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# LASER RANGE DATA, PHOTOGRAPHS AND ARCHITECTURAL COMPONENTS.

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**KEY WORDS:** Laser scanning, building model, terrestrial photogrammetry, contextual modelling, architectural heritage, parametric modelling

## ABSTRACT:

In this paper we deal with 3D modelling from point clouds issued from laser scanning and also from photographs. Architectural parametric elements are semi-automatically adjusted in real time to the point cloud by varying the parameters describing the element. The scanned picture is correctly positioned in the virtual scene relatively to the point cloud and to other 3D parts of the scene. In the two cases (photograph and point cloud), points can be selected (3D points in the range image and 2D pixel in the photograph) and the building of the architectural element is processed relatively to the dimensions and positions specified by these points. Our research is carried out on various architectural styles (ancient, classic, gothic, khmer). The application field of our method is wide: it goes from cultural heritage virtual documentation to accurate model for archaeologists based on laser scanning of relics of the past. 3D models of existing buildings for lighting simulation, movie or game sceneries are also other possibilities.

## 1. INTRODUCTION

3D modelling based on a point cloud issued from laser scanning has led to many scientific publications. Two kinds of methods can be distinguished to achieve this modelling: first the modelling with automatic adjustment of simple geometrical shapes on the point cloud with mean square methods (plane, cylinder, box, sphere...), and secondly the treatment of the point cloud (filtering, ceiling...) for the mesh creation of complex shapes (sculptures). In the former kind of studies, databases of reconstructed objects are memory cheap but there are not many libraries of shapes available and shapes are simple. Nothing exists for complex architectural shapes such as the classic order capitals or the gothic vaults for instance. In the latter case, databases are so memory expensive that it can be used only for sculptures and non-geometrical shapes. We propose a new method that distinguishes itself from the two existing ones. In this method architectural parametric elements are semi-automatically adjusted to the point cloud or to a photograph (the three main dimensions) and interactively varying the element parameters allows accurate adjustments.

After a state of the art in parametric modelling (part 2), part 3 explains the principle of our method. Parts 4 and 5 explain how we take into account laser point clouds and photographs to help with the modelling process. In part 6, we present the methodology of studying architectural components in the aim of determining the pertinent parameters and the building method. Some examples are then exposed in part 7 and finally we conclude in part 8.

## 2. STATE OF THE ART

3D meshes from laser point clouds (Remondino, 2003) produce data with high precision. However the modelling

step is tedious because only simple geometrical objects are recognized (no architectural libraries are available). The Trimble society (Trimble 2008) proposes laser captors and software for the 3D reconstruction of objects. It also sells libraries for pipelines, car components but nothing for architectural elements.

Image based and photogrammetry methods (Debevec et al., 1996) (photomodeler, 2008) are also widespread but are able to model the general shape of the building but not its details. Texturing makes the model realistic without geometry modifications.

Modelling from architectural rules (Fuchs, 2007; De Luca et al, 2007) and parametric design (Schnabel, 2007) is a promising investigation field because architectural objects can be created in real time with default dimensions (taken from architectural treaties for example). Then object shapes can be adjusted to create the desired shape.

Techniques that combine several methods (El Hakim et al, 2002) are the most interesting for architectural purposes as we deal with a wide range of various data (both simple and complex shapes): photogrammetry for global and simple shapes, laser scanning for accurate model of complex shapes such as sculptures, with interactive and automatic methods according to the element complexity.

De Luca et al (De Luca et al, 2007) have developed an interesting tool for the 3D reconstruction of ancient buildings taking into account point clouds and photographs. However they only deal with moulding profiles that can be revolved or extruded. Their library of parametric objects is also composed of components based on mouldings. They do not deal with other kind of components and more complex shapes (doors, windows, facades, vaults...). Objects are built and positioned in space according to laser range data and photographs.

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### 3. PRINCIPLES OF THE METHOD

Our 3D reconstruction method is based on laser point clouds, photographs and theoretical architectural rules of the objects to be modelled in order to automatically create 3D models that can be interactively adjusted.

The principle of the method is as follows: the most common architectural components (moulding, vault, door, window, pediment...) are described by their own parameters in a file library. When the user chooses a predefined object from this library, it is created in real time with the values of the parameters read from the file. It can then be adjusted by modifying the parameters to adapt the shape to the various practical situations (Figures 1 and 2). Parameter adjustments let us obtain a 3D model close to the real object. Finally, the usual modeller functions allow specific creations and deformations of the shape (erosion, breaking, imperfect shapes). Sculpted elements modelled with meshes (issued from laser scanning or user-modelled) can be inserted in the global description of the parametric scene. The creation of the library relies on a preliminary study of each architectural element to define the dimensions and the various shapes in time and space. Laser point clouds (part 4) and photographs (part 5) are used to help the process of parameter adjustments.

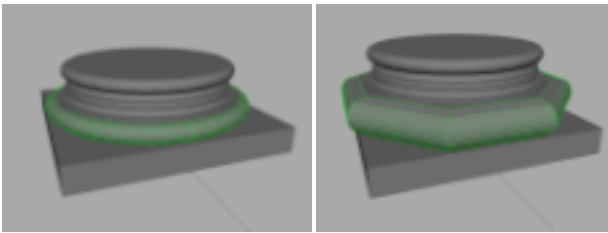


Figure 1: Corinthian base: le second moulding parameters have been modified between the first and the second image. The new height value translates automatically the following mouldings upwards.



Figure 2: The architectural model is a vault: the number of arches and their heights are different in the two instances.

Software development is performed in C++ and Mel (Maya embedded Language) to create new menus and plugins for Maya (Maya, 2008). A Maya object is described by a set of attributes that appear in a window (the attribute editor) when the corresponding graphical 3D object is selected in the scene. When an attribute is modified, the “compute” method is called and the object is generated again with the new values of the parameters. To each of our architectural components 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 various uses: archaeological presentation as it was in the past, 3D scenery for movies and much more.

### 4. TAKING POINT CLOUDS INTO ACCOUNT

Automatic adjustment of the architectural element to the point cloud is not undertaken as it could lead to wrong modelling: we are dealing with complex shapes and point cloud often contains noise due to measurement errors and modifications of the imperfect scanned shape (damages by erosion, breaking...). It is then difficult to distinguish small elements like thin moulding profile for example (Figure 3). For ancient, classical and also Khmer styles, theory is almost respected in the existing buildings and is then a great help for the modelling process. On the other hand, gothic style monuments have their own specificities according to theory: theoretical values have to be adjusted with the help of the point cloud (vault, pillars...).

Points of the cloud can be selected. Two points are selected to define a bounding box. If required, a rotation can be specified to orientate the bounding box. Then the user selects the architectural component (which can be a single element or a compound of elements) he wants to build (for example a Doric column according to Vignole). The component is then automatically built by adapting its global dimensions (here the total height of the column) to the selected points and by positioning it in space. In this case, only the height is taken into account because the entire mouldings of the column are described according to a module. For other architectural element (the gothic vault for example), the three dimensions are taken into account for the reconstruction. Then all the parameters can be adjusted by the user to better fit the point cloud.

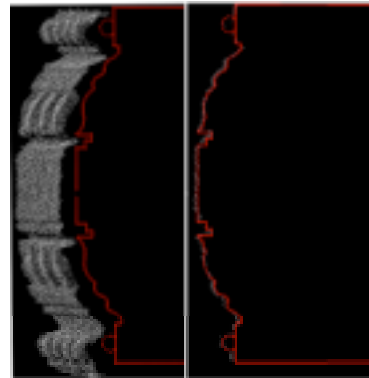


Figure 3: a profile of a Khmer element. It is difficult to distinguish small moulding shapes. The theoretical parametric model is a great help in the modelling process.

### 5. TAKING PICTURES INTO ACCOUNT

Most 3D reconstruction projects only dispose of photographs, since laser scanning is still expensive and time consuming. Pictures are taken into account in two different ways: with the viewpoint recovery (part 5.1) or with an upright picture (5.2).

#### 5.1 Use of viewpoint recovery pictures

The first step is to compute the point of view of the picture (5.1.1) and then to use this picture for the reconstruction of the monument (5.1.2).

##### 5.1.1 Point of view recovery

A photograph is not a perfect perspective projection of the existing objects. Distortions have to be taken into account for the viewpoint recovery. Some software exist to correct

such defects according to the specifications of the used camera. We use Dxo software to distort the pictures (Dxo, 2008).

- Viewpoint recovery with a manual method.

The advantage of this method is that it requires only two points and a direction. The result estimation is only visual but is sufficient in most cases. It could also be the first estimation of the automatic adjusting process when the automatic first estimation results are too erroneous. See (Chevrier et al, 2001) for more explanations of this method.

- Viewpoint recovery with an automatic method

At least six points are required. First an estimation of the external camera parameters is computed by a direct method (linear system resolution). Secondly an adjustment is performed if we dispose of more than six points, by a mean squared method. We had to develop a plugin for Maya with this method as Maya only deals with movies and not pictures for augmented reality purposes.

Once the viewpoint is estimated, one can use it to help the 3D reconstruction.

**5.1.2 Use of the pictures for the reconstruction**

The first step is to select 2D points in the pictures to create the associated 3D points. Then these 3D points are used in the same way as the range data points (part 4). We use two different methods:

- Use of a point on the image plane and of a 3D construction plan.

The user positions a plane in the 3D scene and selects points in the image plane. 3D corresponding points are then constructed on the plane: it is the intersection of the line [viewpoint, 2D image point] with the plane (figure 4).



Figure 4: Using a photograph for the 3D reconstruction process: positioning 3D point in the scene with the help of a viewpoint recovery picture and a positioned plane.

- Use of several pictures

On two or more pictures, the same corresponding image point is selected (called  $P_i$ ). With the known camera positions (called  $C_i$ ), straight lines are defined ( $P_i C_i$ ). Theoretically, these lines intersect at one point. In practice, with two lines, the shortest distance between the lines gives a small segment, on which the user can locate the 3D point. If we dispose of more than two pictures, by taking them two by two, we can define various segments, defining a small 3D space where the 3D point can be situated (Figure 5).

If we have a point cloud, this small area is a help to find a point in the cloud. It is a future work to automatically search

in the point cloud the points closest to the segment or inside the small area.

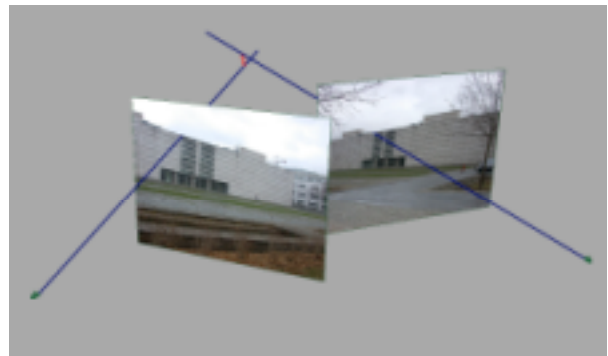


Figure 5: The 3D point is in the area where the 3D lines are closest to each other.

**5.2 Use of a set-upright picture in an orthogonal projection.**

Dxo software also allows a manual righting of pictures, so that they can be used as a support for a 3D reconstruction according to orthogonal projection.

Let's take an example of a façade (see figure 6). A rectangle with the same ratio as the picture and the same dimensions as the existing façade is positioned by the user in the scene where we want to build the façade. This rectangle is textured with the upright picture and points in the picture can be selected to create the parametric component on the 3D rectangle. The depth position component can be adjusted with the parameter components (for example, the two columns on each side are in front of the door plan). This technique is less accurate than the other because we use the picture as if it was an orthographic projection but it is not.



Figure 6: Using a set-upright picture for the 3D reconstruction. Here is a classical auditorium in Nancy (France).

## 6. ARCHITECTURAL COMPONENT STUDY

### 6.1 Component study

The creation of the library relies on a preliminary study of each architectural element to define the dimensions and the various shapes in time and space.

This step is important because good parameters and good 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 allowing the building of the 3D virtual object. For some kinds of gothic vaults for instance, few parameters are required: all the other dimensions can be deduced and the creation can be carried out following building rules.

Architectural components are first theoretically studied for various styles (ancient, classic, gothic, Asian styles...) from bibliography and also from building practices. Lots of architects, from Vitruve (Vitruve, 1996) to XVIIth century architects (Palladio, 1965) have described ancient and classic styles. Lines are straight; symmetry and geometry are widely used. These styles are principally based on mouldings, each moulding having a shape (cavetto, circle...). Dimensions are given proportionally to a module (Figure 7). A module is subdivided into minutes (12 for Tuscan and Doric styles and 16 for Ionic, Corinthian and composite styles). When the value of the module is chosen, all the dimensions of the object are known. The basic parameters for a moulding are simple: shape and height. The shape requires from one to several parameters (type, radius, offset centre...). Complex mouldings, like cyma, echinus or break are composed of several basic mouldings. 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...).

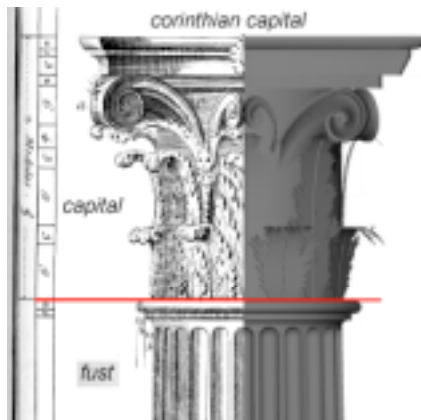


Figure 7: Capital of a Corinthian column. All the dimensions are given according to a module.

Lots of compound elements of the ancient and classic styles are also based on moulding (doors, windows, pediments...). From the study of each of these elements, a set of parameters and moulding profiles enable them to be described. For instance, a pediment can have various shapes (triangular, circular, with one or several arches, open, broken or scrolled pediment...). The bottom profile can go further than the top profile. A head profile can be added, etc. The pediment will thus be specified by its global dimensions, specific parameters, various profiles and by the presence or not of its sub-elements (entablure, head, oculus...).

Gothic style architecture does not differ from ancient art in that it can be split into several sub-styles (chronologically speaking) and in that it is mainly based on geometrical rules of arrangements of architectural elements, themselves based on their own dimensioning rules (Figure 8). On the other hand, there are very few textbooks describing these geometrical canons, for two reasons: at that time there was no distinction between craftsman, architect or erector, the knowledge of building rules was mostly transmitted "talk shop", plans and elevations were often drawn directly on the ground site. Secondly paper was precious, books were rare and most of them have been damaged or destroyed since then.

Probably the most commonly admitted reference texts are those from Villard de Honnecourt (Honnecourt 2008) in his "Carnet" (notebook), around 1230, in which only sixty pages out of one hundred remain. More recently in the 19th century, Viollet-le-Duc published his "French Architecture Argumentative Dictionary, from 11th to 16th century" (Viollet-le-Duc, 1967). These books and the great number of remaining buildings lead to the main point of the gothic style: it is far more various and rich than the ancient art styles in shapes and measurements.

Our study of gothic architecture focused firstly on the gothic vault. All the vault types (derived from previous Romanesque styles) were classified depending on their plans, as well as their ridge and web geometrical and structural constitution: pointed barrel, groin vault, rib vault... The choice of a set of geometric parameters can then be used to entirely build a specific vault by instantiating its architectural elements (boss, ridge, web...) and applying to them the geometric rules of that particular vault type.

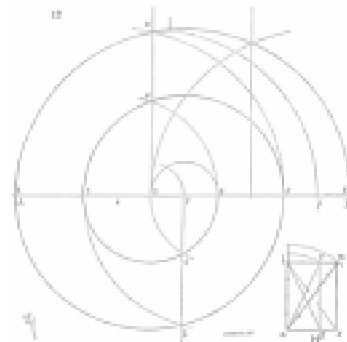


Figure 8: Scheme of dimensional rules between the various arches according to Villard de Honnecourt.

### 6.2 Library construction

The aim of the previous study is to describe an architectural component by a minimal set of parameters allowing its construction by a specified method. The element can then be developed and various practical or theoretical examples of this element can be instantiated in the library by identifying the values of each parameter.

Library files are written in Open Inventor file format but it could be any format that allows simple hierarchy description. We do not use Maya file format because it does not allow such a description in a simple way. A file can contain the description of one or more parametric elements. Files can be included one in another. Thus a description of an entire project (a building for example) can be easily organised in several files according to architectural considerations. Creation and adjustments can be tested on

elementary parts. Afterwards, these parts can be associated hierarchically in another file to create a more complex component.

### 6.3 Complex scenes

Several architectural elements have to be generated to create a compound element. A column is composed of a stacking of mouldings, a monument is composed of several columns, cornices and so on. 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. 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 description of a large scene and description of relative positioning between objects. More details can be found in (Chevrier, 2008).

## 7. EXAMPLES

The application field of our method is wide: it goes from cultural heritage virtual documentation to accurate models for archaeologists based on laser scanning of relics of the past. 3D models of existing buildings for lighting simulation, movie or game sceneries are also other possibilities.

### 7.1 Nasium gallo roman site

In the case of archaeological projects, our method and range images of some relics of the past allow us to determine the diameter of the column of the Nasium Gallo-Roman temple. (Figure 9). Figure 10 shows the 3D models and the point clouds of the parts of columns.

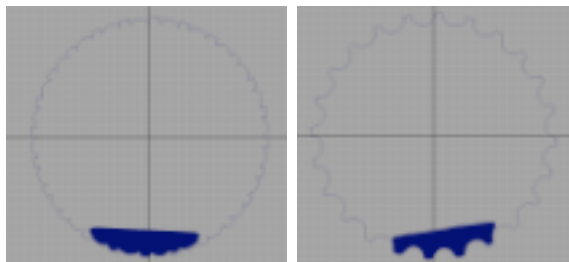


Figure 9: Adjustment of the parameters to the existing data (laser point clouds of parts of the columns).

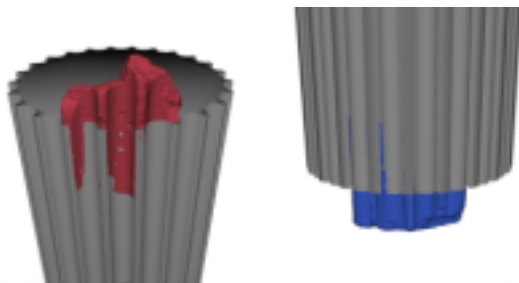


Figure 10: Column of Nasium project. In red and blue are surfaces built from the laser range data and in grey is the 3D model of the columns.

### 7.2 Montsec: American cemetery monument

The aim of this project is to illuminate the monument. For this, we were asked to produce various simulations with

computer graphic techniques so that the deciders could choose the project they wanted to realize.

We have at our disposal 2D plans, pictures and several measures, but no laser data.

From the 2D plans, we are able to determine the architectural components and their parameter values. Then we describe the entire monument in a hierarchical scene composed of these parametric components. The monument is entirely described with parametric components in several files. No traditional modelling is made. Then the main file is loaded by our plugin in Maya and the monument is built in real time. All the components are positioned according to the others in a relative way also described in the files. Figure 11 shows the 3D model obtained with our description and Figure 12 is an example of a simulation project.

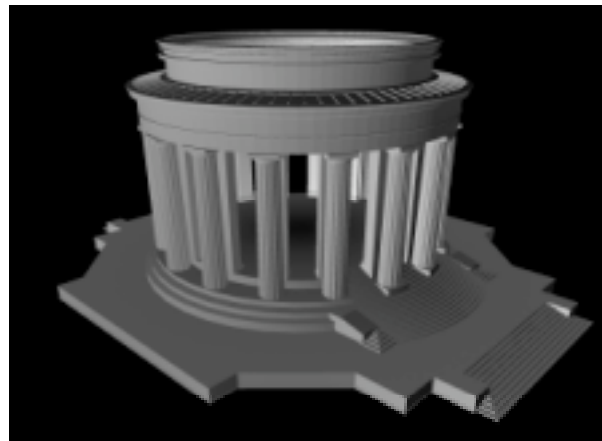


Figure 11: The 3D model of Montsec monument.



Figure 12: Lighting simulation of the monument realized by Didier Bur (CRAI UMR MAP ENSA Nancy).

### 7.3 Tholos: Marmaria Site (Delphi, Greece)

Here is also an archaeological project for which we only disposed of pictures and archaeologists' hypotheses for the 3D shapes of the building. A part of the monument (on the left in the picture in figure 11) has been rebuilt with the pieces of rock found on the site. Figure 12 shows the realistic simulation with a computer graphics image.



Figure 11: Archaeological site reconstruction.



Figure 12: Realistic simulation with computer graphic image composed with a background picture.

## 8. CONCLUSION

In this paper, we have described the method we use for the 3D modelling of architectural components from building rules of styles (ancient, gothic, ...) and also from laser range data and photographs.

In the future, we want to combine, in the 3D representation of a unique element, parametric modelling and mesh modelling for keeping damage effects for example. We also want to extend the study to other architectural styles: other styles can be simply added if they can be described by parametric models. The method will also be extended with photogrammetry methods to adjust both the camera parameters and the main dimension parameters of an object (initially for simple objects).

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