (1967) or more recently Jean-Jacques Terrin (1997)).
- The **second** step is the determination of the parameters for the creation of the various cupola kinds with the help of the typological organigram. This step will be the main part of another paper. We just want here to explain the importance of the architectural study and shows the various cases and variations of that element. Finally comes the implementation (Part 7).

The cupola is a complex construction that requires technical and geometrical knowledge when built on squared or rectangular walls. Most buildings are conceived on an orthogonal scheme. The semi-sphere of the cupola lays only on four contact points on the supporting walls. To secure its stability, a continuity is essential between the vault and the supporting walls so that the horizontal and vertical pressures are not to strong. Therefore we see the importance of the transition between the curve of the cupola and the straight of the wall. The cupola has required many centuries of experimentation and adjustments to be correctly built.

The main elements of a cupola are (Figure 4):

- **transverse arches** that define the shape and the size of the cupola.
- **transition elements** (one or two in a cupola). They can be:

a) *pendentive surfaces:* hemispheric triangles that make the transition between the transverse arches and the cupola circle.

b) *Squinches* (concha, corbelled or conical squinches, stalactites): they transform the square to an octogon.

c) *Triangles and stalactites*: repetitive units of concave surfaces to create a rich 3D shape (One can find them instead of the pendentive surfaces or as squinches).

- tympan walls (surfaces inside the transverse arches (Figure 7) that can have openings), **cornice** and **drum** (circular or octogonal, with or without openings) are optional elements.

- dome (with radiant or interlaced nervures, with stalactites, an octogonal dome...).

Let's take the case of the transverse arches: they can be of several kinds (Figure 3) according to the architectural style, to the period and to the place on Earth: circular arch, pointed arch with centre in various positions. Once the basis dimension of the arch is set, the user chooses the kind of arch he needs, and one can build the transverse arches. We also specify the case of other pointed arch with the position of the centre as a supplementary parameter. Pendentive arches are also based on that kind of arches.

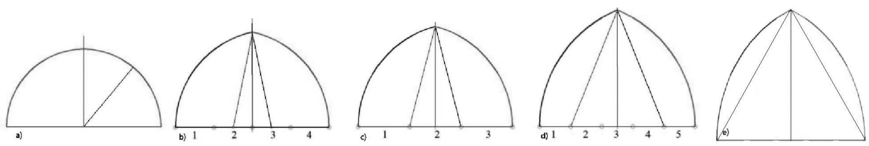

Figure 3: Various arch kinds; a) circular arch : the centre is on the axis. b) Two quarters and a half arch: inherited from the Clunisians who imported it from the East. The centre of the arches is at 5/8 of the arch basis. c) Three point arch: centre at 2/3. d) Five point arch: centre at 4/5. e) Common arch: any point as centre.

We classify the cupola (Figure 5) according to the supporting walls (squared or rectangular) and to the transition methods. For circular or elliptic walls, the dome is directly laid on them. Then from the typological organigram, we have studied each element that can compose a cupola. From its variations in time and space, we have determined a set of parameters and 3D creation methods. A cupola is then described by the presence or not of sub-elements and by the description of each sub-element (value of each parameter).

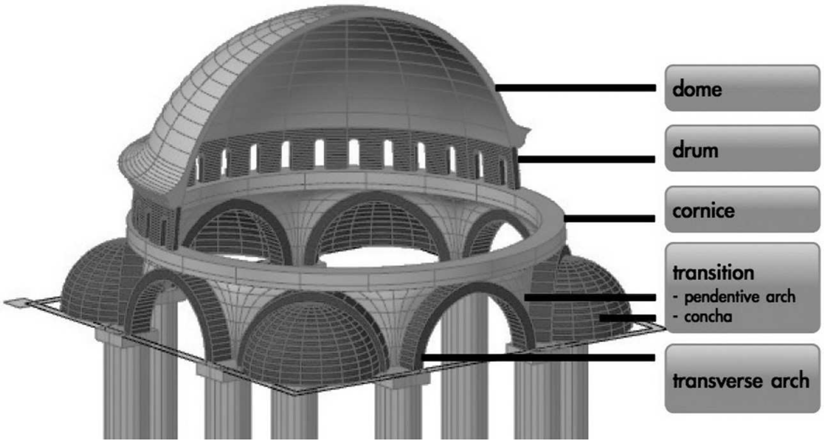

Figure 4. Elements that compose a cupola

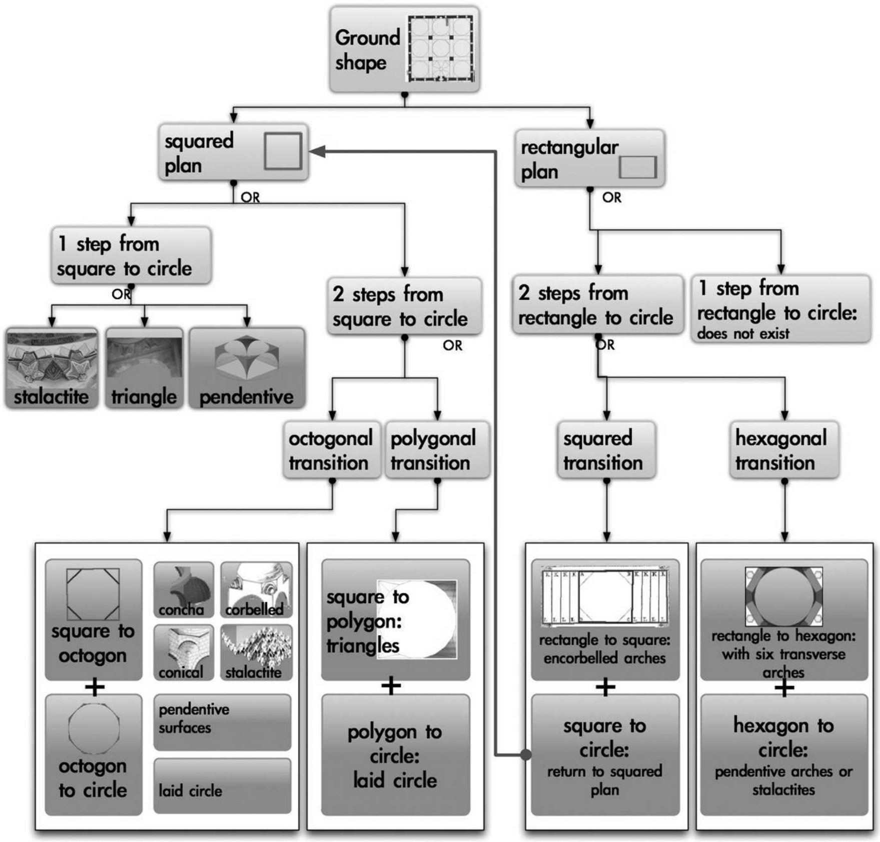

Figure 5. Typologic organigram of the various cupolas

5. Handling large scenes

Several architectural elements have to be generated to create a compound element. Many elements have to be associated to create a building. A column is composed of a stacking of mouldings, openings can be a complex composition of elements (for example in ancient styles), a monument is composed of various kinds of walls and many openings and other decorative elements. Each element has to be positioned beside the others: the door has to be at the right of another one, the capital has to be above the column fust, etc. In our tool, the location of components is done as simply as possible in a relative way with respect to each other. In order to help this description two methods are used: hierarchical and relative positioning description.

5.1 Hierarchical description

A special node allows grouping elements and the other nodes of the hierarchy are architectural elements (vault, door...). Complex shapes, like pediments, have their own parameters (shape, dimensions, oculus...) and have also some child nodes to describe the moulding profiles. A window has the following child nodes: a lintel, a breast, an outer sill, a balcony node, a pediment node.... Grouping nodes have parameters common to all nodes (global dimensions and positioning parameters). These parameters can be set for the grouping nodes and they will be transmitted to the child nodes by a propagation mechanism. Every modification of one of these parameters is also transmitted to the child nodes and the corresponding 3D objects are recomputed. These parameters are for instance, revolution or extrusion parameters, duplication parameters, relative positioning. Every moulding of a column is a revolution shape, so this parameter is only once specified in the grouping parent node. Each object (leaf or grouping node) can be linear or circular instanciated to form a set. The volutes of the Corinthian capital form a four instance circular set. The dentils of the pediment form a polyline set with the required number of instances (automatically computed) to cover the path. One set can be inserted in another set: a Corinthian column with its four volutes can be globally instanciated to create a column set.

5.2 relative positioning

Architectural elements are built in 3D in a local coordinate system from their parameters and then are positioned in the scene according to their neighbours. They have to be correctly laid out to form the monument. This positioning is also indicated in the parameters of the nodes. Positioning of components is done as simply as possible in a relative way with respect to the other components. No computation has to be performed by the user. Four kinds of positioning can be used: the stacking (mouldings are stacked to form a column), the anchoring to a component point (a sculptured key is positioned in a vault), the relative positioning to the bounding box of another component (a door at the right of another door) and the relative positioning to the bounding polygon (the second edge of one element is close to the fourth edge of another one). A positioning parameter modification of an element leads not only to the rebuilding of the position of this element, but also of all the elements depending on this object if it modifies their location or orientation. For all kinds of positioning, attached components can be architectural elements or grouping nodes.

6. Adjustment to measured data

In order to adjust a parametric shape to user's needs, we can use various data such as a laser point cloud, an upright picture, one picture and a plan, two or more pictures or 2D plans. Point clouds and pictures are imported and positioned in the 3D virtual scene. Points or pixels are selected to dimension (the three main dimensions) and position the parametric architectural elements in the scene. For more details on this part, see (Chevrier 2008b). We recently added the possibility to use 2D plans. They are also imported and positioned in the 3D scene. A bounding box can be specified by the user: in the top view, he can dimension the width and depth of the box and he can also place it correctly in the scene according to the 2D plan (Figure 6). In the front or side view, the height of the box can be set. Then the user chooses an architectural element (or a group of elements) which is automatically created according to the dimensions and position of the bounding box.

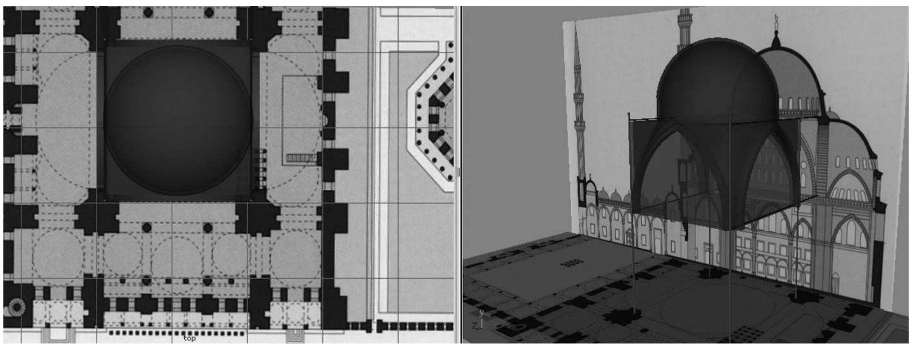

Figure 6. Using 2D plans and bounding boxes to dimension and position architectural parametric elements.

7. Implementation

Software development is performed in C++ and Mel (Maya embedded Language) to create new menus and plug-ins for Maya. A Maya object is described by a set of attributes that appear in a window (the attribute editor). When an attribute is modified, the object is generated again with the new values of the parameters. To each of our architectural elements corresponds a Maya object; to each parameter corresponds a Maya attribute. Finally Maya is not only a modeller but also a computer graphic image generator that can be used for user's needs. Shelves have been added to Maya to have icons for our architectural object library. Each icon is linked to a parametric file in the library. A special plug-in is in charge of reading the file and creating our corresponding Maya objects and the hierarchy.

Several cupolas are often associated in a particular way (see central part of the plan Figure 8). This network of cupolas follows architectural rules that we have transposed to a relation between a main cupola and its secondary cupolas. This is represented by a hierarchy of cupolas in the parametric description of the scene. In Figure 10, you can see the three generation hierarchy for the Mosque.

All classes (cupolas, tympan walls and squinches) derive from the virtual class PositioningObject (Figure 7) that contains methods for the positioning according to a parent cupola. Each of the subclasses can be used as a cupola daughter to hold up the transverse arches of a main cupola. The transition can be in one or two steps as presented in Figure 5 If we have a two step transition, squinches (concha, corbelled or conical squinches, stalactites) are used to transform the square to an octogon. Then the dome is laid on the octogon or pendentive surfaces are used.

Cupolas on rectangular walls can be a composition of cupolas: in the case of the Suleymaniyé Mosque (Figure 8), two hexagonal cupolas with parts of squared supporting cupolas are used.

8. Results

As an example and to validate our method, we have chosen to model the Suleymaniyé Mosque in Istambul. The plans are shown in Figure 8. We have at our disposal 2D plans and pictures. The central part of the Mosque is rectangular. It is composed of a squared main cupola with supporting elements: two tympan walls and two half polygonal cupolas. Each polygonal cupola has two cut squared cupolas and a tympan wall as supporting elements. We rapidly noticed some specificities:

- transverse arches are not equal on each supporting wall: either no arch or arches with various lengths (Figure 8b (A)) or various dimensions (Figure 8b (B)).

- squared cupolas (Figure 8b (C)) are cut according to any angle.
- Supplementary pillars (Figure 8b (D)) appear in transverse arches.
- transverse arches can finish inside one another or not.

Taking into account these specificities, we have adapted our C++ objects. The 3D model of the mosque (Figure 9 et Figure 10) was entirely generated with our parametric elements. Accuracy of the model depends on the accuracy of the data (plans, pictures, laser data). Modeling times are greatly reduced compared to a classical method. One click is enough to build an architectural element without architectural knowledge. The longest step is the data comprehension (plans and pictures) to understand the building scheme. But this step is unavoidable whatever the method used.

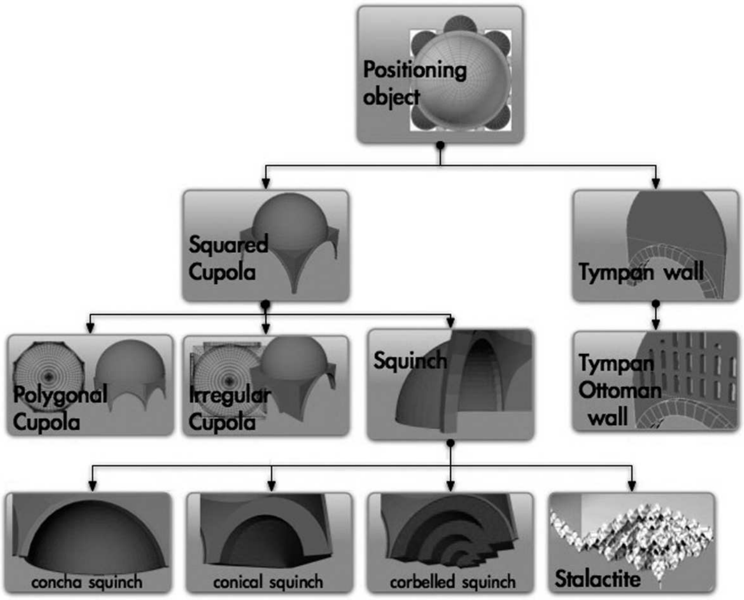

Figure 7. C++ classes for the cupolas

9. Conclusion and future work

In this paper we have presented the method we have conceived and developed for the 3D modeling of architectural buildings. The results obtained on the Mosque are promising. We have also studied vaults and built the 3D model of a Gothic abbey. The principles of the geometrical study are the same, but every architectural element is unique and must be studied for implementation. In the future we will go on: we have begun to study openings in various architectural styles and also the composition of openings in a facade. We also would like to improve the parameter adjustment step with photogrammetry and point cloud techniques. Indeed it is difficult to see clearly the objects and to select the good points in a laser data: the more the objects are numerous and composed of many elements the more it is difficult to interprete the data. We have begun to work with Boulassal et al. to test their method on complex façades and use the results as input data for GOP. The precision will therefore be increased.

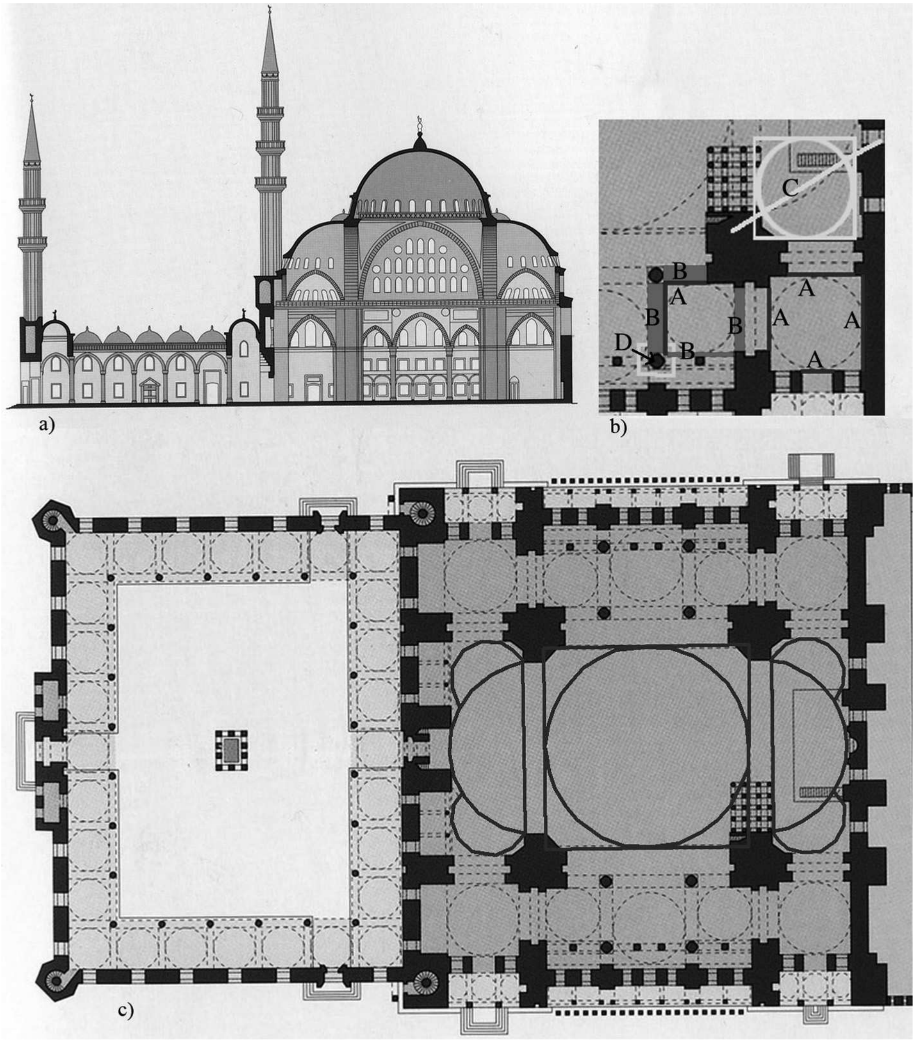

Figure 8. Plans of the Mosque

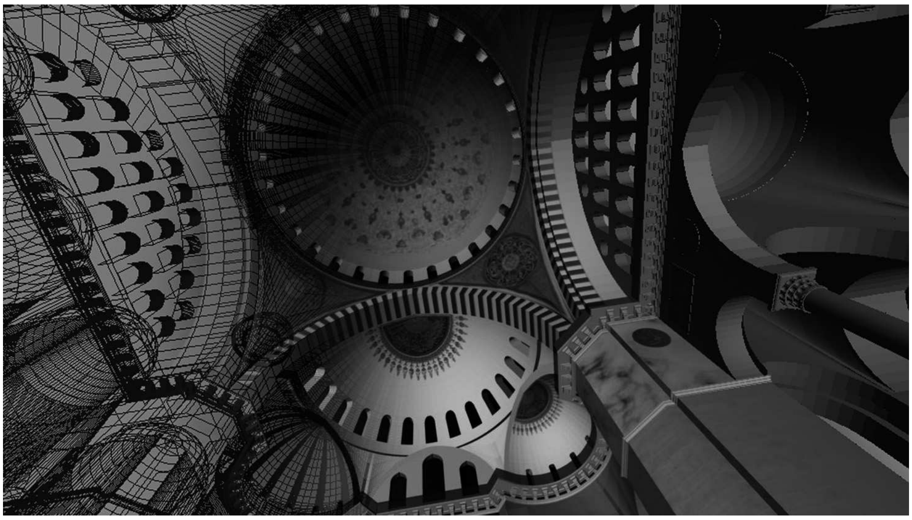

Figure 9. 3D model of the inside of the mosque

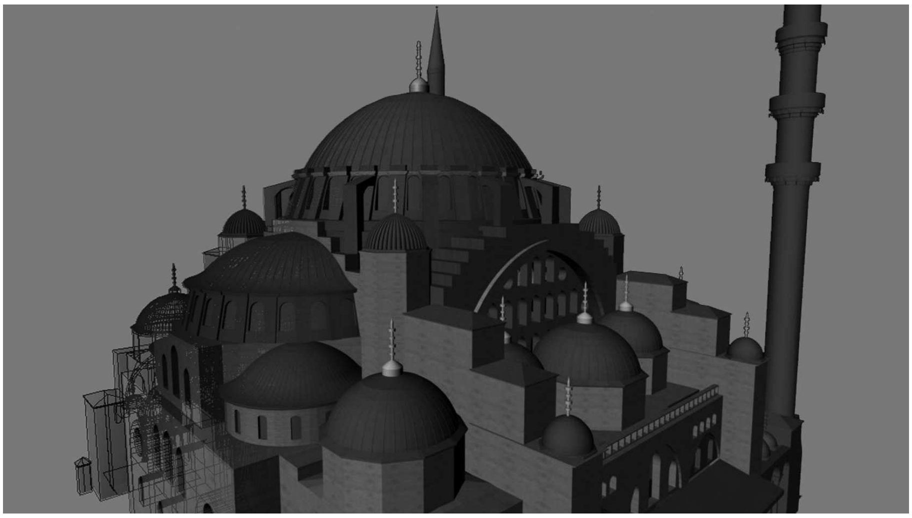

Figure 10. 3D model of the outside of the mosque

Acknowledgements

Great thanks are due to Yoann Maillard who realized the model of the Suleymaniyé Mosque.

References

Boulaassal H, Landes T and Grussenmeyer P, 2008: Automatic extraction of planar clusters and their contours on building façades recorded by terrestrial laser scanner. VSMM 2008 - Conference on Virtual Systems and MultiMedia Dedicated to Digital Heritage. Limassol Cyprus - October 20th - 25th.

Chevrier C and Perrin JP, 2008a: Interactive parametric modelling: POG a tool the cultural heritage monument 3D reconstruction. *CAADRIA conference*, Chiang Mai, Thailand, April 9-12 2008, pp.487-493.

Chevrier, C. and Perrin, J.P., 2008b. Laser range data, photographs and architectural components. *ISPRS conference*, Beijing, pp. July 3-11, p 1113-1118.

Debevec, P. and Taylor, C. and Malik J.: 1996, Modeling and Rendering Architecture from Photographs : A hybrid geometry and image based approach, Proceedings of SIGGRAPH, pp. 11-20.

De Luca, L. and Véron, P. and Florenzano, M. 2007, A generic formalism for the semantic modeling and representation of architectural elements, The Visual Computer, Volume 23, number 3, pp. 181-205.

El-Hakim, S. and Beraldin, J.A.: 2002, Detailed 3D reconstruction of Monuments using Mutiple Techniques, Proceedings of the internaltional workshop for cultural heritage recording, Corfu, Greece, pp 58-64.

Fuchs, A., 2006: Outils numériques pour le relevé architectural et la restitution archéologique, PhD thesis, nov 2006, Université Henri Poincaré, Nancy, France.

Palladio, A. 1965: *The four books of architecture*, traduction Isaac Ware, Dover publications.

Mueller P, Zeng G, Wonka P and Van Gool L, 2007: Image-based Procedural Modeling of Facades, ACM Transactions on Graphics, volume 26, number 3, article number 85. pages 1-9. Proceedings of SIGGRAPH 2007

Remondino, F., 2003: From point cloud to surface: the modeling and vizualisation problem. In proceedings of ISPRS International workshop on vizualisation and animation of reality-based 3D models, Tarasp-Vulpera, Switzerland.

Terrin J.J: 1997, *La quadrature du cercle, coupoles d'Orient et d'occident*. Ed. L'Esperou, Montpellier.

Viollet-le-Duc E: 1967, Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle, Editions. De Nobele, Paris.

Vitruve : 1996, Les dix livres d'architecture, translate in 1684 by Claude Perrault, Edition P. Mardaga.

References from the web:

Maya software: http://usa.autodesk.com (accessed april 2008).

Photomodeler software: http://www.photomodeler.com (accessed april 2008)

Trimble : http://www.trimble.com (accessed april 2008)