

# PHOTOGRAMMETRY AND ARCHAEOLOGICAL KNOWLEDGE: TOWARD A 3D INFORMATION SYSTEM DEDICATED TO MEDIEVAL ARCHAEOLOGY: A CASE STUDY OF SHAWBAK CASTLE IN JORDAN

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## ABSTRACT:

The paper presents an interdisciplinary project which is the first step 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 Montral" in Jordan. The project continues to grow thanks to a synergy between a set of laboratories: The LSIS laboratory, France in charge of the photogrammetric survey phase connected with the knowledge based approach; ITABC, CNR lab in Roma, Italy in charge of the topometric survey, with DGPS and aerial photography with gas balloon, National Institute of Information and Communications Technology, Kyoto, Japan for the 3D view point seek connected to the database, the image processing aspect managed by Stratos documentation, SimVis from The Department of Computer Science, University of Hull, UK, for the virtual reality aspect and of course the Dipartimento di Studi storici e Geografici from the University of Florence, Italy, in charge of the archaeological part.

Our project focuses on a building scale encompassing its atomic elements such as ashlar blocks, cement, stratigraphic units and architectural elements. At this scale we need a full 3D interface in order to manage accurate measurements, a huge quantity of observations and a mainly heterogeneous archaeological documentation.

This project described in this paper is work in progress. After four photogrammetric campaigns in Jordan the first results are available on the project web site: <http://www.shawbak.net>

## 1 THE ARCHAEOLOGICAL CONTEXT: SUBJECT, OBJECTIVES AND METHODS

The 'Medieval Petra – Shawbak Project' archaeological mission, promoted by the Department of Historical and Geographical Studies of the University of Florence, is part of a programme of the Italian Ministry for Foreign Affairs ('PilotProject' from 1999), Italian Ministry of University and Research ('Scientific Project of National Interest' from 1987; 'FIRB Project' 2005-8) and is carried out by researchers coming also from the Universities of Udine, Urbino, Venezia, ITABC-CNR of Rome, CNRS- LSIS of Marseille, University of Hull.

The mission operates, since 1999, within the 'Athenaeum Strategic Project' ("The Mediterranean feudal society: archaeological profiles. Apogee and decline, at the origins of Modern Europe") directed by the chair of Medieval Archaeology and dedicated to the archaeological study of material structures of the feudal society – by means of settlement-patterns analyses in Mediterranean territorial sample areas – at the time when the above is a protagonist of prolonged comparison with new political realities which, from Western European Christianity to the Mediterranean Islamic Middle East (with the new Ayyubid and Mamluk 'empires'), lay at the origin of modern state-nations (Vannini et al., 2007).

In such a picture, the Archaeological Mission – 'Medieval Petra' Archaeology of the Crusader-Ayyubid settlement in Transjordan. The Shawbak Project – is engaged for a project devoted to analyze characteristics and forms of the Crusader "incastellamento" in the area corresponding to the Lordship of Transjordan in 12th century, in its structural aspects but also as 'observatory' on the Crusader-Muslim frontier of Holy-Land, in relation

with the Ayyubid settlement patterns. The research proposes to document the 'original material characters' of the first phase of Crusader occupation of "Outremer", where these characters are better preserved and stratigraphically readable, after the total and definitive abandonment caused by the consequences of the battle of Hattin (1187).

Major results of almost two decades of research include the identification of the renewed central role of Petra in 12th century Transjordan, as well as of the classical system of "Incastellamento" of its valley – al-Habis, Jabal Atuff, al-Wu'ayra, Hormuz, up to Ash-Shawbak ("Crack de Montral"). Such a settlement system appears to have been aimed at controlling 'the Kings' Highway' (connecting Syria and Jazeera to Hijaz and Egypt) and the strategic natural resources of the pre-desertic belt of springs and exploitable lands (Vannini et al., 2007).

Since 2002, the 'Medieval Petra' project has been focused on archaeological analyses (excavations as well as researches of 'light archaeology') at the castle of Shawbak, within the frame of a specific programme (integrated with conservative restoration and valorisation) which is the object of an international agreement of Italian-Jordanian scientific and cultural cooperation between the University of Florence and the Department of Antiquities of Jordan. Such an agreement aims at using the results obtained by means of the stratigraphic analyses in order to complete a restoration project.

The methodology of analyses which has been adopted for the 'Medieval Petra – Shawbak Project' integrates excavations with a programme of non-invasive investigations of 'light archaeology'. Stratigraphic analyses of upstanding buildings hold a key role within the aforementioned the system of archaeological studies.

In particular, the outstanding stratigraphical availability and visibility of the preserved architectures of Shawbak allow 'archaeology of architecture' to play the role of interpretative barycentre in the reconstruction of the site's material history. Moreover the very presence of medieval stratified architectures surviving to a great extent above the ground makes of Shawbak a wonderful case-study for the development of an integrated management system of heterogeneous data such the one proposed hereafter. As to stratigraphic analysis of upstanding buildings, it first developed within Italian Medieval Archaeology in the 1970s, though a consistent methodological approach was implemented between mid 1980s and mid 1990s and the first issue of the dedicated scientific journal "Archeologia dell'Architettura" (/Archaeology of Architecture/) was published in 1996. In contrast with other (and earlier) traditions of archaeological study of architectures, the focus theoretical concept of this recent Italian approach is to consider upstanding structures as a special type of stratified archaeological deposits. In so doing architectures can be reduced to a series of stratigraphic units whose relationships can be assessed and expressed by means of Harris Matrix. Such an approach has given the opportunity to fully integrate architectural records and archaeological analyses in the excavation practice as well as to produce stratigraphic datasets for the analysis of historical upstanding architectures even without excavation: the so-called 'light archaeology' approach.

In order to fully exploit the archaeological dataset (which at the moment includes stratigraphic analyses of 36 buildings "Corpi di Fabbrica" with a concentration in the southern area of the fortified settlement) common GIS systems proved unable to deal with complex 3D architectural objects with relevant information positioned and georeferenced on non-parallel planes. Moreover distinct documental procedures were needed for recording: archaeological data (database), Harris Matrixes, topographic geometry and excavation plans/sections (laser total station and direct survey), vertical stratigraphy (ortho-rectified photographs), Digital Elevation Models (D-GPS and motorised laser total station), etc.; thus making it virtually impossible to contextually manage the whole dataset and also multiplying the recording activities on single objects according to what kind of representation was required time by time.

Such needs, though particularly difficult to solve at a first glance, provided indeed the opportunity to set up a large and multidisciplinary team whose aim is to project and implement an integrated management system able to deal with representation and survey issues common to many territorial-archaeological research investigating the dynamic modifications of ancient historic landscapes in a given region. The results so far achieved are briefly exposed in the next paragraphs.

## 2 A TWO STEP PHOTOGRAMMETRY CAMPAIGN

We define a network of 3D points georeferenced by DGPS, in the entire castle in order to orient all the photograph taken. Two kinds of photographic survey are required: the first one dedicated at wall survey is done from the ground; hand made by a photographer; the second one is aerial photography from a gas balloon (figure 1).

The gas balloons can reach maximum height of 50-60 meters. In addition, the ashlar block survey and wall stratigraphic unit study, aerial photogrammetry is used to evaluate the traditional excavation and can also be used to follow the castle restoration project.

### 2.1 Measuring 3D Blocks

Once all the photographs are oriented The I-MAGE process standing for Image processing and Measure Assisted by GEometrical



Figure 1: The gas balloon used during the aerial photogrammetric survey.

primitive, developed in 2001 (Drap et al., 2001), has been designed to help during the measuring process in photogrammetric surveys (Drap et al., 2000). Users can make a 3D measurement using one single photograph, without altering result precision. This method was already published in CIPA congress; it allows the user to concentrate on the archeological aspect of the survey with less attention on the photogrammetric one. We use this approach also to produce 3D models of building blocks (i.e. ashlar) based on the only observable face.

The morphology of each ashlar 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 morphology (extrusion vector) and the data provided by the archaeologist (depth, shape). Computing an extrusion vector can be easy in the case where the architectural entity morphology is obvious; during a wall survey for example an extrusion vector can be computed by a minor square adjustment of a plane around the survey zone. In our case it's the plane used in the 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). This approach for measuring blocks was already published in a VAST congress and has been combined with the I-MAGE process in order to obtain an integrated tool.

## 3 ASSISTED PLOTTING

### 3.1 Introduction

In architectural photogrammetry, the number of measurements needed to represent the object to study can be quite huge. Up

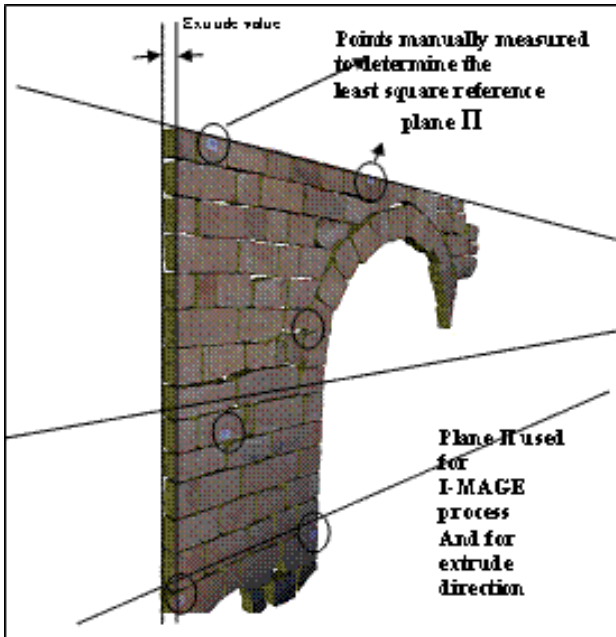


Figure 2: Extruded ashlar blocks using a plane as an approximation of the exterior face of the wall.

to now, the Arpenteur Project has been thought to achieve leverage using the knowledge of archaeologists and architects. For example, the I-MAGE process. (Image processing and Measure Assisted by Geometrical primitive) enables the user to obtain 3-D measurements while digitizing a single image. The process is based on the coupling of image correlation and the expected shape of objects, such as primitive surfaces or partial surfaces like planes, cylinders, cones and spheres. This already enables to save a lot of the human operator time.

Starting from that point, we now want to provide the user with effective solutions that will help him to deal with the acquisition of characteristic shapes in architectural photogrammetry. Up to now, digitizing such shapes is made by measuring points generally on the edges of the desired objects. This digitization is part of the tedious tasks that are still slowing down the completion of projects of Wiedemann and Roderhost (Wiedmann and Roderhost, 1997). The idea of using digital image processing to ease these tasks has already been used in a large variety of projects, for example see (Wiedmann and Roderhost, 1997), (Stylianidis and Patias, 1999), (Blacke and Isard, 1998) and digital image processing is already used in Arpenteur, although not systematically used so far.

Here we consider the design and the use of a framework based on Active Contours with the aim of a first application to a stone by stone digitization.

### 3.2 Active Contours

Snakes or active contours are curves defined within an image domain that can move under the influence of internal forces coming from within the curve itself and external forces computed from the image data. These forces are defined so that the snake will conform to some boundary or other desired features within the image (Xu et al., 1998).

Rather than using pure regular snakes we use here the concept of 'Deformable Templates' thoroughly developed by (Blacke and Isard, 1998). This enables to introduce into the definition of the active contours, some specific prior knowledge about the classes of the objects to digitize and their possible forms.

For instance in a stone by stone digitization, a possible template

is shown in figure 1. The 'rigidity' of the template can be set through a regularizer value and the space of possible transformations can be restrained for example to affine transformations. The result of fitting this template on a wall is shown in figure 3.



(a) Active contour seed



(b) Active contour computed

Figure 3: Active contour for an ashlar block.

that, although in an application to stone by stone the template can be very simple as the above example shows, templates can be defined with quite more complex forms. For example it could be as complex as the full drawing of a full front of a house with several windows and doors.

It also worth noticing that in the above example, the user places the template 'near' the desired position. This addresses a key issue when using active contours that is the initialization of the process.

### 3.3 Characteristics of the Contours Framework

The Contours Framework, written in Java, is constructed by following closely the description and implementation (in C++) proposed in (Blacke and Isard, 1998). The figure 4 shows the construction of a B-spline parametric curve (drawn in red) that results from the digitization of its control polygon (drawn in black). The background is made of a simple image representing gray rectangles with (almost) constant intensities. The fit of the curve is made by detecting features of interest along the normals to the curve. One normal is shown as a black line in the upper left corner of the curve and the associated graph of data retrieved from the image is shown in figure 5. The detection can use various operators like gradient, laplacian, statistics or the correlation on a predefined profile. In figure 4, the red vertical line shows the position of the detected edge using a gradient operator (Data are retrieved from the image by starting from the left of the normal with respect to the progression on the curve). The result of the fit is shown in figure 5 together with all search lines. In the above example, we can see that the corners of the fitted curve do not

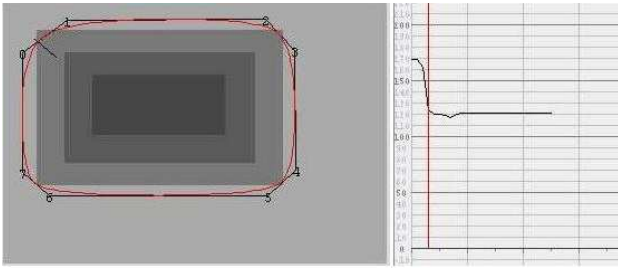


Figure 4: B-Spline construction.

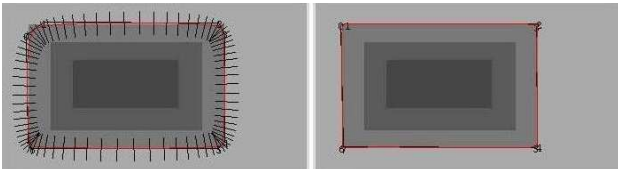


Figure 5: Detected edges.

match closely with their expected position. Performing multiple fits by using as a starting curve the result of the previous iteration adjusts the fitted curve more closely to the true position. Note that the framework also has a graphical tool for testing operators and the effect of the various parameters used when a fit is performed.

### 3.4 Integration in Arpenteur

A basic integration has been made in the Arpenteur for the stone by stone digitization. The figure 6 shows the user interface for 'stereo' digitization, here with a dry masonry wall. The user first creates the template:

- select a desired class of templates (here a 'Rounded Rect.')
- select the left or right image to create the template.
- click on the image to start the creation.

The figure 6 shows the template under creation. As soon as the template is created, the fit is performed. The figure 7 shows the result of the fit performed here with a simple gradient operator. The horizontal slider in the user interface leaves a way for the user to adjust the threshold used by the detector. He can also use the 'Fit' button to perform as many fits as needed - although one fit is generally enough. Once the template is correctly adjusted to the expected edges, the user press the '3D' button and obtains a 3D shape of the digitization.

He can then move the template to another location, adjust the size of the template, perform a fit and get the shape of another stone as shown in figure 7.

### 3.5 Work in progress

Working with the Contours framework clearly shows that deformable templates can greatly help the user and accelerate the plotting phase. Nevertheless the usage pointed out two key enhancements that clearly show the directions of future work.

First improve the robustness of operators. For example, considering the figure 7 shows that the true edge of the stone is somewhat larger than the result of a single fit. As shown in figure 7, performing multiple fits improves the result, but this could also be done with better operators. Compound operators, for example,

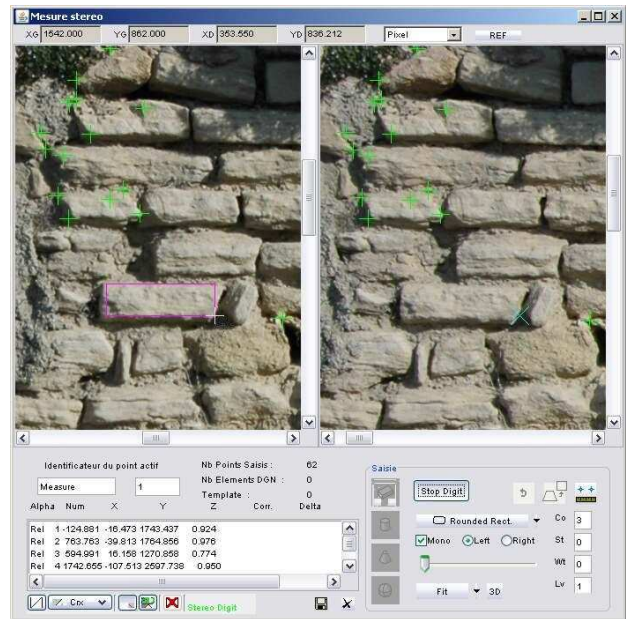


Figure 6: Active contour integration in Arpenteur.



Figure 7: Active contour use.

can detect a border by a logical 'AND' with the magnitude of a gradient and the correlation with a slope profile. Successive operators, for example, use a first fit performed with a gradient operator to retrieve a good approximation of the true edges position. Then a second iteration provides a more accurate fitting by using another operator.

## 4 ARCHAEOLOGICAL DATA AND 3D SURVEY: A SINGLE DATABASE

This project deals with heterogeneous data. We can group data in two kinds. Archaeological data are made by documentation, conceptual knowledge and classifications and surveyed data coming from photogrammetry, observation and measurements.

### 4.1 The plotting interface

After the orientation phase done with Photomodeler all the oriented photographs are stored in the database with all the associated computed parameters. The archaeological plotting phase is done with a specific photogrammetric module, using only two images. At this stage the accuracy is sufficient with a measure done with two images and the interface is simpler to manage. The user has to choose two photographs, already measured blocks are displayed as we can see in figure 8 and Arpenteur will generate a correspondent photogrammetric model on the fly. The application will connect to the database over the Internet to display thumbnail and load photographs and already plotted blocks. A direct link to the Php Database interface is available by picking the displayed blocks.

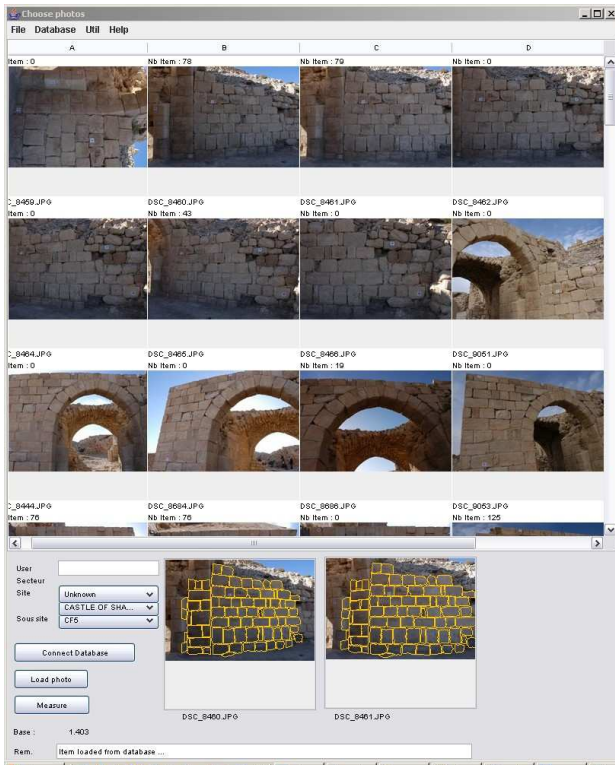


Figure 8: Choosing oriented photographs from database with Arpenteur.

#### 4.2 The orientation phase and how to manage hundred of photographs

The first step is orienting all the photographs in the same reference system, this is done with photomodeler V5. Once the hundred of photographs are oriented and loaded in our database we need a method to help the user to choose the most relevant photographs according the zone he wants to plot. Now we are trying to integrate viewpoint-based photo search (Kadobayashi, 2005) with our database. In the viewpoint-based photo search, 3D viewpoint information is used as a query rather than keyword which is used in keyword-based search or content features which are used in content-based search. The 3D viewpoint information consists of position and direction of a camera and is attached to each photograph. When searching a picture, users can easily formulate queries by just specifying the view of the 3D model. The system compares the 3D viewpoint information of the view of the 3D model with that of each photograph, and shows the results according to the similarity of the viewpoint. Figure 9 shows the user interface of the photo search system. The 3D model of Shawbak is shown in the top using Cortona VRML Client. A user can interact with the 3D model so that the user can view the scene of interest. After choosing a 3D scene, the user clicks on a "search" button located in the top right. The system searches photographs which have similar 3D viewpoint information as that of the 3D scene. The system, using the functions of Cortona, first obtains the position and direction parameters of the virtual camera which is used to render the 3D scene. Then it compares the position and direction parameters to that of each photograph in the database. The position similarity is calculated based on the distance between the virtual camera and each photograph while the direction similarity is calculated based on the cosine similarity of direction vectors. The final similarity score is obtained by adding weighted position score and weighted direction score. If the score is 0 it means that position and direction are the same.

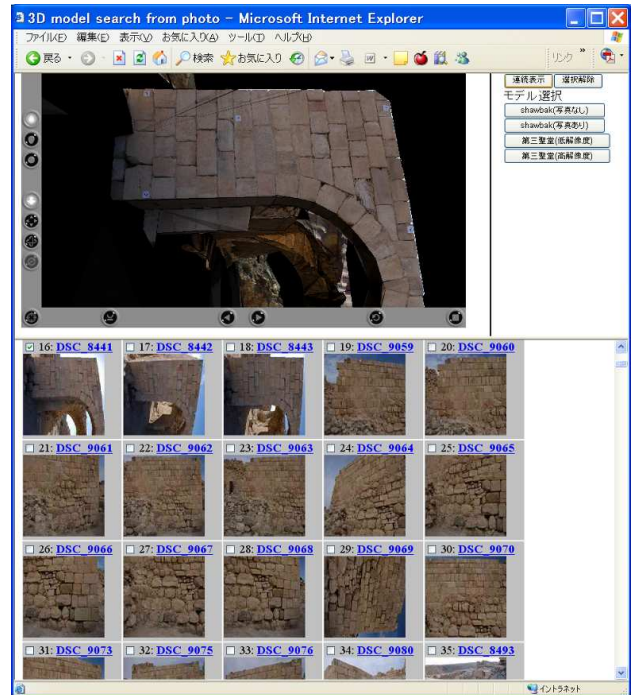


Figure 9: 3D model search gui.

Note that users can control these weight which affects search results as shown in Figure 10. Table 1 summarizes the scores of top

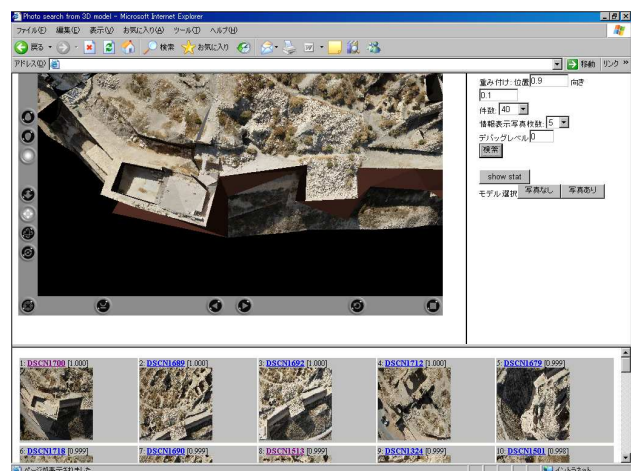


Figure 10: 3D model search with given weights.

three photographs.

## 5 A TOOL FOR DEALING WITH INCONSISTENCY

During the survey of the Shawbak castle, due to the number of the involved actors and the huge size of the site, many measurement sessions are produced therefore the final survey of the site results from the fusion of the measured sessions. Since measurements are performed by different persons, at different times, they can conflict. Common conflicts are mismatch identifications (same object with different identifiers or same identifier for different objects), multiple object measurements in different sessions or bad theoretical model assignment for an object. We propose a fusion method based on (Seinturier et al., 2006a) and (Seinturier et al., 2006b) which consists of two steps: the

wp=0.9,wd0.1	position score	direction score	total score
DSCN1689	0.083644	0.062174	0.081497
DSCN1431	0.088455	0.076124	0.087222
DSCN1690	0.100077	0.081248	0.098194
wp=wd0.5			
DSCN1689	0.083644	0.062174	0.072909
DSCN1431	0.088455	0.076124	0.082289
DSCN1682	0.155532	0.011486	0.083509
wp=0.1,wd=0.9			
DSCN1682	0.155532	0.011486	0.025891
DSCN1692	0.196404	0.040072	0.055705
DSCN1407	0.306095	0.030130	0.057726

Table 1: Example of the difference of similarity scores

first one detects the objects involved in the inconsistency, and the second one helps the surveyor to restore consistency. This method is implemented and a tool with an intuitive interface is provided.

### 5.1 Detection of objects involved in the inconsistency

Within the Arpenteur framework, the objects representation stems from the entities (Drap et al., 2006). An entity is a tuple  $\mathcal{E} = \{\mathcal{C}, V_d, C^a, \mathcal{R}, C^R\}$  where  $\mathcal{C}$  is a class of object,  $V_d$  denotes a set of default values for the object attributes,  $C^a$  denotes a set of constraints on the object attributes, called intrinsic constraints,  $\mathcal{R}$  denotes a set of relations between objects and  $C^R$  denotes a set of constraints on the relations of  $\mathcal{R}$ , called extrinsic constraints. In the case of the Shawbak castle, all measured objects are ashlar blocks and the only class we deal with is the *Block* class.

Formally, each measurement session produces a set of measured objects  $O_i$ . Since  $m$  measurement sessions,  $m > 0$ , are performed, the final survey results from the fusion of the  $m$  measurement sessions, that is the construction of a set of measured objects denoted by  $O$ , where  $O = O_1 \cup \dots \cup O_m$ , characterized by the entity  $\mathcal{E}$ . The result of the fusion has to be consistent, in our context the consistency of a set of objects is defined with respect to the entity  $\mathcal{E}$ . A set of object  $O = \{o_1, \dots, o_n\}$  is consistent w. r. t.  $\mathcal{E}$  if all the constraints of  $C^a$  are satisfied by all the objects  $o_i \in O$  and if all the constraints of  $C^R$  are satisfied by all the couples of objects  $(o_i, o_j) \in O \times O$ .

The first step of our fusion method consists in detecting the objects involved in the inconsistency w. r. t.  $\mathcal{E}$ , it leads to determine the two following sets. The first set contains all the intrinsic inconsistencies. It is defined by  $\Theta^a(O) = \{(O', c_k^a) \mid O' \subseteq O, o \in O', c_k^a \in C^a, c_k^a(o) \text{ is not satisfied}\}$ . If no intrinsic inconsistency is detected, this set is empty. The second set contains all the extrinsic inconsistencies it is defined by  $\Theta^R(O) = \{(o, o'), c_i^R \mid o, o' \in O \times O, c_i^R \in C^R, c_i^R(o, o') \text{ is not satisfied}\}$ . If no extrinsic inconsistency is detected, this set is empty.

In order to compute the sets  $\Theta^a(O)$  and  $\Theta^R(O)$ , we propose a logic representation based on predicate logic instantiated on the finite domain of the measured objects  $O$ . Each constraint  $c_k^a \in C^a$  is represented by a predicate  $pc_k^a$  and for each  $o_i \in O$  if  $o_i$  satisfies  $c_k^a$  then  $pc_k^a(o_i)$  is true otherwise false. Each constraint  $c_i^R(o, o')$  is represented by a predicate  $f_i^R$  and for each  $(o_i, o_j) \in O \times O$  if  $(o_i, o_j)$  satisfies  $c_i^R$  then  $f_i^R(o_i, o_j)$  is true otherwise false.

Let  $O$  be a set of  $n$  objects, and  $t = |C^a|$ ,  $v = |C^R|$ <sup>1</sup>, the computation of the set  $\Theta^a(O)$  and  $\Theta^R(O)$  relies on the construction of a  $n \times n$  matrix, denoted by  $M$ , that represents the satisfaction of all the constraints by the objects of  $O$  as follows:

- $M_{i,i} = \sum_{k=1}^t pc_k^a(o_i) \times 2^{k-1}$ .
- $M_{i,j} = \sum_{l=1}^v f_l^R(o_i, o_j) \times 2^{l-1}$ , where  $i \neq j$ .

$M_{i,i}$  is an integer representing the satisfaction of the constraints of  $C^a$  by the object  $o_i$  and  $M_{i,j}$  is an integer representing the satisfaction of the constraints of  $C^R$  by the couple of object  $(o_i, o_j)$ . Parsing the matrix  $M$  enables to efficiently compute the sets  $\Theta^a(O)$  and  $\Theta^R(O)$  therefore to detect the measured objects involved in the inconsistency w. r. t.  $\mathcal{E}$ . The complexity of the method is  $2(n(t + ((n-1)v)))$ . This method has been implemented in Java within the Arpenteur framework and is integrated into the proposed management tool.

When objects involved in the inconsistency are detected, a correction is required. A possible way could be to remove objects involved in the inconsistency. However, information is precious and more often difficult to obtain, thus in our context we provide a tool for helping the surveyors to correct the measured objects. Manual correction requires a dedicated tool that can show to the surveyors all objects involved in the inconsistency in a comprehensive and efficient way.

### 5.2 Management tool for correction

We have developed an intuitive interface to pilot the fusion of measurement session results. This interface has been used for the final result on the Shawbak castle survey. The tool aims to provide all needed information in a comprehensive way. The knowledge based photogrammetric survey provides photographs, points set and 3D models attached to information. The tool has to make all this information available to the user but also to deliver it intuitively. As we can see in figure 11, all kind of displayed

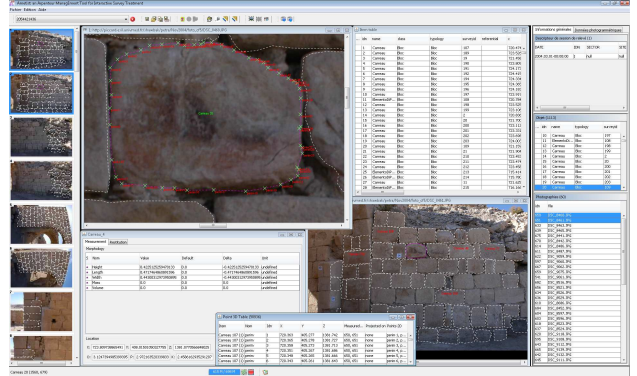


Figure 11: Ametist general interface

information are linked to help manual verification and detection of objects involved in the inconsistency. Selecting a measured object enables to show the photographs where it was measured but also the values of the measured 3D points. The objects can be selected by using a textual table or by directly clicking on their reflects on a photograph. If the user wants more information, he can open the tables containing all photogrammetrics (3D points, 2D points, photograph orientation, ...) and object specific data (Block length, Block Stratigraphic information, ...).

The detection of the objects involved in the inconsistency is available within the tool interface. Clicking on detection, the inconsistency sets  $\Theta^a$  and  $\Theta^R$  are automatically computed and a report shows the objects involved in the inconsistency as illustrated in figure 12. The surveyors can find the causes of inconsistency and correct them investigating the available data on the objects with the interface. This tool involves knowledge in the measurement session results fusion and enables to process a large amount

<sup>1</sup>where  $|X|$  denotes the cardinality of  $X$ .

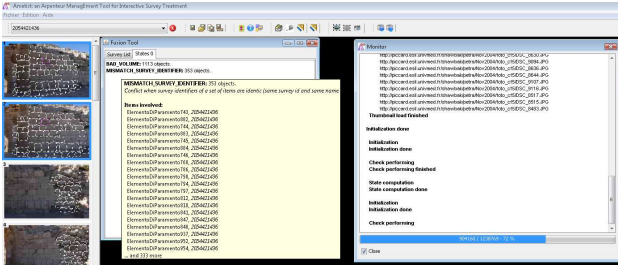


Figure 12: Ametist detection report

of data in an efficient way. The intuitive interface is adapted to cultural heritage data management and to non computer science actors.

## 6 AN IMMERSIVE VIRTUAL REALITY INTERFACE FOR SHAWBAK CASTLE

In recent years, VR has greatly facilitated the interaction and interpretation of archaeological data (Pansiot et al., 2004). For example the remarkable work of Vote (Vote et al., 2002) and her team who provided archaeologists with an efficient tool to interact with the Great Temple in Petra, Jordan using a CAVE virtual environment.

We are using the Hull Immersive Visualization Environment (HIVE) facilities in order to provide a 3D GIS interface to the relational database described above. The HIVE includes an auditorium with a large screen, stereo video projectors and a Vicon tracking system.

Figure 13 provides a high level description of the HIVE architecture used in this project. It shows the rear projected wall (thus eliminating shadows), main and tracking computer, infrared cameras for the tracking systems, a user wearing shutter glasses for the stereo display and a special pointing device for interacting with the Shawbak castle database.

Our rendering system has been developed using OpenSceneGraph (OpenSceneGraph, 2006). OpenSceneGraph (OSG) is an open source high performance 3D graphics toolkit, used by application developers in fields such as visual simulation, games, virtual reality, scientific visualization and modelling. OSG is written in C++ and OpenGL and runs on all Windows platforms, OSX, GNU/Linux, IRIX, Solaris and FreeBSD operating systems. The

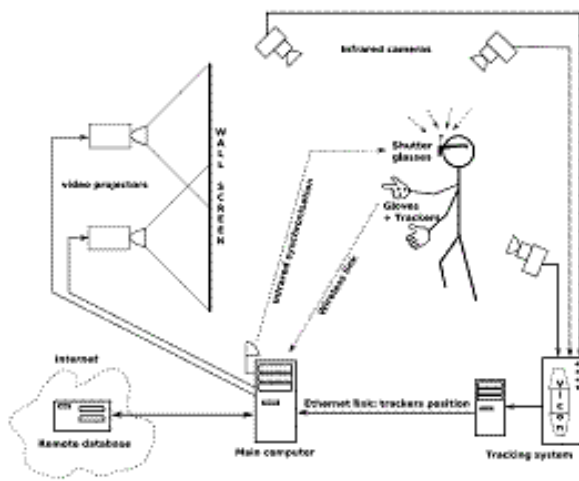


Figure 13: HIVE architecture description.

geometry acquired with the I-MAGE photogrammetry technique

is retrieved from the MySQL database at the start of the application. The geometry acquired is cached which makes future reloading instantaneous. The user is able to dynamically choose which blocks they want to display at any time: the software maintains a continuous connection to the database and requests blocks required that have not yet been loaded into memory.

The drawing of the blocks is an extrusion of the polygon retrieved from the database. The extrusion value will have been previously specified and entered into the database by archaeologists. Finally, the blocks are textured with extracts from the photographs used during the photogrammetric process.

Each photograph contains more than one block. There is therefore room for some optimization given that the loading of the photographs is quite CPU and memory intensive. Photographs are consequently chosen in order to minimize their memory load. However, the user can still choose to display another corresponding photograph of their choice for each block. Figure 14 shows

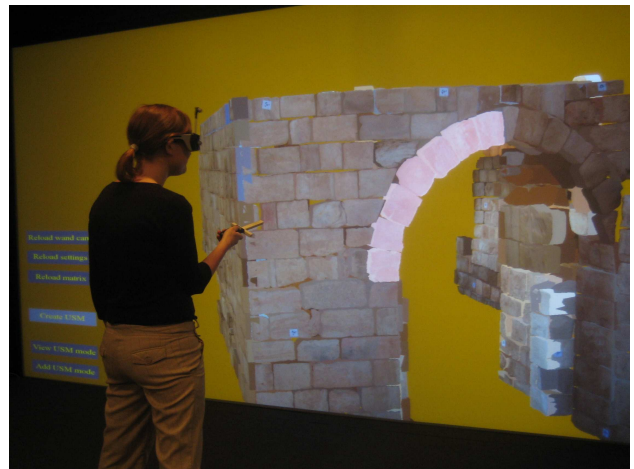


Figure 14: Immersive visualization of part of the castle wall using a 6x2.5m2 rear projected stereo wall.

an archaeologist using the HIVE to interface with the 3D Shawbak Castle. Our user wears head tracked stereo shutter glasses in order to experience an immersive representation of the data. The user interfaces with the system via a tracked pointing device that allows the user to select between two modes: flight or block selection. Flight mode permits the user to fly around the castle by positioning and manoeuvring the pen in 3D space. We restrict the user from rolling the camera as this often complicates interaction. In block selection mode, the user can physically point at blocks on the display and select (highlight) those of interest. In Figure , the user is interested in interrogating the top left hand side of the arch and has consequently highlighted those blocks (shown in pink). Highlighted blocks can then be temporarily removed from the display, or, any block not highlighted can be temporarily removed. A menu system on the bottom left of the display permits the user to further interrogate highlighted blocks and extract further block information stored within the remote database. For example, stratigraphic information or volume of mortar used within the highlighted blocks. The user can also make accurate 3D measurements within the virtual environment.

While the user is navigating through the blocks and selecting them, requests are continuously sent to the database in order to visualize the stratigraphic units and how they are related to other units. The archaeological data which are displayed when a block is selected comes from the same data repository as the geometry, thus providing a better consistency of data.

Our 3D immersive display is not limited to display environments such as the HIVE. The same software will run on a standard desk-

top PC or laptop (with or without stereo). In this instance, the user can interact with the system using a 2D mouse.

## 7 CONCLUSIONS AND FUTURE WORK

The work presented here is the first result of collaboration between three laboratories. It shows the feasibility of the program and will be used as a basis for future developments.

As regards architectural and archaeological analysis, three essential issues of this project are to be pointed out: - the easy method for direct measuring of structural elements. The I-MAGE process (standing for "Image processing and Measure Assisted by GEometrical primitive"), is a useful device for the user and this time implemented in a specific module dedicated to the Shawbak survey. After having measured some points on the object-surface, the system is set up to let the user focus his attention on semantics, considering pictures one by one, while the system automatically completes 3D measurements. The active contour can be improved with the use of a combined algorithm as proposed by (Wiedmann and Roderhost, 1997) with a preliminary watershed algorithm on the original image is already possible since the framework includes the ability to setup some pre-processing over the whole image or over the inner bounds of the initial curve. Nevertheless, this has not yet been tested.

A second improvement resides in automating parameters selection for the fit. Given the great number of parameters involved in a successful fit, it is difficult to give the user access to all of them without cluttering the interface with a lot of technical choices. One envisioned solution is to build a library giving a mapping between image samples and the set of parameters that led to successful contour fittings on these samples. - The link between the scene representation in 3D and a database. This second feature allows combining a representation of the architecture itself to the database serving as a tool for the analysis of its units.

The use of a three-dimensional model as a user-interface to the data allows linking the purely documentary data (references, observations made during the excavation, photographs) to a 3D representation of the object. This graphical expression of the object relies on geometrical data (position, orientation, dimensions) as well as on knowledge of the object (theoretical shape, default values, relationships between diverse objects). The 3D model, produced by the system, shows the generic model of the object, defined by the archaeologists, and measured by photogrammetry and thereby becomes a relevant interface between the user and the collected data. The third point is the use of architectural knowledge in order to perform the measurement process: knowledge is used to get a 3D model of each block by extrude and data fusion. This approach allows inconsistency check and insures the database is always valid.

Finally our immersive visualization system permits the user to stand next to a photorealistic digital model of Shawbak Castle that has been created dynamically from a remote archaeological relational database.

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