Knowledge Representation and Data Fusion for archaeology : The case study of the castle of shawbak

Julien Seinturier[1,3],Pierre Drap[1], Odile Papini[3], Guido Vannini[2], Michele Nuccioti[2]
(1) MAP, umr CNRS 694, Ecole d'Architecture de Marseille, France (Pierre.drap, Julien.Seinturier)@gamsau.archi.fr
(2) Dipartimento di Studi storici e Geografici dell'Università degli Studi, Florence, Italy (vannini, nuccioti)@unifi.it
(3) Université du Sud Toulon Var, La Garde, France (papini@univ-tln.fr)

Abstract

The present paper addresses an approach for merging heritage survey and archaeological knowledge. The theoretical framework is the integration between photogrammetric survey and documentation process, practically used in different archaeological excavation. Information is sorted by source. A source is a set of information provided by the operators involved in the excavation process. The merging process involves the verification of the consistency of different sources and the aggregation of all the information from the sources into a global result. Each source, respectively each operator, owns a personal representation of his knowledge domain. Merging together all these sets of information needs a method which can be easily operated by most of the participants in the research and which can furthermore manage the 'multiple knowledge' on the surveyed object. The merge process is theoretically defined in a reversible framework for propositional bases merging. This framework is presented in a semantic way and applied by the development of merging tool. This tool uses a simple interface for displaying results and knowledge in various form (textual, 2D map, 3D scene, XML). The tool provides a simple easy to use interface. Finally, a real case study will be. The selected case study is the Castle of Shawbak, in Jordan, known in medieval written sources as the "Crac de Montréal".

INTRODUCTION

The Arpenteur project provides a framework for knowledge based photogrammetric survey. It has been used several times during archaeological excavation as for instance at Aleyrac abbey [Drap, Hartmann-Virnich, Grussenmeyer. 2000]. In this paper, we present a new extension of the Arpenteur project: “Ametist”, an acronym standing for **A**rpenteur **M**anag**E**ment **T**ool for **I**nteractive **S**urvey **T**reatment. It is a new part of the project which provides an easy to use system of survey management. This application can perform various posts-processing treatments on data issued from Arpenteur. Operations include data verification, merging different data sources or export data in various formats (such as XML and in the near future VRML). This paper first presents the archaeological research at the site of Shawbak, Jordan. Then a brief description of the Arpenteur knowledge based photogrammetry project is also provided. An introduction of Ametist will follow also addressing the issue of the Arpenteur data merging. Finally an overview of the results gathered on the first experimentation will be given, together with future research perspectives.

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.
One such a 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.

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 Progamme ‘The Mediterranean feudal society: archaeological profiles’ supported and directed by the University of Florence.

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 ‘higways’ leading to the Arabian peninsula), and had the ultimately effect to bring back to life the historic frontier of Roman empire: the so-called *limes arabicus*.
The area spanning from the ancient city of Petra and the site of Shawbak can be considered a real keystone for the Crusaders’ 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.

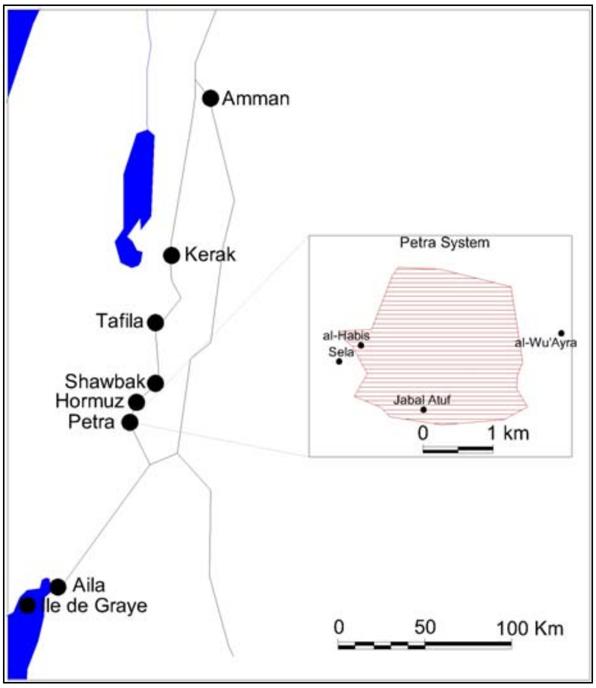

Figure 2: A schematic view of the European settling system in Transjordan at the beginning of 12th century

The area encloses in fact 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 by means of traditional and 'light' archaeological means (see [Drap et alii, 2005] for further details), while a third is currently under study: the castle of Shawbak.

Located approximately 25 km 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 encountered since the beginning a number of problems relating to data management. In particular it was required to find a suitable solution that allowed to gather, edit and query in real-time a very 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.

Knowledge based photogrammetry appeared to provide an extremely valuable solution for the envisaged archaeological needs.

Figure 3: The Shawbak castle

KNOWLEDGE BASED PHOTOGRAMMETRY

The Arpenteur project

The ARPENTEUR project (**AR**chitectural **P**hotogramm**E**try **N**etwork **T**ool for **E**d**U**cation and **R**esearch) started in 1998 by Pierre Drap, Pierre Grussenmeyer [Drap, Grussenmeyer, 2000]. In the past years, the project became 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™.

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 can be consulted at http://www.arpenteur.net.
The project 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 to the experts and allows them to formulate hypotheses and the corresponding measurements related to their field of investigation.

Stone by stone survey

The stone by stone survey of the castle is the first step of the Italian – French collaboration (see [Drap et alii. 2005] for a more detailed presentation on the matter). The archaeologist and the photogrammetrist define together a theoretical model of the objects to be measured. In case of a bloc, the theoretical model is an extruded polyhedron, as we see in the figure 4 and 5:

Figure4: A block perimeter easured with Arpenteur

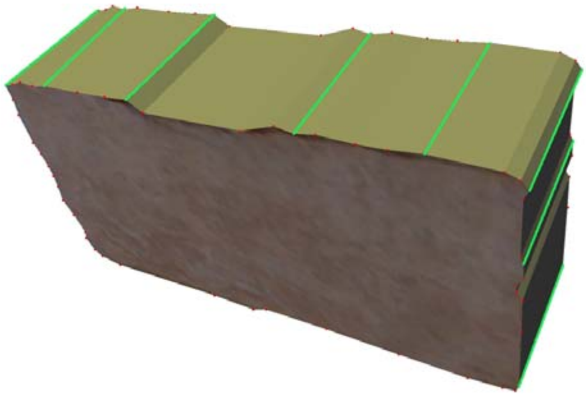

Figure 5: The Figure 4 block, after extrusion and mapping: in VRML

However, when wall masonry is not destroyed, the photogrammetry operator can only see one face of a block (i.e. ashlar). The archaeological knowledge of the blocks used for the construction of the castle enables to generate a 3D model of the real object. As the blocks are box shaped, and as the visible face of a block is almost planar, a 3D model can be generated by extruding the visible face with computed vector. The depth of extrusion is established through the archaeological knowledge of the real objects.
With the semi-automated computation of 3D representation of objects, non photogrammetrist final users have performed the stone by stone survey of a selected samples of walls of the castle (please refer to [Drap et alii, 2005] for further details).

Archaeological needs

This first experiment has shown new needs for the archaeologists. The first of which is the verification of data generated during the survey. When Arpenteur is used, errors may occur. These errors are of various kinds: Points badly plotted, bad identifiers assigned to objects, incomplete documentation, bad attribute values, and finally software errors. The project has to provide a simple way for verifying surveyed data allowing to modify them in any given case. The second need comes from the number of operators involved in the survey. On very large surveys, as it is the case in Shawbak, a joined group activity is required also for plotting. Different operators have to be able to work from distant locations simultaneously but, when the time comes for merging the whole dataset, the results of operators can conflict. The surveyor needs then a tool for merging all the intermediate results into the final result.

The third need is the management of a large amount of data. During a survey, Arpenteur produces a lot of information in various formats. Information has to be processed for a later use, according to the wish of the archaeologists. A management tool that can be used by archaeologists is so necessary.

These three needs require specific solutions. Some of them have already been used in the framework of underwater archaeology and can be used also in the present case study. [Drap, P., Seinturier, J., Long, L., 2003]

Knowledge Representation and Artificial Intelligence for data merging

The data consistency expression and the merge of large amount of data need a formal framework. In this section, we present a reversible framework for propositional base merging. This framework enables to make data merging reversible in a theoretical way and is strong enough to be implanted practically. This work is a generalisation of the reversible revision [Papini, 2001]. The transposition between applicative context and theoretical framework is made by the assimilation of data sources to propositional belief bases. The Figure 6 shows the merge process in the reversible framework. The first step is to express belief on the data sources by propositional base. The data merging is obtained by merging the propositional bases into a merged propositional base. This base provides the global belief on the data. Practically, this belief gives a way for aggregating data in a final result.

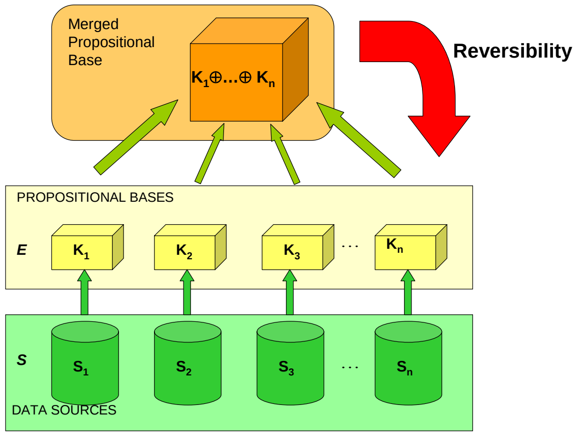

Figure 6: Merge in the Reversible Framework

Priorities and Pre-orders

Merging data is the selection of the most suitable provided data. This selection is based on the expression of priority. Data with high priority have to be in the merge result. Two kinds of priority are used. First, the priority between the propositional bases, called external priority is defined. It expresses priority between the data sources without knowing their content. Then, an internal priority is expressed inside each base. It is representing priority between pieces of data for a same source. For example, in the archaeological context, it can be priority between the operators involved in the survey. It gives the external priority. Moreover, operators can express internal priorities on the pieces of data they provide. More formally, in the semantic way, let $E = \{K_1, \ldots, K_n\}$ be a set of propositional bases and let W be the set of interpretations of the propositional language. For each base K_i a weighting function p_{Ki} assigns an interpretation ω to a polynomial of IR[x] called weight and denoted by $p_{Ki}(\omega)$. Priorities are represented by pre-orders: the external pre-order, denoted by $\leq_E$ is such that for two propositional bases K_i and K_j, $K_i \leq K_j$ iff K_i is prior than K_j, ie that information provided by K_i is preferred to information provided by K_j The internal pre-order, denoted by $\leq_{K_i}$, is such that for two interpretations ω and ω' of *W*, ω $\leq_{K_i}$ ω' iff ω is prior than ω' and so $p_{Ki}(\omega) \leq p_{Ki}(\omega')$. External pre-order relies on a weight distribution for the propositional bases. We call external weighting function an application which associate each base K_i a polynomial weight of *IR[x]* denoted by *q(Ki)*. Most of the time, *q(Ki)* is a constant polynomial. External pre-order is such that $K_i \leq K_j$ iff $q(K_i) \leq q(K_j)$. On the other hand, internal pre-orders rely on polynomial weight distributions for the interpretations. We call internal weighting function an application with associate each interpretation ω and each base *Ki* a polynomial denoted by $p_{Ki}(\omega)$. Internal pre-orders are such that $\omega \leq_{K_i} \omega'$ iff $p_{Ki}(\omega) \leq p_{Ki}(\omega')$. The way for comparing polynomials characterizes the merging operator. We show in [Seinturier, Papini, Drap, 2006] how to characterize well known merging operators such as distance based operators by pre-orders on polynomials in the reversible framework. Let *p* and *q* be two polynomials. Most used pre-orders are the Maximum pre-order, such that:

$$p \leq q \text{ ssi } \max_{i=0}^{k}(p_i) \leq \max_{i=0}^{l}(q_i).$$

The Sum pre-order, such that:

$$p \leq q \text{ ssi } \sum_{i=0}^{k} p_i \leq \sum_{j=0}^{l} q_j \text{. The}$$

The Weighted Sum pre-order, such that:

$$p \leq q \text{ ssi } \sum_{i=0}^{k} a_i \times p_i \leq \sum_{j=0}^{l} b_j \times q_j .$$

With the definition of external and internal weights and external and internals pre-orders, we can perform the propositional base merging.

Propositional base merging in the reversible framework

The merging process combines the two kinds of pre-orders into a global pre-order which express the global priority on all interpretations. As above, global pre-order relies on a weight distribution. The global weight computation formula has to take in account the historic of the merging. For that, we aggregate all internal weights in the global weight such that there is a function which enables to retrieve originals polynomials. The global weight is defined by:

$$p_{K_1 \oplus \ldots \oplus K_n}(\omega) = \sum_{i=1}^{n} p_{K_i}(\omega) x^{\sum_{j=1}^{r(i)-1} MAX_{r^{-1}(j)}}$$

Where

$$MAX_{K_j} = \max_{\omega' \in W}(\deg(p_{K_J}(\omega')) + 1)$$

The *r* function is a bijection which associate each base K_i a unique integer *r(Ki)*. We define the global pre order such that:

$$\omega \leq_{K_1 \oplus \ldots \oplus K_n} \omega' \text{ iff } p_{K_1 \oplus \ldots \oplus K_n}(\omega) \leq_{\oplus} p_{K_1 \oplus \ldots \oplus K_n}(\omega')$$

The result of the merge is given by the set of minimal interpretations following the global pre-order. This set of interpretations is the model of the merged propositional base. More formally, the merged propositional base denoted by $K_1 \oplus \ldots \oplus K_n$ is such that:

$$Mod(K_1 \oplus \cdots \oplus K_n) = \min_{\leq \oplus} \omega \in W$$

The global pre-order relies on the pre-orders on polynomials previously defined. When a merging operation is performed, this framework enables the reversibility of the process.

Reversibility of merging

The first aim of the framework is to make the merging reversible. Polynomials provide aggregation operations which enable to encode historic. The global weight formula compute a global weight composed of all internal weight polynomials. This formula can be inversed and internals weights are retrieved from global weight polynomials by the formula:

$$p_{K_i}(\omega) = \frac{p_{\oplus}(\omega) \bmod x^{\sum_{l=1}^{r(K_i)} (MAX_{r^{-1}(l)} + 1)}}{x^{\sum_{k=1}^{r(K_i)-1} (MAX_{r^{-1}(k)} + 1)}}$$

We can express in this framework all classical merging operators. The syntactic counterpart of merging and the equivalency between semantic and syntactic approaches are show in (Seinturier, Drap, Papini, 2006). The following example illustrates the merging in the reversible framework.

Example:

Let $E = \{K_1, K_2, K_3\}$ be a set of propositional belief bases such that:

$$K_1 = \{(s \vee o) \wedge \neg d\}$$

$$K_2 = \{(\neg s \wedge d \wedge \neg o) \vee (\neg s \wedge \neg d \wedge o)\}$$

$$K_3 = \{s \wedge d \wedge o\}$$

Each propositional variable s, d, o represents belief on piece of data. The set of interpretations $W = \{\omega_0, \omega_1, \omega_2, \omega_3, \omega_4, \omega_5, \omega_6, \omega_7\}$ is such that:

$$\omega_0 = \{\neg s, \neg d, \neg \mathrm{o}\} \quad \omega_1 = \{\neg s, \neg d, \mathrm{o}\}$$

$$\omega_2 = \{\neg s, d, \mathrm{o}\} \quad \omega_3 = \{\neg s, d, \neg \mathrm{o}\}$$

$$\omega_4 = \{s, \neg d, \neg \mathrm{o}\} \quad \omega_5 = \{s, \neg d, \mathrm{o}\}$$

$$\omega_6 = \{s, d, \neg \mathrm{o}\} \quad \omega_7 = \{s, d, \mathrm{o}\}$$

The survey manager expresses priorities on the operators. The operator 3 is the most prior. There is no priority between operators 1 and 2. We express the external priority by the pre order:

$$K_3 <_E K_1 =_E K_2$$

The following table represents the internal weights for each bases and the global weight for each interpretation. Merging the base consists in ordering the interpretations by using a pre-order on the global weights.

ω	$p_{K1}(\omega)$	$p_{K2}(\omega)$	$p_{K3}(\omega$	
ω	x	1	$1+x$	$1 + x + x^3 + x^4$
ω	1	0	x	$x + x^2$
ω	x	0	x	$x + x^3$
ω	x	1	1	$1 + x^3 + x^4$
ω	1	x^2	x	$x + x^2 + x^6$
ω	0	1	1	$1 + x + x^4$
ω	x	1	1	$1 + x^3 + x^4$
ω	x	x^2	0	$x^3 + x^6$

If we use the pre-order Sum, we obtain the pre-order on the interpretation:

$$\omega 1 = \omega 2 = \omega 5 = \omega 7 < \omega 3 = \omega 4 = \omega 6 < \omega 6$$

The result of the merge is such that:

$$Mod(K_1 \oplus K_2 \oplus K_3) = \{\omega_1, \omega_2, \omega_5, \omega_7\}$$

The reversibility enables to retrieve internal weights from global weights.

Implementation of Theoretical Framework in the Shawbak Study Context

We show now the transposition of the theoretical framework for reversible merging. For that, we focus on the study of the Castle of Shawbak.

Consistency of the results

The consistency verification is the first step of the merging. This step is critical because it must detect the conflicts between results. Conflicts are separated in two groups: The attribute conflicts and the spatial conflicts. The first group contains the conflicts relative to items description or documentation. A survey result must respect some constraints on the items attributes. For example, two item must not have the same identifier. If they do, a conflict is detected. The source of the conflict can be the redundancy of an item in different results or an error in the identification of an item. The second group is composed of the spatial conflicts. As Arpenteur provide 3D representation of real items, spatial constraints can be used. For example in a stone by stone survey, the 3D representations of two blocs must not intersect (a standard measurement error is anyway considered for neighbour blocks). The two items in figure 8 are violating this constraints, a conflict must be detected because they represent the same block. Detection of spatial constraints violation is not easy due to the complexity of the algorithms used and the number of items. The conflicts are expressed as rules. Once

the conflicts are detected, rules are generated. A rule is expressed in the form:
If item 1,…, item n violate C then conflict C detected
Where "C" is a constraint. The conflict detection provides groups of items for each constraint violated. The merge aims to choose one item from each group. The tool here presented is still under development and aims at providing a simple attribute merging that will be enhanced by new merging techniques dedicated to spatial conflicts.

Ametist

Ametist, has been designed to provide Arpenteur users with a way to manage all the data produced by the software. This new tool covers the three domain of Arpenteur: Photogrammetric measurement, 3D representation and documentation. The graphic interface (designed to be user-friendly) proposes a global view of the photographs used during the photogrammetric measurement, a workspace which can display representation of the survey and a set of forms for the documentation. The figure 7 shows the Ametist graphic user interface.
As the software can read the XML output from Arpenteur software, users can control the output of Arpenteur as often as needed. Moreover, the user can modify some attributes directly from the interface. A second need is the large amount of data processing capability. The software has to be fast and stable, even if hundreds of items are surveyed

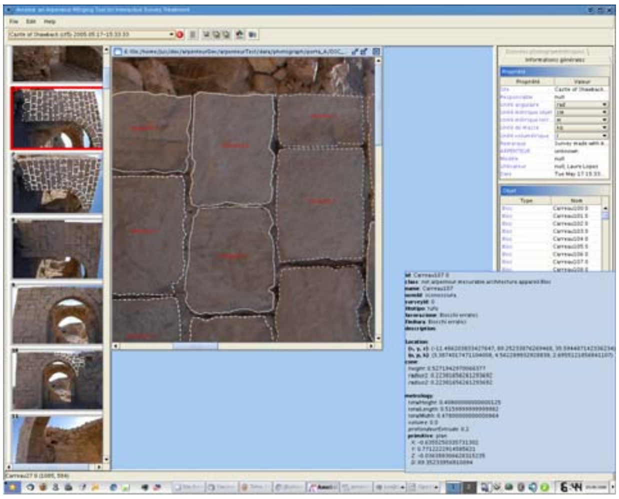

Figure 7: The user interface with a photograph and an item tooltip.

Ametist is a Java application. Since Java 1.4, the Graphical User Interface is fast and stable and is a good base for a strong graphic application. The application is developed for displaying a large amount of high resolution photographs and is therefore based on the Java Advanced Imagery (JAI) toolkit. The primary need is nonetheless the merging of several results: a most complex task indeed.

First Merging Results

As previously said, data merging involves result's consistency verification, and items modification. A traceability of the changes during the merging is also needed, the archaeologists have to be able to see what has been merged and for what reasons. A first practical approach has been set up for the Shawbak survey called "dynamic merging". The dynamic merging is the merging of the instantiated items. When items are instantiated, we can access and modify all information of an item: Attributes, geometry, photogrammetric data and documentation. Moreover, the modifications are taken into account immediately and can be propagated. The conflicts detection capability is maximal due to the access to all information. In case of an identifier conflict, the tool determines if this is redundancy or bad identification. In case of redundancy, only one item is kept in the final result. The choice of which item to keep is done according to an external and editable set of rules. Even if the automation of the merging is our goal, user can choose to make a manual selection among the items. The spatial conflicts are more complicated. In this work, a spatial conflict is raised if two 3D items representation are intersecting. This conflict can have two sources. First, an error in the measurement gives a bad 3D representation. In this case, the measurement of the items has to be verified and modified. Secondly, the 3D representations in conflict can be different representation of the same item. In this case, the merging has to provide a new item issued from both conflicting items information. The Figure 8 illustrates a spatial conflict. The spatial conflict detection and correction is presently under development. 3D algorithm for polyhedron intersection has to be implemented. Moreover, a merging formalism and its implementation is needed in response to the conflict detection capability.

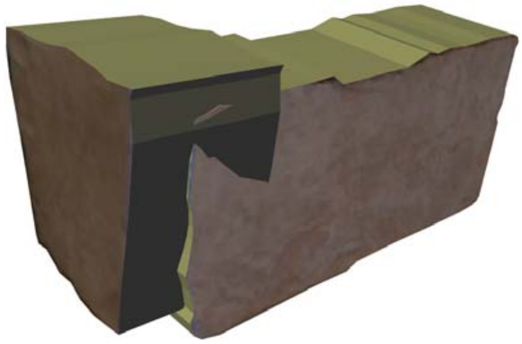

Figure 8: Spatial conflict for 2 survey of the same bloc at an angle of a wall

Data Storage and static merging

During a survey, artefacts are represented as instance of object taxonomy. The artefacts are in a dynamic state. However, persistence of the results needs a static state that stores all data, and so, a static merging capability. There are two kinds of static states. XML based expression of a survey provides a suitable way for representing heterogeneous artefacts due to its semi-structured model. Arpenteur generates 3D representation as VRML / X3D files and XML files containing all the items information. The 3D representation only contains geometry. Merging of 3D expression of the results could be used for the creation of a global representation of the survey. As the files are static and only geometry is available, the merging capability is very limited. It could be also difficult to control if different items are in the same location. Finally, it is impossible to merge the non geometrical attributes of the items. The XML representation is more suitable for the merging of the results. These files are the core of the Arpenteur data and contain all information on a survey: Attribute values, documentation, photogrammetry measurements and geometric primitives for 3D representation. Even if XML representation is static, like VRML and X3D representation, the first is far more useful. As XML contains all information on a survey and on the items composing it, this representation can be used for merging item attributes or documentation. However, the complexity of large XML document manipulation algorithms is big and working directly on XML representation is impossible with large amount of data. Classic database storage provides a solution for storing large amount of data, but reduces the heterogeneity. In the case of Shawbak, this is a good solution because there are a large number of homogenous artefacts. Some of the merging operations defined in a dynamic way can be expressed in this case by requests on the database. More advanced merging operations cannot be reduced as database queries and involve the load of the artefacts to merge. The first results of the Shawbak excavation survey are now presented.

Shawbak excavation survey

At this time, the first merged results of the survey contain 825 blocks measured. Two final users, Elisa Pruno in Italy and Laure Lopez, in France are working on the photogrammetric measurements. The figure 9 shows a first VRML 3D representation of the excavation.

Figure 9: 3D representation of the gate of the castle of Shawbak

Conclusion

We have presented the use of a new data management tool for archaeological photogrammetric survey. The first results for the Shawbak archaeological photogrammetric survey have shown the need for it. The software here presented partially succeeded in filling a part of the need. Its simple interface can be used by non specialists. The merging capability of results makes the creation of global results easier. However, multiple enhancements are underway. The implementation of the reversible framework for the merging and the development of new geometric algorithms will open new ways for a more efficient resolution of conflicts and a quicker computation. On a formal way, the extension of reversible framework for propositional base merging to description logics should provide a bigger expressivity to the merging capability and a strong way to express consistency of object heritage and semi structured representation.

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