

GOING TO SHAWBAK (JORDAN) AND GETTING THE DATA BACK: TOWARD A 3D GIS DEDICATED TO MEDIEVAL ARCHAEOLOGY

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ABSTRACT:

The paper presents an interdisciplinary project which is a work in progress towards a 3D Geographical Information System (GIS) dedicated to Cultural Heritage with a specific *focus* application on the Castle of Shawbak, also known as the “Crac de Montréal”, one of the best preserved rural medieval settlements in the entire Middle East.

We develop a set of tools for medieval archaeological analysis ranging from the production of traditional graphical documentation like orthophotos and low-resolution 3D models (VRML) to the use of 3D/2D GIS through the creation of centralized and exhaustive object storage tool both for archaeological and photogrammetric data.

Using these tools archaeologists will be able to produce, store, visualize and manage both archaeological and 3D data, according to their needs. The Shawbak archaeological project is a specific and integrated project between medieval archaeological research, conservative restoration and site's valorization.

Focusing mainly on stratigraphical analysis of upstanding structures provides archaeologists with a huge amount of data to collect on site and useful records that will be used to understand the structures from stratigraphical and technological point of views.

The foundation stone for this project is the analysis of documents produced and used by archaeologists in order to identify specific archaeological requirements

The first phase is to give archaeologists traditional photogrammetric tools so that they can be autonomous in producing graphical documents (taking photographs, photo orientation and traditional orthophoto generation). The second step is to develop a common model structure for both photogrammetric and archaeological data storage using a unique database and allowing to link archaeological data with 3D measurements.

Specific photogrammetry tools dedicated to stone by stone measurement have been under development since 2000 to help archaeologists to easily produce photogrammetric surveys. These tools are now integrated in a more complex system which allows automatic production of 2D or 3D representations from archaeological database queries. The graphical 2D documents produced through this process look like the handmade drawings done by archaeologists using orthophotos.

The 3D GIS is the last step of this chain and aims the automatic production of 3D models through archaeological database queries: these 3D models are in fact a graphical image of the database and at the same time the interface through which the user is able to modify it.

This approach enables automatic 3D thematic representation and new archaeological analysis through bidirectional-links between 3D representation and archaeological data.

All these developments are written in Java within Arpenteur framework. (Arpenteur, 2008)

1. ARCHAEOLOGICAL CONTEXT: THE NEED.

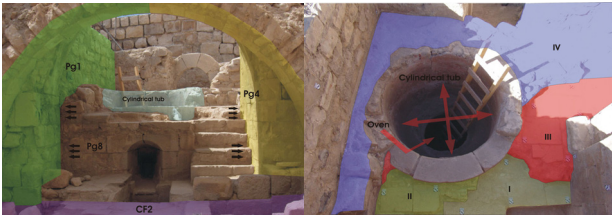
The archaeological research of the Castle of Shawbak, also known as “Crac de Montréal”, (Figure 1) one of the best preserved rural settlements in the entire Middle East (Drap et al. 2007, Vannini et al. 2007) has been chosen to develop a new documentation system. In fact the site is very huge, stratigraphically complex both in deep stratigraphy and in upstanding structures strathigrapy. Because its features and in accordance with the University of Florence research in Petra Valley (Vannini et al, 2007), the Shawbak analysis starts from upstanding structures (Vannini et al. 2002). First of all this allows to collect many archaeological data in relatively short

time. Only later on the archaeologists have decided to open some excavation areas to better understand the dynamic of settlement.

The stratigraphical analysis of upstanding structures produces a very large amount of data both graphical and stratigraphical. For the first one the common method to collect and to record them on the site is the survey. The survey is achieved in different ways, often it is two-dimensional. Its goal is to define the area, the perimeter and the volume of all the recognized USM (standing for *Unità Stratigrafica Muraria* – similar to the stratigraphic unit for digging archaeology). Every USM is a building homogeneous action which is representative of different building moment. In other words to identify and record

For the second one we use commonly a schedule in which the stratigraphical data is written, that means chronological data and also the technological data of the buildings (lithotype, presence of mortar and its quality, stone measurement), that can lead to summarize the workers technological level and the power of the owner.

Hence we must work with both graphical and archaeological data and we need to connect them. We need also to spend less time in the field drawing the survey because we need to spend more time to identify and know all the USM, but, at the same time, we need to produce the best possible graphical data because this is the best way to study and to compare our data to produce historical knowledge. (See Figure 2 below).



2. THE TRADITIONAL PHOTOGRAMMETRIC RESULTS

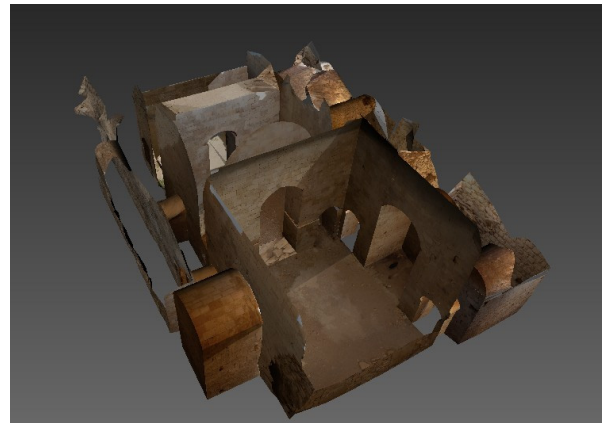
Several photogrammetric campaigns have been accomplished in Shawbak in the past years allowing the production of several graphic outputs representing archaeological features and constructions. These campaigns are composed of photographic sets acquired with calibrated digital cameras both in convergent and parallel coverage with the survey of control point by Total station and DGPS. These control points are used to reference the photogrammetric models in a common geodetic system. Among the most common outputs achieved in this process are orthophotos, low-resolution 3d models and vector graphic drawings representing constructive features.

Orthophotos are two-dimensional projections of physical elements (like walls, pavements or ceilings) (Figure 3) that provides archaeologists with scaled and orthographic representations which can be used for multiple purposes like vector restitution, planar measuring or archaeological interpretation (as in USM definition).

Three-dimensional models are the result of 3D shape restitution of built structures in the photogrammetric models. In this case they are low geometric resolution representations although they present high definition photographic texture (Figure 4).



The process of shape acquisition consists in defining the geometric characteristics of buildings or other archaeological elements by defining edges and surface discontinuities in order to achieve a geometric representation of the reality. They provide archaeologists an “absolute” 3D representation of all the features on a site, expressing the spatial relationship between them and going one step forward (in this case one more dimension) comparing to orthophotos.



Traditional vector graphic drawings correspond to operator-assisted restitution of specific features, like blocks perimeters, using photogrammetric models (See Figure 10). In this process photographs are used to interpret and measure morphological characteristics on the objects under study, resulting in drawings that extract or enhance information for archaeologists. Although 3D data is far more complete than 2D planar projections it is not used usually in traditional archaeological workflow as, in most cases, there are not appropriate interfaces for archaeologists to interact with. Two-dimensional outputs are easier to work with because they correspond to the traditional concepts of archaeological or technical drawings (i.e. 2D plans, elevations, etc.).

Once all the photographs are oriented The I-IMAGE process (Image processing and Measure Assisted by GEometrical primitive), developed in 2001, is used to support the user during the measuring process in photogrammetric surveys. Users can make a 3D measurement using one single photograph, without altering precision of the result. This method was already

published in CIPA congress, (Drap et al., 2001); it allows the user to concentrate on the archaeological aspects of the survey with less attention to the photogrammetric one.

We use this approach also to produce 3D models of building blocks (i.e. ashlar's) based on the only observable face.

The morphology of each ashlar's block is expressed as a polyhedron with two parallel sides, or faces. In most of the cases, only one side is visible, sometimes two, rarely three. The survey process can inform about the dimensions of one face, then the entire polyhedron is computed accordingly to the architectural entity's morphology (extrude vector) and the data (depth, shape, etc.) provided by the archaeologist (Figure 5).

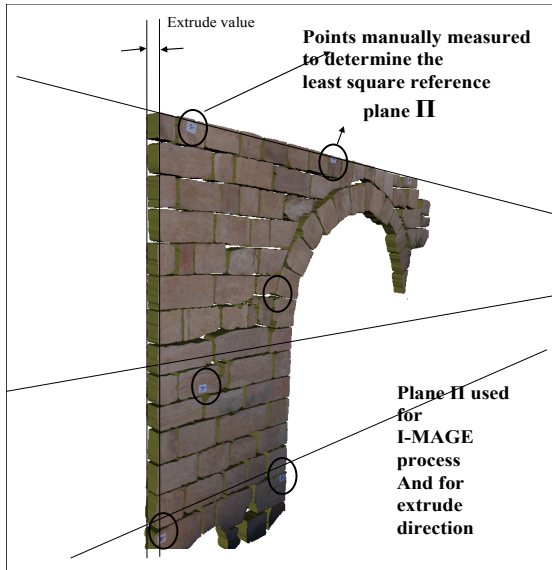


Figure 5. Ashlars' blocks using a plane as an approximation to the exterior face of the wall (Drap et al. 2007)

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

This approach for measuring blocks was already published in a VAST congress (Drap et al., 2000) and has been combined with the I-MAGE process in order to obtain an integrated tool.

4. WORKING WITH USM – AN EXAMPLE, THE CEMENT EXTRACTION.

The example demonstrated below shows the algorithm used to extract the cement from a set of blocs belonging to the same USM. All the computation is performed in 2D, i.e. in the plane defined by the wall.

The purpose of this computation is to evaluate the area covered by the mortar between the blocks. This 'cement extraction' enables a visual representation and the evaluation of the area covered by the mortar.

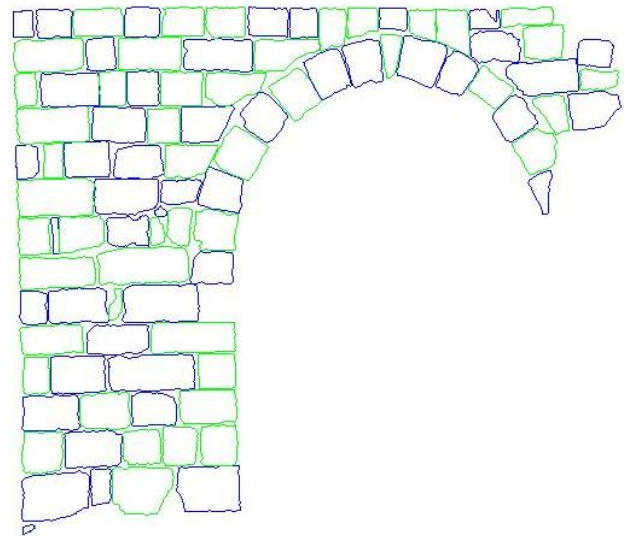


Figure 6. Original Blocs

The figure 6 shows the original blocks belonging to the USM. Note that the colours have no specific meaning.

The algorithm here assumes that an upper limit exists to the distance between blocs and further that this limit can be expressed in term of the size of the blocs. The algorithm also assumes that blocs are represented as closed polygons.

All polygon calculations use the GPCJ – java version (Bridenbecker, 2004) – of the General Poly Clipper algorithm developed by (Murta, 1997). Only minor refactoring was made to the Java version.

4.1 Step 1. Find an approximate value for the USM perimeter.

In this step, the bounding boxes of the blocs are used. The algorithm searches iteratively for a minimum scale factor enabling the union of all the boxes to be one single polygon 2D.



Figure 7. Blocs bounding boxes scaled at 1.25 (left) and the computed perimeter displayed in magenta (right) superposed with the original blocs.

During iteration, the boxes are *blown* by this factor meaning that they are scaled while their center of mass remains the same before and after scaling. The scale factor is allowed to go from 1.0 to 1.3, incrementing the scale by 0.05 at each iteration.

This step also enables to select the blocs on which the next step will perform: only blocs whose blown bounding box has points on the perimeter are selected. In other words, only the blocs standing on the perimeter of the USM will be used.

4.2 Step 2. Adjust the perimeter to be in contact with the actual blocs.

Starting from this step, the perimeter is represented with a B-Spline curve 2D - description in (Blake & Isard, 1998) – and the properties of the curve are used. The points on the curve are resampled and moved to be in contact with the blocs belonging to the perimeter of the USM. The figure 8 below shows the curve perimeter before and after this fitting step.

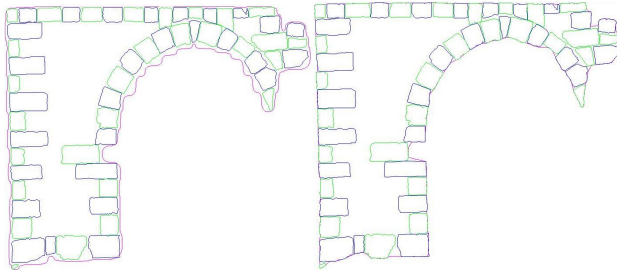


Figure 8. (Left) Initial perimeter as a B-Spline Curve 2D.
(Right) Initial perimeter adjusted to the actual blocs.

Note that the curve touches almost all blocs but does not really adhere to the blocs that stand a little bit far from the initial position. See for example, the upper right corner in the right image.

4.3 Step 3 and 4. Fit the perimeter to the USM blocs and cement extraction

Points along the curve perimeter are resampled. For each of these points, the n (constant) closest blocs are selected (by their distance between the point and their center of mass). If one of these blocs has a segment whose distance to the point is less than a threshold value, this point is kept as it is. The threshold value is computed as $0.02 \times$ the mean size of blocs. The mean size of blocs is evaluated as the average dimension value of all bounding boxes of blocs. The constant 0.02 has been found to be experimentally acceptable.

Otherwise the normal to the curve at this point is calculated and the nearest blocs are scanned to find the closest segment intersecting the normal. The intersection point is added in the curve perimeter. The Figure 9 shows the resulting perimeter.

Note that now the curve better fit to the blocs but further fitting could improve the result. To do that and avoid dealing with an increased number of points it would be needed to add new points only in the regions of the curve where it does not 'touch' the blocs.

Finally the cement can be extracted by performing a difference between the union of all blocs and the found perimeter, as shown in the image below with the mortar in green. (Figure 9)

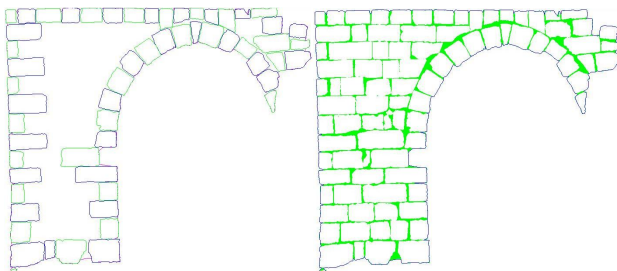


Figure 9. (Left) Perimeter fitted to the blocs.
(Right) Cement extraction.

5. ARCHAEOLOGICAL DATA AND 3D MEASURE: A COMMON DATABASE

Since 2006 (Drap et al., 2006a) the data produced by Arpenteur is stored both in XML and in a relational database. The main way to store data is a relational database in order to manage a big amount of data but XML is still used to work on subset of data or offline.

The database contains geometrical data (photogrammetric measures, oriented photographs and artefact geometry) as well as archaeological data (USM definition, site data and observation on measured artefact as lithotype and so on).

The database is used to generate views on the model according to archaeological requirements. 2D or 3D representations are produced by queries on the database: the projection plane for 2D representation, the subset of blocks according to the requested USM are used to generated geometrical representations with a bidirectional link between the graphics and the database.

6. AUTOMATIC 2D DOCUMENT GENERATION

The central database enables to represent various queries into 2D documents. 2D GIS software like ArcGIS (c) or libraries as Geotools can be used for producing specific views of the database and working in a GIS context. This capability is an automation of the manual drawings originally done by archaeologist (Figure 10). As we can see in Figure 11, ArcGIS interface shows a projection plane with USM represented by different colours. User can then work in ArcGIS and export results in other formats suitable for specific works.



Figure 10. Orthophoto with manual design of USM.

The second kind of 2D database representation is the generation of annotated orthophotos. This representation merges GIS features and real visual information in one document that enables to see the objects as they are on site with the adjunction of information coming from archaeologist's knowledge.

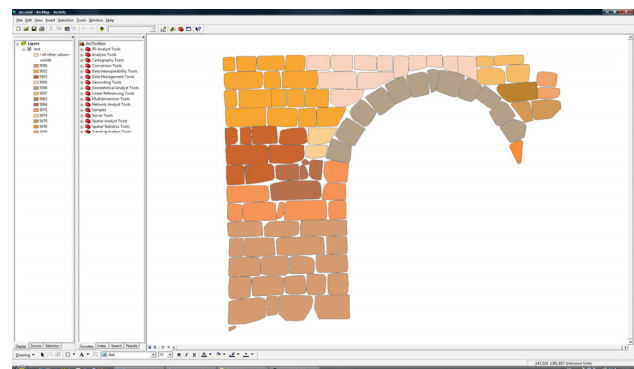


Figure 11. Database query exported in Arc-Gis software.

Figure 12 shows an orthophoto resulting from the query for the blocs (with texture), the USM (green perimeter) and the cement (yellow) attached to a given projection plane.



Figure 12. Orthophoto generation on a query related to blocs, with design of USM perimeter and the cement paint in yellow.

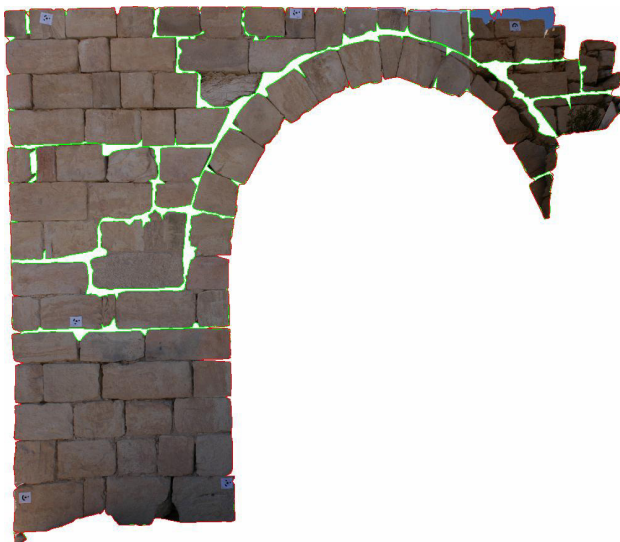


Figure 13. Orthophoto generation on a query related to USM, with cement between USM paint in white.

The orthophoto shown in Figure 13 represents the query of the USM and the cement attached to the same projection plane. In this representation, the blocs are not represented individually and the different USM are clearly visible.

Queries resulting in orthophotos can also be close to a static GIS representation. As we can see in Figure 14 both orthophotos represents the same queries used for generating the orthophotos seen in Figure 12 and Figure 13 but without integrating photographic data related to USM and blocs.

With the two kinds of 2D documents created from the database, archaeologists have two complementary ways for reading the site. The GIS representation is dynamic, enables multiple queries and iterations and can be embedded in dedicated applications while orthophoto generation produces easy to use and handmade-like documentation.

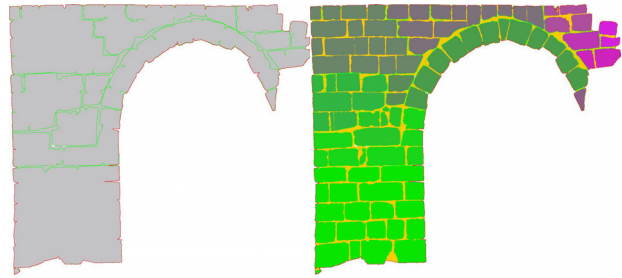


Figure 14. Orthophoto generation (without texturing) on a query related to USM, with, on the left, the design of USM perimeters and on the right the bloc representation with a colour depending of their USM.

7. A 3D GIS APPROACH

7.1 JReality-based software for interacting with 3D data

Computer tools that enable interactive 3D representation and new analysis of the studied objects through a bidirectional-link between the 3D representation and the archaeological data look very interesting for archaeologists.

In this sense, specific software has been designed for allowing the 3D interactive visualization, the analysis and the enhancement of the archaeological data collected on the Shawbak Castle. This problematic was already addressed on this case study (Drap et al., 2006a) but this time we use a full Java development allowing more integration and interaction. This software has been developed into the Arpenteur framework by means of the jReality (<http://www3.math.tu-berlin.de/jreality/>) application programming interface which is an Open source Java class library for interactive visualization of a large spectrum of 3D data. The last version of JReality is a light but efficient library offering a wide set of data structures and classes for handling common geometric entities (e.g. point sets, line sets, face sets, parametric curves and surfaces), a rendering engine allowing surface shading and texture mapping, a picking process for selecting 3D scene entities, a native import format (JRS), and several export file formats such as (RIB, VRML 1.0, U3D, PS, STL, Image, Sunflow). Moreover, several Java classes devoted to the design of Java-Swing based programs are available in the JReality package. The latest allows to rapidly producing graphical user interfaces for interacting with 3D data. The communication of JReality with the Arpenteur framework and consequently the object database is a straightforward task. Indeed, since both are fully written in Java code, displaying geometrical entities coming from Arpenteur with JReality simply requires implementing some suitable exchange procedures allowing converting the Arpenteur geometrical data structures to the JReality ones.

7.2 Archeology oriented Java procedures

To fulfill the needs of archeologists, a set of Java procedures have been designed for interacting with the database fields from the 3D representation of the database objects. Since the last development, all attributes of each block stored in the database (e.g. index in the database, name, dimensions ...) can be read and/or modified through a devoted panel.

It is notably possible to interactively request and modify the database from its 3D representation by displaying USM spatial distribution of blocks and modifying manually each bloc attribute. This kind of actions can be achieved on a single block or on a block set, and enables archaeologists to work on the

chronological building phases of the walls or answer to many questions regarding the masonry's technological aspects. Since the measurement of the blocks is important information in a statistically approach to a building, procedures for displaying and sorting blocks from their dimensions (block length, block height) have been also implemented. The later notably allows evaluating the spatial distribution of the bloc dimensions and represents a relevant tool, for instance to analyze different chronological building periods in medieval constructions (e.g. chronotypology).

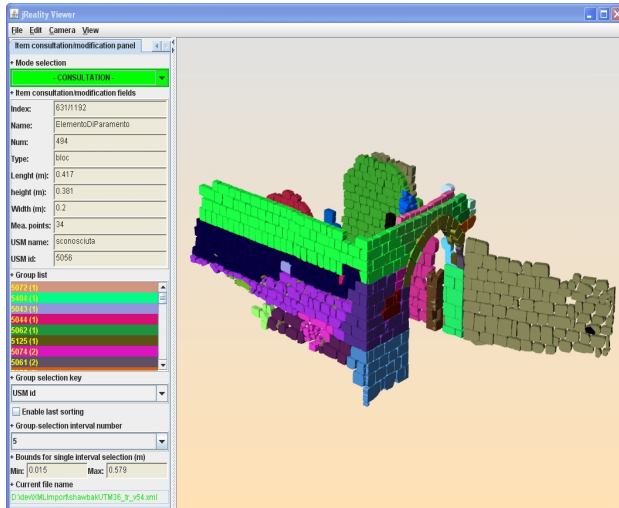


Figure 15. 3D visualisation with a colour panel chosen according to the block height classification.

These procedures also allows archeologists to exactly inspect/adjust each block dimension (collecting these dimensions on the field takes a lot of time and is only possible for easily-accessible blocks), and to gather blocks in different homogeneous classes (Figure 16).

This dimensional information is also available for each bloc in the USM schedule through editable text fields. In upstanding structure stratigraphy, this is meaningful because the size is one of the distinctive features to differentiate USM, along with shape and other features (Figure 15). Another under-construction development aims the area of the mortar which is another distinctive character of the USM. This information is almost neglected in different kind of survey but seems relevant for producing new knowledge and enhancing the database of the studied objects.

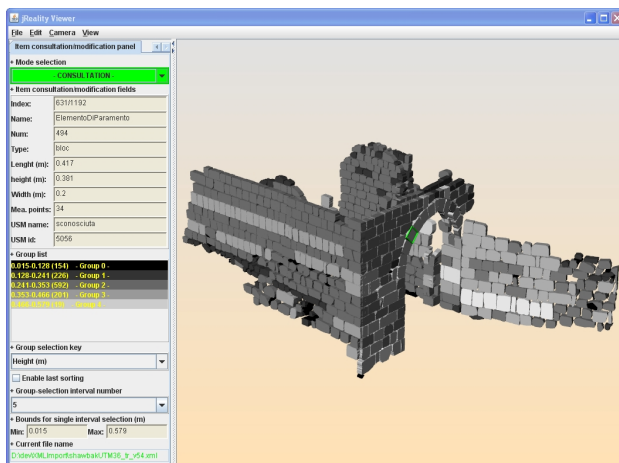


Figure 16. 3D visualisation with a colour panel chosen according to USM.

7.3 A tool to check photogrammetric data

This 3D tool is in fact a tool to visualize the database, from both archaeological and photogrammetry point of view.

In the same way can make archaeological interpretation by 3D thematic representation it is also possible to combine artifact visualization with the photogrammetric data (oriented photographs, optical center, 3D point errors, line from 3D points to 2D points, etc...) (See Figure 17).

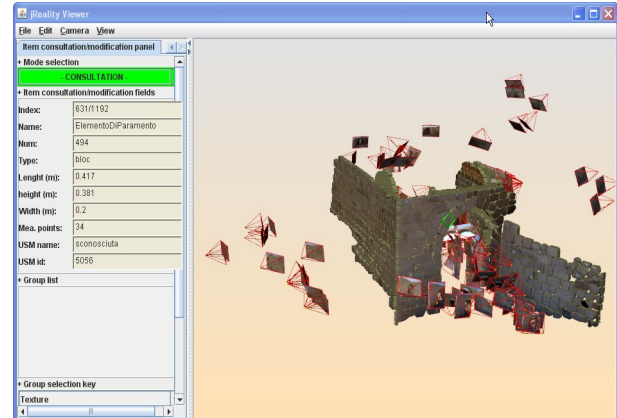


Figure 17. Photogrammetric data 3D visualization.

Other use of this tool (some of them are currently under development):

- This tool allows to check the final result and to obtain an indicator of quality by artifact. This is the first step of a tool that can make a diagnostic and propose a way to consolidate measures in case of inconsistency.
- This tool allows using texture for each measured bloc: only the measured face is textured and 2D observations are available from this interface.
- Finally this module will be also used as a control for bundle adjustment (photo orientation, RMS on 3D points).

8. AUTOMATIC CLOUD POINT GENERATION

We use the 3D measured point on the block perimeters and the oriented photographs to compute automatically a set of 3D points by correlation. This surface's densification process uses a mesh build on the 3D points measured manually and can produce a huge quantity of new 3D point only in the specific studied zone. A first version of this software already existed and was published (Drap et al., 2006b) but with a lower number of generated points (also it was not possible to detect false correlations and no texture information was possible).

In the version presented here we have generated more than four million of 3D points on the main door studied here and we export them in VTK - Visualization Toolkit - (VTK 2009) with blend color information (or more generally in ASCII file as XYZRGB). (See Figure 18).

The previous version of the tool was purely correlation based: given an initial set of measured points, a mesh was generated in the 3D space. Then moving on the produced triangles, the process tried to perform correlation between the points projected on the photographs. However, this is highly dependent of the local contrast and frequently fails if images have different orientation or scale.

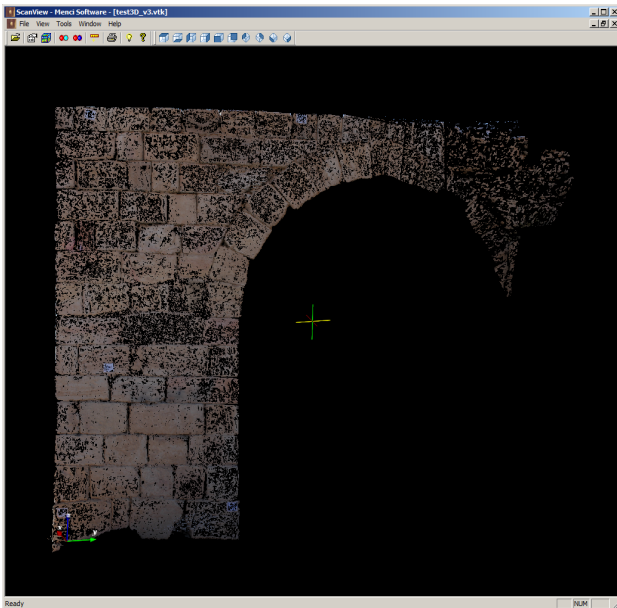


Figure 18. 3D cloud point generation based on autocorrelation and an approximate surface given by the measured blocs.

Therefore we start to implement another way to get homologous points, based on SIFT algorithm (Lowe, 2004). This approach is quite different from correlation because it is based on extraction of so-called keypoints. The keypoint extraction and match operation automatically return a set of homologous points fetched on the basis of the image dynamics. They can be used to define a surface or increase the surface definition (also to make an automatic orientation of the camera).

High surface definition is connected with orthophoto generation, as we need to produce, according to archaeological requirements, also 2D representation. We will use this 3D surface definition to produce accurate, georeferenced orthophotos. The way to produce such orthophoto will fully use the 3D data we have produced before: oriented photographs, dense 3D points cloud, dense surface for wall/USM definition. We have developed an orthophoto generation based on the 3D surface analysis which produces both an image in GeoTIFF format and a set of 3D points with color information gridding the site area.

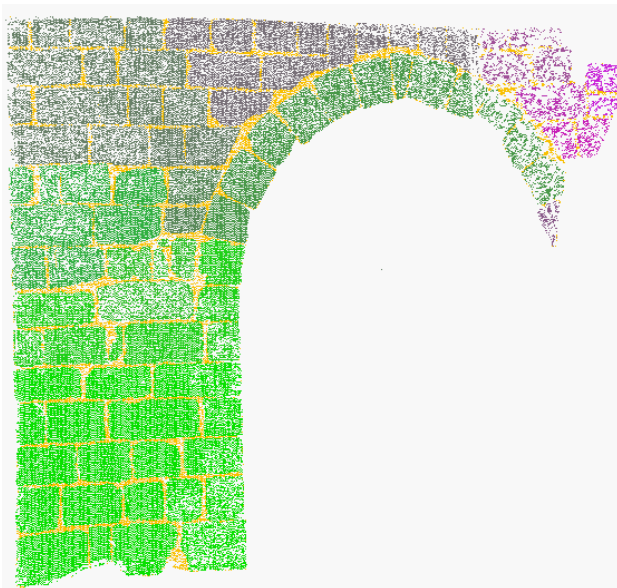


Figure 19. 3D cloud point generation based on autocorrelation where semantic information is used to obtain a colour.

This method will allow combining vector survey, where an expert of the domain, here an archaeologist, is making the survey and cloud of measured points in some zone where a huge quantity of point can help to understand, for example the stability of a wall. Such combined approach is already explored; see for example a study made by Haala and Alshawabkeh (Haala & Alshawabkeh, 2006) on a famous tomb in Petra, close to Shawbak.

Two points are fundamentally different in our approach

- The method is only based on and oriented photographs; in such case (Jordan, desert, etc...) this should be an interesting advantage.
- All the geometrical data obtained are the result of database queries and thus they are linked with archaeological data (See Figure 19).

9. CONCLUSION AND FUTURE WORK

Automatic 3D thematic representation with bidirectional-links between 3D representation and archaeological data allows new archaeological analysis. It is possible to record data and to produce new knowledge about the studied object.

We focus on block measurement, developing specific photogrammetric tools which use *a priori* knowledge to help the operator during the plotting phase. As the main goal of this project is linking measured geometry with archaeological knowledge, we tried to propose a photogrammetric tool that can be used by an archaeologist. In this application 3D measurements are done by using only one photograph through the user interface and automatically computing reprojection and correlation. The archaeologist-operator can focus his effort on inserting archaeological data instead of spending time and concentration in homologous point determination.

It is also important to say that the archaeologist can spend more time on a field to analyze the structure because we can “survey” directly on the 3D model in laboratory and insert in it a lot of different kinds of data.

The 2D/3D GIS context can also be used as a suitable interface for managing survey consistency and session merging. The knowledge driven survey process enables to automatically check consistency of a survey (Seinturier et al, 2006) and to semi-automatically merge different survey sessions of the site. As consistency checking and merge requires expertise, the 2D / 3D GIS can be used for providing experts a global view of the site with geometry, documentation and photographs. With a unique access to all information available, an expert can easily drive the consistency restoration and the merge processes.

Of course archaeologists need some more! Currently the system must be tested with all the buildings already studied in order to compare the results of this method in different examples of structures. The next step will be to find the way to visualize all the chronological aspects of the upstanding structures interpretation, in other words, to visualize the Harris Matrix (Harris, 1989) (Allen, 1983).

Finally, ways for making persistent the documentation of a site have to be explored. New formalisms and specifications such as ontology (Niccolucci F., D’Andrea A. 2006) and CIDOC-CRM (D’Andrea et al. 2006) (CIDOC-CRM, 2004) are now thoroughly used in the cultural heritage domain. A theoretical study and an implementation of such formalisms and specifications could enhance the current framework.

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