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Towards a Photogrammetry and Virtual Reality Based Heritage Information System: 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 Montréal" in Jordan.
Current 3D GIS already provide support for urban models on a city scale. Our project however focuses on a building scale encompassing its atomic elements such as ashlars blocks, cement, stratigraphic unit and architectonic elements. At this scale we need a full 3D interface in order to manage accurate measurements and a mainly heterogeneous archaeological documentation.
The project is conducted by four laboratories: the MAP-GAMSAU located in the school of Architecture of Marseilles, France in charge of the photogrammetric survey phase; The LSIS laboratory, France, will be in charge of the knowledge based approach; 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.
To manage these archaeological data the project is divided into three phases: The survey phase: using a knowledge based photogrammetric tool, Arpenteur (http://www.arpenteur.net), the photogrammetric campaign ensures a survey founded on archaeological knowledge and directly linked with a database built by archaeologists. The objective here is to link an already existing archaeological database with a photogrammetric tool in order to simplify the photogrammetric process. Our goal here is to offer to the archaeology community a new tool for surveying where technical photogrammetric aspects are more or less hidden from the surveyor. The second phase is the use of the knowledge base to ensure data consistency through a complex and multi-user survey phase. Based on data fusion coming from different sources, this phase will ensure a reversible way to merge several partial surveys exploiting the complementarities between sources, solving different existing conflicts and reducing the possible redundancies. This fusion process deals with archaeological information as well as spatial information. Finally we need a high resolution interface between the final geometry and the archaeological database. Virtual reality using interactive immersive devices and specially designed software tools is an efficient method for revisiting the site and for analysing, updating and revising knowledge.

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

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Virtual Reality

1. The archaeological context

The archaeological study is led by the Dipartimento di Studi storici e Geografici of the University of Florence, Italy. The work in Shawbak is part of a wider research aimed at analysing the structural aspects of feudal society all over the Mediterranean basin through a sampling strategy based on 'historical regions' to define spatial contexts. [VNTD02].
One such region is actually the Trans-Jordan of Crusader-Ayyubid age, organised according to western European standards between year 1100 and 1187 (when the Crusader settlement was abruptly dismantled after the defeat suffered by the army of the Latin Kingdom of Jesrusalem).
The settling strategies adopted in the area by king Baldwin I and his followers resulted in the building of large rural fortified settlements (similar to the ones contemporarily created by the feudal aristocracies in southern France or in Italy) located on a line connecting present-day Amman to the red sea.
Such a display of economic and military means was indeed justified with the attempt to control the most important road system of the Arab world (connecting Damascus to Cairo and to the desert 'highways' leading to the Arabian peninsula), and had the ultimate effect to bring back to life the historic frontier of the Roman empire: the so-called limes arabicus. The area spanning from the ancient city of Petra

Figure 1: *A selection of the archaeological sample used to achieve an actual knowledge of the material aspects of feudal society's lifestyles across the Mediterranean basin. All projects are part of the Strategic Research Programme 'The Mediterranean feudal society': archaeological profile is supported and directed by the University of Florence.*

and the site of Shawbak can be considered a real keystone for the Crusader's project, as can be easily demonstrated by the early interests and the specific instructions given by the king himself to organise a settling system right there. The area encloses a number of fortified villages, known in written sources as castra, literally castles. All of them, except one, are concentrated inside (or in the near vicinity of) the urban area of ancient Petra. Two of them (al-Wu'Ayra and al-Habis) have been widely investigated in previous years

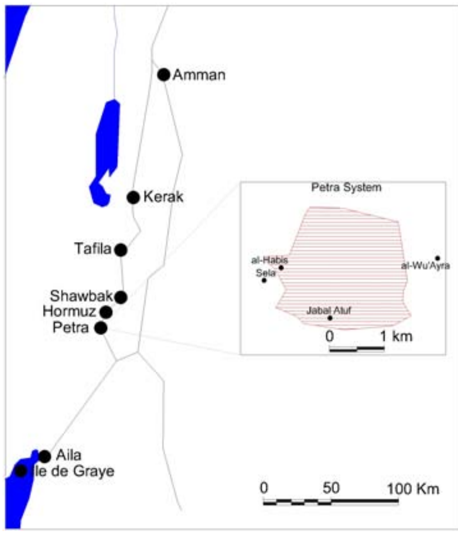

Figure 2: *A schematic view of the European settling system in Transjordan at the beginning of the 12th century.*

by means of traditional and 'light' archaeological means (see [DDS*05] for further details), while a third is currently under study: the castle of Shawbak.
Located approximately 25km north of Petra, the archaeological-monumental site of Mons Regalis/Shawbak can be considered one of the best preserved rural medieval settlements in the entire Middle East. Its key characteristics include a relevant time-spanning readable stratigraphy (from Roman to Othoman periods), an astonishingly well preserved nucleus of still standing medieval historical buildings and (connected with the above) a primary role played over the centuries by the castle (from Crusader age) in the political and military control of the whole Transjordan.
Archaeological readings at the site have always encountered a number of problems relating to data management. In particular, a suitable solution was required that allowed the acquisition, editing and querying in real-time of a large amount of data belonging to different documentary series (i.e. archaeological textual records, archaeological survey, architectural plans/elevations, 3D digital terrain models etc.) so as to maximize the possibilities of historical interpretation. [VN03].
Knowledge based photogrammetry appeared to provide an extremely valuable solution for the envisaged archaeological needs.

2. The 3D survey

2.1. The Arpenteur project

The Arpenteur project (ARchitectural PhotogrammEtry Network Tool for EdUcation and Research) started in 1998 by Pierre Drap, Pierre Grussenmeyer [DG00]. In the past few

years, the project has become both a WEB-based tool and traditional software running in Java on several platforms (Windows, Linux). It has been regularly completed and updated according to the evolution of the Java Development Kit proposed by SUN^{TM}.
Arpenteur is a photogrammetric project devoted to architectural survey that offers a simple and efficient tool for archaeologists and architects and that does not require a deep knowledge or expertise in photogrammetry. Once the first orientation step is performed by a photogrammetrist at least for photogrammetric model control and validation, the measuring step, made with the Arpenteur software, can be performed with the help of experienced researchers of other domains of knowledge, archaeologist or architect. Examples are available at http://www.arpenteur.net.
The project's main objective is founded on the idea of a process guided by knowledge related to one's personal field of study. The results can be shown as documents (XML), visual file (SVG, VRML, X3D) or as a body destined to database. For this purpose, the system makes a set of tools available for the experts and allows them to formulate hypotheses and the corresponding measurements related to their field of investigation.

2.2. A two step Photogrammetry campaign

The photogrammetric campaign was held in November 2004 and was aimed at surveying the fortified gates CF3 and CF5. Raw data of this campaign include: 743 photographs, 234 oriented photographs, 5325 3D points calculated, 100 control points and 10 working days for an archaeologist to make the orientation with Photomodeler. The archaeological team uses two Leica laser total stations that, in a previous field season, were employed to lay out a local reference system for the entire site.

2.3. Measuring 3D blocks

Once all the photographs are oriented The I-MAGE process (Image processing and Measure Assisted by GEometrical primitive), developed in 2001, has been designed to help during the measuring process in photogrammetric surveys. Users can make a 3D measurement using one single photograph, without altering result precision. This method was already published at the CIPA congress, [DDG01]; 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. ashlars) based on the only observable face. The morphology of each ashlars 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 provided by the archaeologist (depth, shape, ...). Computing an extrusion vector can be easy in the case where

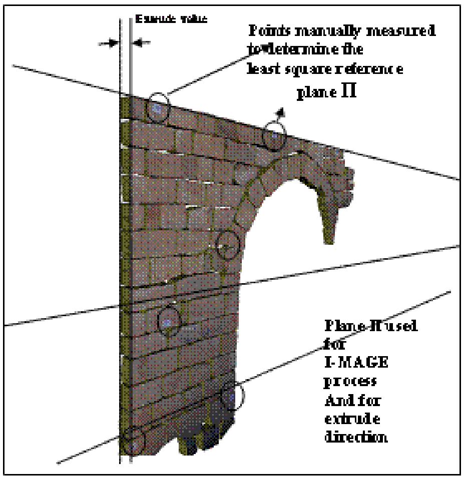

Figure 3: *Extruded ashlars blocks using a plane as an approximation of the exterior face of the wall.*

the architectural entity's 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 [DHVG00] and has been combined with the I-MAGE process in order to obtain an integrated tool.

3. Archaeological data and 3D survey: a single database

This project deals with heterogeneous data. We can group data into two kinds. Archaeological data are made by documentation, conceptual knowledge and classifications. Surveyed data is gathered from photogrammetry, observation and measurements.

3.1. 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 and Arpenteur will generate a correspondent photogrammetric model

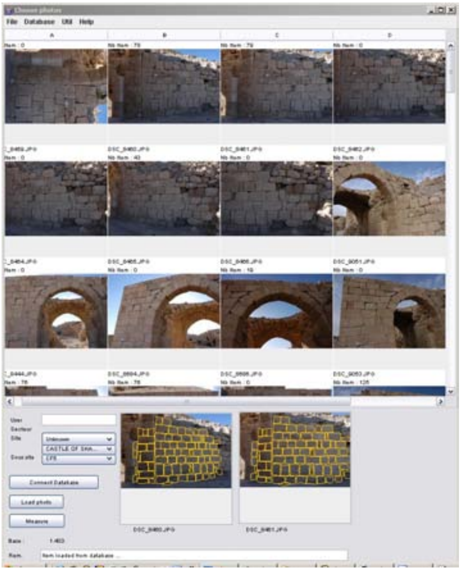

Figure 4: *Choosing oriented photographs from the database with Arpenteur.*

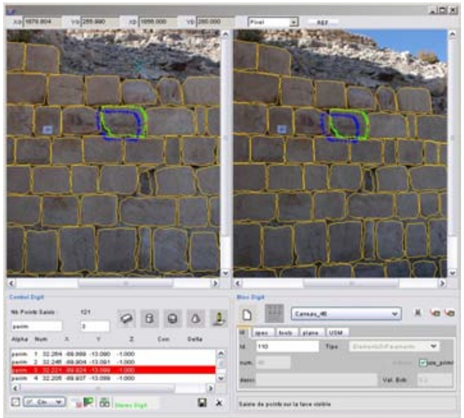

Figure 5: *Arpenteur. Block measuring interface.*

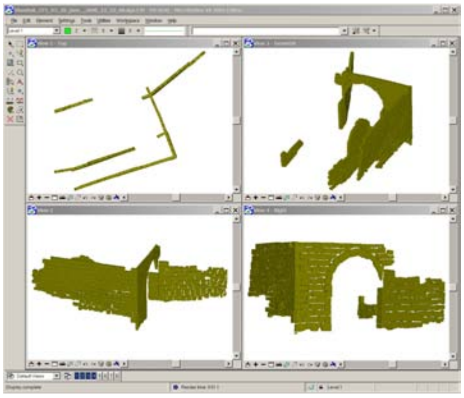

Figure 6: *Shawbak plotting with Arpenteur, exported in CAD Microstation (Bentley).*

on the fly. The application will connect to the database over the Internet to display thumbnail and load photographs and plotted blocks. A direct link to the PHP Database interface is available by picking the displayed blocks. The specific plotting interface, connected to the database was designed according to archaeologist needs and in connection with I-MAGE approach.

The plotting phase result is stored as a set of XML files before they are stored within the database. As several archaeologists can have concurrent access to the database and the survey can be done on several months. In order to ensure a coherent database inconsistency is solved before the final storage in the database. These aspects will be discussed in section 3.3. The Block plotting Arpenteur interface ensures a full integration of the I-MAGE process and allows the archaeologist to perform 3D measurements on two photographs focussing on the block's details.

A link with the database through a PHP based interface allows access to all the archaeological data already stored, neighbouring blocks, stratigraphic units, etc.

3.2. A relational database for archaeological and georeferenced data

Until now the formalism of data storage used in Arpenteur was XML. The constraints and the evolutions which presided over the choice of a relational database storage was initially the growing quantity of the data of the Shawback project, with XML storage becoming heavy in terms of performances and management. Then the choice was to migrate on the SGBD MySql up to version 4.2 which should support foreign keys, transaction and concurrent access. The second main reason for this migration was that the archaeologists of University of Florence developed a database to describe the stratigraphic units, in terms of archaeological knowledge, geometric, and spatiotemporal data. The archaeologists then formulated the need to have a tool which also integrates the data coming from Arpenteur. In the objective to have a unified model facilitating the access and the archaeology data analysis, the choice of a relational database storage was imperative.

The design of this database was conceived to be generic and reusable for all the projects, for all types of objects measured under Arpenteur, and to respect the Arpenteur object model. This was made by storing the Java class in the data description of the measurable item. This item inherits from a generic item which is instantiated by loading common data. The inherited item is then instantiated by loading the items specific data like the item description, the item metrology etc. All the measurement data of 2D and 3D points, photos and models that were used for the orientation are all stored in the database. The restitution of the specific model item is made in the air. The data access object is developed in Java and use a JDBC driver. The JDBC access data object implements usual requests like loading the database for instantiation of the Arpenteur model, insert new item, delete and update an existing item, and requests returning associations between items and photos on which they were measured.

This new data access model was applied on the Shawback project and the genericity was tested by using the same database scheme, the same JDBC access data object, and the same viewing interface for these projects. We need to implement only the specific Arpenteur object interface for each types of measurable item, to have a new application of Arpenteur. This is the main advantage of the Object model.

Our goal now is to extract knowledge based on spatial requests needed by the experts. Some of them are already available like loading all the items located in a sphere or in a bounding box. But close work and collaboration with the experts is required in order to identify their needs and produce an efficient spatial exploration tool. From this perspective, the idea to develop a 3D GIS tool integrating all these data was naturally imperative to provide an efficient research data analysing tool.

Work is beginning to redesign the existing archaeological database in this direction. We will adopt the Harris matrix and the ontology methodology for knowledge acquisition.

The development will be done using Geotools Java interface,(http://geotools.codehaus.org/) with a full integration in Arpenteur, virtual reality tools, and a Java 3D module to define the projection plan. These new research developments will be documented in future papers.

3.3. Using knowledge to ensure consistency

A detailed photogrammetric survey, stone by stone, will generate a huge quantity of measured objects. The plotting phase is extremely time consuming (several months and more than one operator may be required). In addition the data managed is strongly heterogeneous, all these factors increase the probability of inconsistencies in the measured objects set.We propose in this part a formalisation allowing detection of inconsistencies between sets of measured objects as well as an automated treatment of re-establishment of consistency and fusion.

3.3.1. Consistency of a set of objects

Our model of measurable objects relies on the object paradigm associated with a description. It is composed of:

1. The Object Class;
2. Default attributes values;
3. The set of constraints on the attributes denoted by $\mathcal{C}_a$;
4. The set of relations between objects denoted by $\mathcal{R}$;
5. The set of constraints on the relations of $\mathcal{R}$ denoted by $\mathcal{C}_r$.

Aspects 1, 2 and 3 of the model form the intrinsic part. Indeed, these three aspects relate to only the objects themselves. Aspects 4 and 5 form the relational part of the model. Aspects 2, 3 and 5 form the description added to the object formalism. Practically, this description is an XML file assigned to a class. The following example illustrates this model:

Exemple 1 Let $O = \{b_1, b_2, b_3, b_4\}$ be a set of measured objects of the class Block. For the sake of simplicity, we use in this sample only the attributes *name*, $length$, $width$, *volume*, $localisation$ and the set of photographs, denoted by *photos*, on which a block is measured. Constraints on attributes are:

- $0 < b.length < l$
- $0 < b.width < w$
- $0 < b.volume < v$
- $card(b.photos) > 0$

Where l, w and v are values given by the experts. For two blocks b and b', a sample set of relations $\mathcal{R}$ is defined by:

- $sameName(b,\ b')$ iff $b.name = b'.name$
- $sameLoc(b,\ b')$ iff $b.localisation = b'.localisation$
- $commonPhoto(b,\ b')$ iff $b.photos \cap b'.photos \neq \emptyset$

The computation of the relations is not always simple. For example, the computation of the relation $sameLoc(b,\ b')$ have to take into account specific geometry and measurement threshold. Experts given constraint on relation is for example:

- c_l: Two blocks b and b' of O, should not verify $sameName(b,\ b')$ if $sameLocation(b,\ b')$ is not verified.

In this model, a set of objects is consistent if and only if each object satisfies all the constraints on its attributes and each relation of $\mathcal{R}$ satisfy the constraints on the relations. If a set O of object is not consistent, there is a finite number of subset of O which are inconsistent. These sets are distinguished according to the type of constraints which they violate. A set of objects violating the constraints on attributes is called an intrinsic inconsistency set. A set of objects violating constraints on the relation is called a conflict. We now propose a formalism in order to represent our model.

3.3.2. Logic formalisation

In order to formalise the coherence of a set of objects, we use first order logic instantiated on the domain made by the set of measured objects. This choice is carried out by its simplicity of expression as well as its decidability. For us, the domain is the set of measured objects. Usual logical connectors are used $\vee$, $\wedge$, $\neg$, $\leftarrow$ and usual quantifiers are $\exists$, $\forall$. Unary predicates correspond to constraints on attributes and are such that:

Definition 1 Let o be an object of the set O belonging the class A. A constraint denoted by c_a from $\mathcal{C}_a$ enable us to define the unary predicate $c_a^A(o)$ such that:

$c_a^A(o)$ is satisfied if and only if c_a is verified for the object o.

The constraints of the sample 1 are expressed by: $length^{Block}(b) : 0 < b.length < 1{,}50m$, $width^{Block}(b) : 0 < b.width < 1m$, $volume^{Block}(b) : 0 < b.volume < 2m^3$, $photos^{Block}(b) : card(b.photos) > 0$ The set of the unary predicates is denoted $\mathcal{PC}_a$. Binary predicates are attached to relations between objects and are such that:

Definition 2 Let o and o' be two objects of O and let r be a relation of $\mathcal{R}$. The binary predicate $r(o, o')$ is defined by:

$r(o, o')$ is satisfied if and only if o et o'verify r.

Predicates representing relations of the sample 1 are: $sameName(b, b')$, $sameLoc(b, b')$, $commonPhoto(b, b')$, $pointsMix(b, b')$. Finally, constraints on the relations are represented by formulas whose terms are binary and unary predicates. The constraints on relations for the sample 1 are:

$$c_l : \forall b, b' \in O\ \neg sameName(b, b') \wedge sameLocation(b, b')$$

The set of binaries predicates is denoted by $\mathcal{PC}_r$.

3.3.3. Consistency of a set of objects

This formalisation enables us to define the coherence of a set of objects.

Definition 3 Let O be a set of measured objects and let $\mathcal{PC}_a$ and $\mathcal{PC}_r$ be the set of predicates representing the model constraints. O is consistent if and only if it is model of the set of formulas $\mathcal{PC}_a \cup \mathcal{PC}_r$.

If a set of objects is inconsistent, the inconsistent subsets are needed. Each one of these subsets is associated with the constraints which it violates to form a state. More formally, a state may be described as:

Definition 4 Let O be a set of measured objects and let O' be a subset of O violating the set of constraints $\mathcal{PC} \subset \mathcal{PC}_a \cup \mathcal{PC}_r$. A state , denoted by e is the couple $(O', \mathcal{PC})$.

The state associates the inconsistent subset of measured objects the violated constraints, and thus the cause of the inconsistency. We are currently working on an application which enables us to provide statistics to an expert and make treatments to solve inconsistency. This application will rely on the latest logical solver to find inconsistency.

4. An immersive virtual reality interface for Shawbak Castle

In recent years, VR has greatly facilitated the interaction and interpretation of archaeological data. For example the remarkable work of Vote and her team [VALJ02] 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 [PCVH04] 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 7 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* (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 geometry acquired with

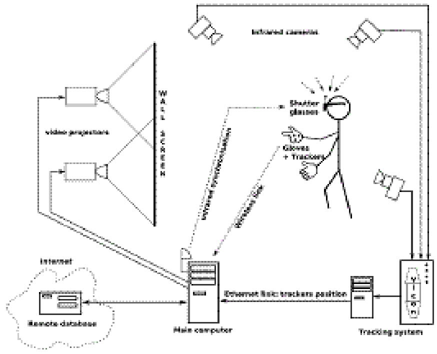

Figure 7: *HIVE architecture.*

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 optimisation 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 8 & 9 shows 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 8, 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.

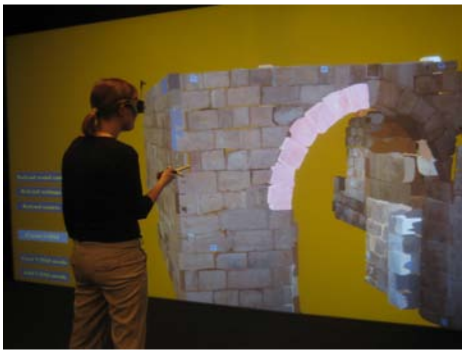

Figure 8: *Immersive visualization of part of the castle wall using a 6x2.5m^2 rear projected stereo wall.*

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

5. Conclusion and future work

The work presented here is the first result of a collaboration between three laboratories. It shows the feasibility of the program and will be used as a basis for future developments. Regarding architectural and archaeological analysis, three essential issues of this project are to be identified: the easy method for directly measuring structural elements. The I-MAGE process (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 their attention on semantics, considering pictures one by one, while the system automatically completes 3D measurements.

Figure 9: *Stereo visualization of part of the castle wall.*

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 "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 extrusion 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. The user can also interrogate the database using predefined SQL queries. Future work will permit the user to construct any database query within the virtual environment and will involve the development of novel techniques for the visualization of temporal and multivariate block data.

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