A STONE-BY-STONE PHOTOGRAMMETRIC SURVEY USING ARCHITECTURAL KNOWLEDGE FORMALISED ON THE ARPENTEUR PHOTOGRAMMETRIC WORKSTATION.

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ABSTRACT

ARPENTEUR is a web application for digital photogrammetry mainly dedicated to architecture (Architectural PhotogrammEtry Network Tool for EdUcation and Research) available at http ://www.arpenteur.net. ARPENTEUR has been developed by two complementary research teams: the "Photogrammetry and Geomatics" group of ENSAIS-LERGEC's laboratory (Strasbourg, France) and the Gamsau-MAP CNRS laboratory located in the school of Architecture of Marseilles (France).

This paper focuses on a new approach of stone-by-stone surveying in which formalised architectural knowledge is used as a prerequisite to the photogrammetric measurement process.

In addition to this morphological definition, the structure point of view is implemented in the model in order to consider some architectural elements as containing a set of ashlar blocks. In our approach of stone-by-stone surveying, which has been conceived for the study of historical ashlar masonry but can be applied to other types of investigation, the measurement is performed directly on each individual stone in its built context. A previous edifice analysis , conducted by an archaeologist, is necessary to define the construction characteristics and chronology, and the properties of all the measured architectural entities. This results in the definition of an approximate depth for each type of stone, allowing a limited survey to the blocks visible part. An extrusion vector is computed in order to inform lacking geometrical description of the block.

Once the instanced block is measured a polyhedron representation of its morphology is generated. The instance is also added to a data structure in which it is positioned according to topological or geometrical order. The result is therefore a collection of ordered blocks that includes, for instance, for each block data on its neighbours (adjacent blocks). When completed, the tool will create a direct link between the architectural object and the database, enabling to locate and thus identify the properties of each block registered in the database. The possibilities of this new type of approach to architecture extend from archaeology to restoration and maintenance to any type of structure treated by photogrammetrical survey.

Retrieving architectural information (for example the intrados radius of an arch) is the approach we have developed in architectural surveying. We are currently working on giving this possibility in the stone-by-stone surveying process on which this paper focuses.

1   INTRODUCTION

1.1   Architectural survey

ARPENTEUR is a web tool dedicated to architectural survey. It has the benefit of the two partner laboratories' expertise in the field of close range photogrammetry and architectural knowledge representation in a survey process. This collaboration is enriching for both researchers and students working on the project.

The plotting module dedicated to architecture is based on a formalization of architectural and geometrical knowledge. The architectural corpus must be first identified and structured. Then the architectural knowledge is used to guide and control the building measuring process. This means that the morphology of the measured object is already known. This knowledge is provided by previous analysis of the measured structure, e.g. by the archaeological survey of an historical building. Building elements are described as "entities" (elementary elements) providing that they meet two requirements:

➢ An entity is a unique " object " identified by a single element of the architectural vocabulary.

➢ An entity has an obvious and permanent role in the physical structure of the building.

The object-oriented programming approach enables to gather generic entities into hierarchies of elements sharing properties or common behaviors or attributes, each property added giving birth to a new, more specialized (lower in the hierarchy), generic element .

In addition of architectural entities, the system is able to manipulate others concepts present in the architectural knowledge corpus used to describe the building, as ashlar block or topological relation between architectural elements.

1.2 Two different point of view

This paper focuses about the use of two different point of view on the architectural element to be measured : we consider an architectural entity (for example a wall or an arch) as a structural element with its own function in the building and also as a set of different ashlar blocks. The goal is to obtain a complete geometrical description of both the architectural entity and the set of ashlar blocks using a partial measurement of the stone and the information, for each stone, of the architectural entity owner.

Each ashlar block morphology is here considered as a polyhedron with two parallel faces, in most of the cases only one face is visible, sometime two, rarely three. The survey process can inform about the dimensions of one face, then the entire polyhedron is computed according to the architectural entity's morphology (extrude vector) and the data provided by the archaeologist (depth, shape …).

> *Marco Polo describes a bridge, stone by stone.*
> *« But which is the stone that supports the bridge? » Kublai Khan asks.*
> *« The bridge is not supported by one stone or another, » Marco answers, « but by the line of the arch that they form. »*
> *Kublai Khan remains silent, reflecting. Then he adds:*
> *« Why do you speak to me of the stones? It is only the arch that matters to me. »*
> *Polo answers: « Without stones there is no arch. »*
>
> Italo Calvino, (Calvino, 93)

Computing an extrude vector can be easy in the case where the architectural entity morphology is obvious; during a wall survey for example an extrude vector can be computed by a least square adjustment of a plane around the survey zone. In this case where the entity's geometrical properties are simple, the extrude vector is calculated before the survey phase and the block is extruded directly from the measured points. In the case of a round arch the extrude action should be radial and needs the geometrical features of the entity (intrados, radius, axis).

In this case a post process computation is necessary to elaborate the main architectural entity's features from the ashlar block's measures. In order to achieve to obtain the whole block morphology it is often necessary to compute the architectural entity's features. This can be done by specifying for each type of entity the relevant mathematical operation and the way to extract relevant points from the measured ashlar blocks.

1.3 Using ARPENTEUR : a photogrammetric survey through Internet

The ARPENTEUR photogrammetric approach is based on the well known routines (Kraus, 1997). The standard steps are developed : internal, relative and absolute orientation and since the version 1.4.2 a bundle bloc adjustment is available.

ARPENTEUR is developed in JAVA, using actually JDK 1.1.8 and is operational from any hardware platform supporting a web browser using this level of Java. Presently the software is tested with Netscape ™ Communicator 4.5 on PC platform and SUN workstation.

The ARPENTEUR software is client-server oriented and provides a way to transfer architectural measured objects on the server witch is able to generated report files and 3D CAD model survey interpretation. These generated files are available on the server thought a FTP transfer.

2 THE CASE STUDY : "LA PRIORALE NOTRE-DAME D'ALEYRAC"

Our case study is dedicated to the Romanesque priory church Notre-Dame d'Aleyrac, in northern Provence (France). The choice of this building is motivated as follows: the building, which has been studied recently by the co-author of

this paper (Hartmann-Virnich 1996), is an excellent example of the refined ashlar two-shell masonry characteristic of the latter 12th century in southern France. The church is preserved in a semi-ruinous state, offering an insight into the internal structure of the walls, necessary to develop the relevant extrude vectors for an ARPENTEUR survey. The Romanesque builders of Aleyrac had obviously a good empirical knowledge of the mechanical properties of their building material, as they used deliberately different types of stone for different functional entities, such as cornerstones, arches and windows, the vaults alone being assembled with three different sorts of limestone (hard, soft, and tufa). This tends to prove that the criteria defining different types of ashlar material : ordinary blocks, cornerstones, voussoirs, are relevant, and can be used consistently for an ARPENTEUR survey.

The stone-by-stone analysis of a medieval building implies a great number of interesting aspects, essential for the knowledge of the building process and chronology, the technical standards and skills of the builders, the mechanical properties of the edifice (deformations) as well as the economy and the history of its development. The dimensions, the finish of the stones (e.g. the precision of angles and sides, tool marks, mason marks etc.), the geological properties of the distinctive materials, the continuity or discontinuity of the courses, are irreplaceable clues (Hartmann-Virnich, 1998, 1999). A virtual stone-by stone survey is of great interest, especially if allows to visualize relevant information for each constructional unit.

The selected part of the building is the north transept. The study has been focused on the round arch opening on the north side of the nave. The sample is of particular interest as it can be easily defined as a coherent unit composed with similar elements, the voussoirs, which share the same properties : each voussoir course is assembled with three or four blocks, two of which have visible front sides. Ideally, they all share the same intrados and extrados, i.e. the curved inner and outer sides, and their joints converge towards one same central axe parallel to the intrados and extrados. On the other hand, their thickness and depth vary. Thus the structure offers several types of relevant parameters, variable and invariable, for a test of ARPENTEUR's capacities.

Our research project is originated from the dialogue between specialists of different disciplines who rarely collaborate to create new tools. The interdisciplinary exchange is at a beginning but will generate further exchange and, we hope, far-reaching results. Although ARPENTEUR is presently being developed to serve in the architectural field, its possibilities might go far beyond, the tool being adaptable to the photogrammetric survey of any type of structure composed of characterized units.

3   THE PHOTOGRAMMETRIC SURVEY

3.1   The photogrammetric campaign

The photogrammetric campaign was achieved in August, 1999 in Aleyrac, Drôme, France. The pictures were taken with a P32 Wild camera using Agfapan 25 roll film. No control point was taken, we used plumb lines and distances to create a local referential. Three stereo pairs have been used. The film was scanned by Kodak and the result file is 4860 x 3575 pixel in GIF format.

Figure 1. Example of picture used for the survey.

3.2   Definition of blocks

The survey first step is a building rigorous analysis to isolate the architectural entity and the ashlar blocks types to be measured. For each entity, arch, wall, gable wall, we have to determine which type of stone has been used and how to measure it. We can isolate two generic cases of measurement :

➢ The geometry of the entity is easy to modelize (a wall offers the opportunity of determining a plane for extrude)

➢ The geometry is not obvious and the extrude method needs to be informed about any indirect results from the measurement (intrados radius and axis of an arch).

In each architectural entity there is a block manager's object in charge of managing blocks. It is possible to obtain a lot of data from each single block :

➢ Owner : the architectural entity.

➢ Model : the photogrammetric model used for survey.

➢ Plane : the plane used for extrude (including measured points to compute the plane).

➢ Measured points .

➢ Computed points (after the extrude phase).

➢ Extrude depth : measured or defined by the archaeologist.

➢ Access to the polyhedron of morphology representation.

All these data are available from each ashlar block or from a Block-Manager object in charge of managing all the entity's blocks, or also from a general Block-Manager. The Block-Manager is also in charge of ranking blocks (finding adjacent or neighboring objects according to special criteria), calculating statistics (on volume and dimensions).

3.3   Measuring the blocs

As often as possible we try to compute the complete geometry of a block during the survey process. The measurement can be done, and has in fact been done by an archaeologist, the most important point at this step being not a high competence in photogrammetry (the correlation process help a photogrammetrist neophyte to determine the homologous points) (Drap P., Grussenmeyer, P., 1998), but the integration of architectural knowledge into the model.

During the survey process the operator informs the system on which kind of ashlar block he is measuring, its third dimension, the architectural entity it belongs to ; he chooses the points used to compute the extrude plane and decides or not to use the 'on the fly' extrude facilities.

The depth can be determined in two ways :

If, as generally, only one face is visible, the depth

Figure 2. The survey process in Arpenteur.

is evaluated by the archaeologist according to properties known from the monument itself. At Aleyrac, the dismantled walls give an insight into the inner structure of the masonry and the dimensions of ashlar blocks of the facing. These actually differ from course to course, in order to create a firmer link with the stones and mortar filling the space between the two facings. In the specific case of certain cornerstones or voussoirs the third dimension can be deduced from the other apparent face or faces.
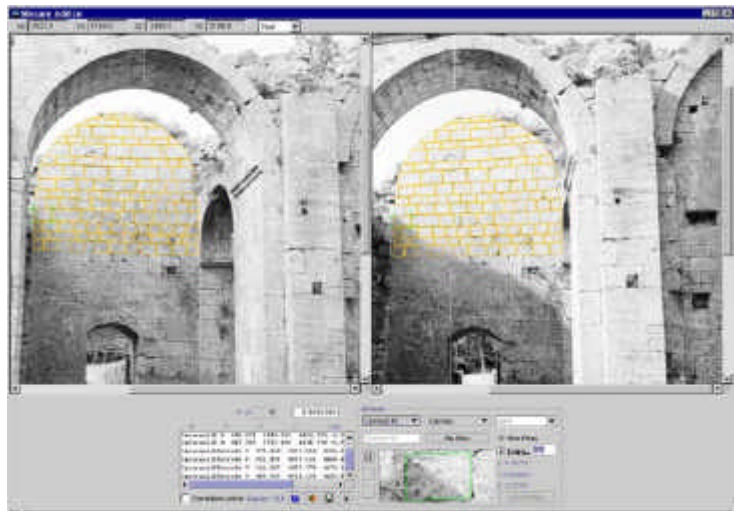
4   CALCULATION OF INTRINSIC PARAMETERS: THE CASE OF AN ARCH

In the present case the aim is to determine the geometric definition parameters of each architectural entity using both the measured blocks and the architectural knowledge (the geometrical definition of the entity morphology, structural and building knowledge).

For each architectural entity it is possible to isolate a set of relevant blocks giving some information on the geometric parameters. This approach requires three steps :

➢ The determination of the object's bounding box and of it's own referential.

➢ The isolation, according to geometrical and topological data, of several sets of blocks for each geometrical parameter to compute.

➢ Finally isolating points (held by the blocks) and computing by least square adjustment the geometric parameters of the entity.

As specified above, we present here the case of the north transept arch.

4.1 Determination of the bounding box

A relevant bounding box is corresponding approximately to the minimum volume of the object. We are working on a generic method to compute such a bounding box.

For all convex object with a dominating direction we can use an analysis of the main component, which can be used without any consideration on the object. The first problem is to determine the capable transformation going from the original referential to a local referential where one of the axis is equipollent to the object main axis. This is equivalent to looking for a maximum variance through this axis. In this new referential it is possible to compute a bounding box by sorting coordinates which results in a good approximation of the smaller bounding box.

Unfortunately, this method does not function well if the points are inside the volume, or if the architectural volume is concave. This means that we have to get first the convex envelop before using the covariance method to get the bounding box. Actually we use an

Figure 3. The minimum volume bounding box.

hybrid method, as we already have a set of relevant information on the architectural object. These information are collected during the survey phase by the operator according to the architectural model used.
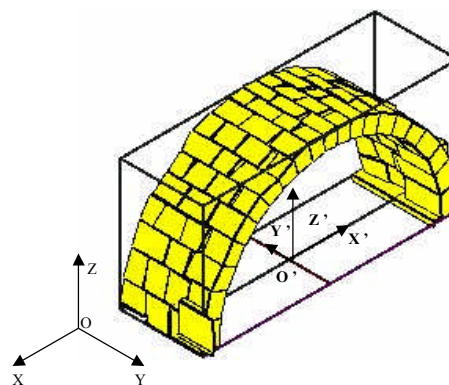
4.2 Determination of relevant points using topological organization

Here, we want to retrieve objects, like blocks with particular values of their attributes. For example, we may wish to get all blocks of the entity belonging to the same course. To solve this problem, we could ask the operator to point out for the current block which block is the next or the previous in the course. Then this information could be store in some attribute of the block. Nevertheless, this works fine as long as you don't need to find also, for example, which is the upper block: in this case, you'll have to write a new procedure to take upper blocks into account.

A more general way is to consider blocks as spatial objects and the entity (or its Bloc-Manager) as a spatial database. It is then possible to find all blocks with a particular value of their coordinates in the referential of the entity. To achieve this, a direct solution is to scan all blocks meeting the criterion or more generally to sort data according to this criterion. This is fine but could be quite time consuming as the whole set of data have to be examined at least once before getting an answer. Moreover, if such queries are often made, ordering has to be done at each time making the program unusable. Finally, last but not least, the desired ranking could be partial: for example we may wish to find the *k* nearest neighbors of an item that are closer than a certain distance.

In this experimentation we make use of an octree as an implicit spatial index. An octree is a hierarchical data structure which uses a regular decomposition of space to index spatial objects. Each octree block is a cube (a container block) where leaf blocks contain the spatial objects, whereas non-leaf blocks are decomposed into 2^d sub-blocks, where *d* is the number of dimensions (3 for us). In this case the bounding boxes that contain the objects are disjoint and, due to its extent, an object can be associated with more than one bounding box or container block. We then use the algorithm proposed by Hjaltason and Samet (Hjaltason and Samet, 1995) to rank the objects. This method recursively visits the tree nodes containing some query points, starting from the root. This algorithm replaces the recursion stack by a so called *priority queue* which enables to record the blocks whose descendants have not been visited yet as well as the objects which have not yet been visited. In this *priority queue* the objects as well as the container blocks are ordered according to their distance to the query point, so that, at each step, the next object or block to be examined is the closer from the query point. The efficiency key of this method is, (a) that not all the objects have to be visited before getting the result, (b) the search can be dynamically adjusted depending on the objects already reported: each time an object is reported the algorithm can resume from the point it has reached instead of starting again from the beginning. Another interest of this algorithm is that it can be extended to more than three dimensions as long as consistent distance functions can be defined (see Hjaltason and Samet).

At this point, we have armed ourselves with an efficient method to make queries based on positional definition of objects. For instance, we can search for neighbors of a block, after it has been measured, asking which are the blocks in the direction defined by the normal vector of one of its faces and located at less than a given threshold distance of this face.

4.3 Calculation of intrinsic parameters

In the case of an arch we have five parameters to compute : the cylinder axis, the intrados radius, the extrados radius and the two circle centers (who should be on each top of the cylinder axis); After the determination of the blocks, the points are easily located by geometric criteria.

Here we need to develop the architectural model : by construction the intrados and extrados centers have to be at the same location.

4.4 Extrude of blocs measured in the intrados

Once we have computed all the geometric arch parameters we can extrude the bloc which has been measured only by their face visible in the intrados. (internal part of the arch). This extrude is radial from the main axis of the intrados axis cylinder. Each point has its own extrude vector define by the projection of the point onto the main axis and the point itself. Each computed stone of the arch is represented as an arc of a rectangular torus centered on the intrados main axis.
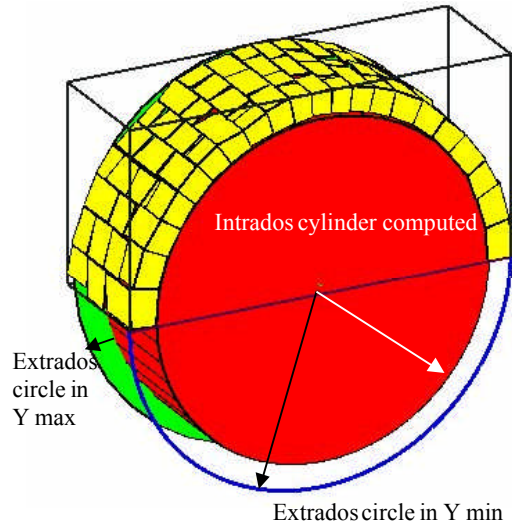

Figure 4. Arc intrinsic parameters scheme.

5 RESULTS : A NEW INTERPRETATION OF THE BUILDING

5.1 Geometric primitive least square optimization

We made two kinds of least square optimization in order to make the numerical results explicit. We present in figure 5, the two sets of points measured on the intrados and extrados front stones. On the figure, each point at the angle are on the same stone. On figure 6 we can see an intrados representation on the developed cylinder. The cylinder is the least square cylinder from all the indrados measured points. On the X axis we have the curvilinear abscissa of each points, the Y component have not changed and the Z one is the residual distance from the optimized cylinder.
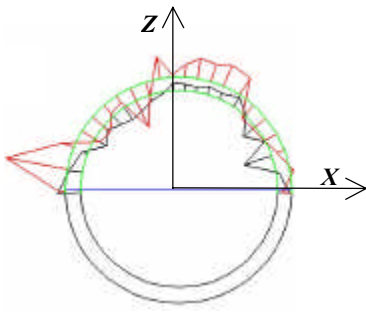

Figure 5. Intrados and extrados circle least square optimization with 20x anamorphosis of residuals.

Figure 6. Intrados cylinder least square optimization with 20x anamorphosis of residuals. : iso-deformation curve (each 5 cm) from the computed Cylinder. In green out of the cylinder, in black inside the cylinder.

This type of approach is of considerable interest, as it permits to verify the exactitude of the stone cutting and the deformations undergone by the built structure. According to the architectural properties of the arch, as defined by the comparison with other arches of the building itself and other contemporary examples of the same technical quality, the arch should ideally be a precise hemicycle. The magnified irregularities (20x anamorphosis of residuals) tend to demonstrate a partly close approximation of the intrados to this theoretical curve, and confirm the high standard of the workmanship of the edifice. The comparatively slight deformations in the lower parts and at the top might be due to movements subsequent to the settling down of the masonry after the removal of the sustaining auxiliary wooden structure, and the increase of the weight of the surrounding masonry, the arch being - according to archaeological evidence - normally built before.

Least square optimization can thus be helpful for the approach or the identification of an ideal form, i.e. the theoretical concept of this form In the case of a gothic pointed arch, for instance, relevant geometrical proportions can thus be determined and compared. Applied to more complex structures, the process can help to characterize and to comprehend deformations as being related either to the more or less exact or inexact realization of a project, or to statics.

5.2   3D cad outputs

The resulting architectural model, entities computed and measured ashlar blocs have a set a 3D writing method able to generate ASCII WRML file and binary design file for MicroStation cad software made by Bentley. We choose to generate binary design file for MicroStation instead of the widely used DXF file format because we can easily introduce non graphical data linked to the architectural element representation. It's now easy to establish a link between the architectural element and its MicroStation representation.
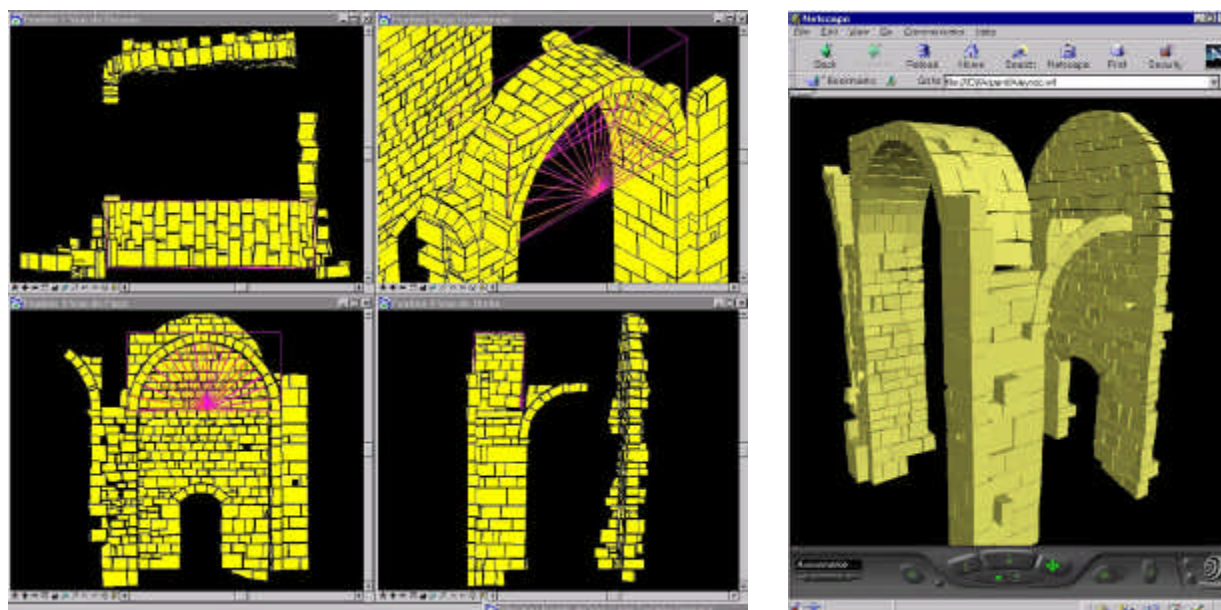

Figure 7. Results outputs for Microstation, Bentley and VRML 2.0.

6   CONCLUSIONS

As regards architectural and archaeological analysis, two essential issues of ARPENTEUR are to be pointed out : the use of the tool for direct measuring structural elements, and the link to be established between the image and a database. This second feature is of particular interest, as it combines a representation of the architecture itself to the database serving as a tool for the analysis of its units. It will be in fact most useful to locate in or through the virtual image all the blocks of one same category, as defined and registered in the database files, such as : type of block (voussoir, cornerstone, column, capital,…) or architectural unit (window, buttress, vault, bay…), type of stone, state of preservation, details of surface (mason marks…). Spotting these categories in their architectural context offers the advantage of relevant groups clear perception . It is easy to imagine the wide range of possible applications, far beyond the domain of architecture and restoration.

Mechanical simulation

Beyond this work presented here this approach of the link between photogrammetric survey and architectural knowledge is the first step to another project dealing with a new approach for the mechanical modeling of historical monuments built with blocks. (Acary and all., 1999). The computational method, Non Smooth Contact Dynamics (NSCD), is used to simulate masonry as a large collection of bodies under unilateral constraints and frictional contact. The computational method, NSCD, within an architectural and archeological model are merged in a single tool providing a interdisciplinary approach of historical buildings where the presented work, a photogrammetrical survey monitored by an architectural and archeological knowledge, gives the building's morphology and initial deformations.

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