3D MODELING AND SEMANTIC CLASSIFICATION OF ARCHAEOLOGICAL FINDS FOR MANAGEMENT AND VISUALIZATION IN 3D ARCHAEOLOGICAL DATABASES

Anna Maria Manferdini[1, *], Fabio Remondino[2,3], Simone Baldissini[1], Marco Gaiani[1], Benedetto Benedetti[4]

[1] Dept. DAPT - Bologna University, Italy - am.manferdini@unibo.it
[2] Institute of Geodesy and Photogrammetry - ETH Zurich, Switzerland - fabior@ethz.ch
[3] Centre for Scientific and Technological Research - Bruno Kessler Foundation, Trento, Italy
[4] Scuola Normale Superiore - Pisa, Italy - benedetto@sns.it

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ABSTRACT:

The generation of digital 3D models of archaeological finds can be followed by further products, applications and studies such as a semantic classification in order to organize the digitally documented finds and provide connections between 3D models and databases. In this contribution we present a methodology developed to assist the superintendence of archaeological excavations or sites in the digital classification, management and visualization of finds inside advanced database/repository. Our approach, divided in three mutually connected steps (modeling, segmentation and visualization), has been realized as general as possible and tested on different types of archaeological objects. Firstly a reality-based 3D model of a find is produced, using photogrammetry or active sensors. Secondly the geometric model is semi-automatically segmented and classified according to archaeological and architectural rules. The semantic classification of the finds is afterwards linked to an archaeological database to e.g. decide whether the object is constituted by original pieces or some of them belong to other finds and should be re-located. Finally the modeled and classified find is visualized in 3D open-source systems linked to an archaeological database. The visualization of the achieved results (3D models and thematic layers) is thus very useful for monitoring and updating intervention policies within the archaeological area.

1. INTRODUCTION

In archaeology the systematic and well-judged use of 3D information for documentation and conservation is a relatively recent innovation, not yet applied on a regular basis as considered too expensive, not really useful and difficult to be linked to classical 2D information. The reason of this lack can be attributed to the perceived ‘high cost’ of 3D, the difficulties in achieving good 3D models, the perception that this is an ‘optional’ process of interpretation (an additional ‘aesthetic’ factor), the difficulty of integrating 3D worlds with other 2D data and documentation and the episodic use of 3D models for scientific analysis.
Nowadays the most common techniques used for 3D documentation are based on image data (Remondino and El-Hakim, 2006) or range data (Bernardini and Rushmeier, 2002; Blais, 2004). Both approaches, often combined (El-Hakim et al., 2008), have their own advantages and disadvantages and generally the choice between them is made according to the budget, project size, required degree of detail, surface characteristics, objectives and experience of the working team. Once a 3D digital model is produced, many further products and studies can be led. Besides visualization, VR, physical replicas, the recovered digital 3D data can be used to rebuild the original architectural layout of archaeological sites and / or programme intervention policies. Furthermore 3D geometry can be segmented, classified and linked to databases (Attene et al., 2007).
In this contribution we present our work and methodology developed to assist the superintendence of archaeological excavations and heritage sites in the digital reconstruction, classification, management and visualization of finds inside advance 3D repositories. The problem required a solution able to provide segmented and classified 3D models which could be interfaced and linked to archaeological databases and GIS. Our approach, divided in three and mutually connected steps (modeling, segmentation and visualization), has been realized as general as possible and tested on different archaeological objects.

2. THE DEVELOPED METHODOLOGY

The generation of 3D models of heritages and archaeological finds is receiving more and more attention in the last years. In which way we can fully exploit and correctly use the recovered 3D information for archaeological purposes is still under discussion and evaluation. But motivated by the practical need of archaeologists to classify, document and retrieve historical and architectural information of finds, we developed a system to assist archaeologists in the digital classification, management and visualization of finds inside 3D GIS linked to existing databases. The method (i) produces reality-based photo-realistic 3D models, (ii) classifies them in layers and (iii) assigns to each element archaeological and architectural information beside the already known geometric properties (Figure 1).
Therefore 3D structures are broken down into their component parts (e.g. capital, shaft, base, etc.) following basic libraries of geometric primitives and then associated to information extracted from existing databases. Each part of the find is then connected to series of information created to ease the retrieval process (on a web-based interface) in a semantics-based context.Our goal is also to improve the retrieval of 3D objects and related information within a repository by annotating each shape not only as a whole, but also in terms of its meaningful subparts, their attributes and their relations. Therefore the

* Corresponding author.

possibility to semantically annotate shape parts may have a relevant impact in several domains, like archaeology.
The developed methodology is based on the concept of 3D information organization using semantics and it follows the shape grammar concept introduced by Stiny and Mitchell (1978) and Stiny (1975, 1980). The original formulation of the shape grammar concept operates directly on an arrangement of labeled lines and points. However, the derivation is intrinsically complex and usually done manually, or by computer, with a human deciding on the rules to apply.

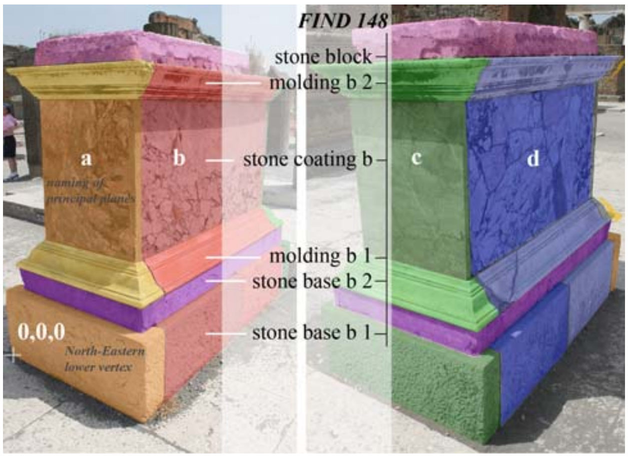

Figure 1: Example of geo-location, reference system, identification and naming of single elements and groups constituting a particular archaeological find.

2.1 Related works on modeling and semantic

The first example of 3D modeling and semantic classification was presented in Quintrand et al. (1985). The authors clearly state that to associate semantics to an architectural shape requires to regard the building as a system of knowledge, then to extract a model from its description and finally to define its representation according to the objectives of the analysis.
Afterwards several researches concentrated on the development of classifications of architectural elements in theoretical frameworks (Tzonis and Lefaivre, 1986) or in applications of the geometrical modeling (Gaiani, 1999). De Luca et al. (2007) presented a methodological approach to the semantic description of architectural elements based both on theoretical reflections and research experiences. Attene et al. (2007) developed the ShapeAnnotator, a modular system to load a 3D triangular surface mesh (and its domain ontology), define the meaningful shape parts, annotate them properly and save the result in a database. For the shape parts definition, they used an approach able to automatically select the most suitable primitive to approximate a set of triangles in a cluster. Semantic modeling and classification has been also used in city modeling applications (Emgard and Zlatanova, 2008). Recently semantic classification was also used as pre-step for a successive procedural modeling of architectures (Mueller et al., 2006).

3. REALITY-BASED 3D MODELING

The generation of reality-based 3D models of objects and sites is generally performed by means of image-base techniques or active sensors, depending on the surface characteristics, required accuracy, object dimensions and location, project's budget, working team experience, etc. Active sensors (Blais, 2004) provide directly 3D data and combined with color information, either from the sensor itself or from a digital camera, can capture relatively accurate geometric details. Active sensors are still costly, usually bulky, with limited flexibility, not easy to be use everywhere or at every time and affected by surface properties. Nevertheless they have reached a maturity since some years and the range-based modeling pipeline (Bernardini and Rushmeier, 2002) is nowadays quite straightforward and supported by many commercial packages, although problems generally arise in case of huge data sets.
On the other hand, image-based methods (Remondino and El-Hakim, 2006) require a mathematical formulation (perspective or projective geometry) to transform two-dimensional image measurements into 3D coordinates. Images contain all the useful information to derive geometry and texture for a 3D modeling application. But the reconstruction of detailed, accurate and photo-realistic 3D models from images is still a difficult task, in particular for large and complex sites and if uncalibrated or widely separated images are used.
Besides range- and image-data, surveying information is also generally combined for correct geo-referencing and scaling. Although many methodologies and sensors are available, nowadays to achieve a good and realistic 3D model, that contains the required level of detail, the better way is still the combination of different modeling techniques. In fact, as a single technique is not yet able to give satisfactory results in all situations, concerning high geometric accuracy, portability, automation, photo-realism and low costs as well as flexibility and efficiency, image and range data are generally combined to fully exploit the intrinsic potentialities of each approach (Stumpfel et al., 2003; El-Hakim et al., 2004; Lambers et al., 2007; El-Hakim et al., 2008).

3.1 Image-based reconstruction

Accurate and detailed 3D models can be created using photogrammetry. Semi-automated measurements (Figure 2) are generally preferred although the latest developments in automated and dense image matching are promising (Remondino et al., 2008). Generally some manual interaction on architectural features is still mandatory when precision and reliability are the first priority of the work.

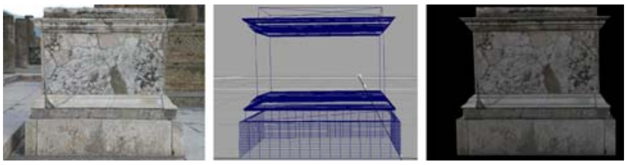

Figure 2: Texturized 3D models based on photogrammetry.

Using photogrammetry, the required level of detail can be obtained defining the correct number of surfaces in which the entire volume can be fragmented. Particular attention has to be paid to silhouettes and deteriorated corners.
The derived geometric model is then textured for photorealistic visualisation (Figure 3). In order to add more detail to geometry (where the model does not require the same accuracy), the manipulation of textures, for example by means of bump mapping, can also help in simulating relief and irregularities.

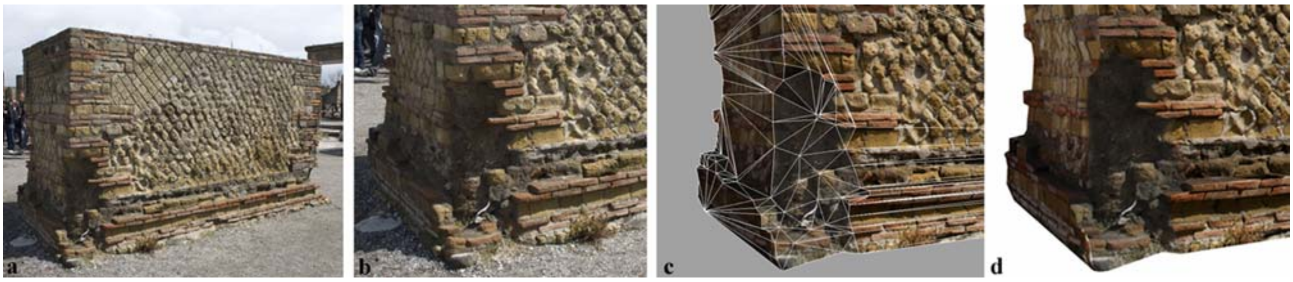

Figure 3: Reality-based 3D modeling and generation of the desired level of detail of deteriorated corners. (a, b): images of the find and closer view of a deteriorated corner. (c): 3D geometry rebuilt using photogrammetry. (d): texturized 3D model.

3.2 Range-based reconstruction

Accurate digital 3D models of archaeological finds can also be created using range-based active systems (triangulation-based or ToF laser scanners, patter projection systems, etc). This surveying and modeling approach implies the use of costly

instruments which are in any case widely used within the architectural and archaeological field.

The use of range sensors involves planning and knowledge about the accuracy and quickness of measurements, costs, surface properties, object location, etc as well as good experience of the working and modeling team.

We employed both triangulation-based and ToF scanners to survey and model some finds. The obtained point clouds were registered, meshed and the 3D models textured for photorealistic visualization. Then, like in the image-based case, our work continued with the segmentation phase (Section 4) and the linking to the database. For some models (e.g. Figure 6) additional surfaces have been introduced in order to rebuild hidden volumes and clearly separate the different architectural elements.

4. FINDS SEGMENTATION

This operation requires the help and support of archaeologists and architects to recognize transitions between different elements that constitute the find and semi-automatically segment it. The semantic classification of the finds is used in the archaeological database to decide whether the object is constituted by original pieces or some of them belong to other finds and should be re-located. Furthermore, the semantic classification of the finds leads to the identification of classical orders, building functions and materials as well as extra information. The semantic segmentation is done directly on the 3D geometry using a supervised classification. Additional information such as geo-location and numbering are also added in order to uniquely indicate a single element within the entire set of finds (

Figure 5, 6, 7 and 8).

Each part is connected to an instance in a knowledge base to ease the retrieval process in a semantics-based context. The naming of each single element and of the classes in which they can be grouped is an important process that strictly depends on archaeological and architectural considerations.

Assuming that each single element has to be considered regardless of the context in which it is located, the name can be derived from classical orders only if specific morphological analysis can be leaded, otherwise, the name has to suggest building function or building material that guarantees more general and versatile interpretations. The segmentation of a find in its single components follows the 3D modeling phase. For models obtained using range data, due to the large number of triangles, it is not possible to automatically recognise the transition among different elements – especially when their surfaces are coplanar or have similar finishing characteristics. On the other hand, for 3D models obtained using image data, the search of borders and transitions among elements could be done during the modeling phase, by detecting homologous points and curves on the different images. But this approach could increase the error while orienting the photographs and consequently reduce the metric accuracy of the 3D representation.

For these reasons the segmentation is done using a 3D modeling software, after having built the geometry of the whole find (Figure 4).

The mesh is segmented using instruments that can sub-divide single triangles following the transition profile that can be visually recognized using the texture or surface irregularities.

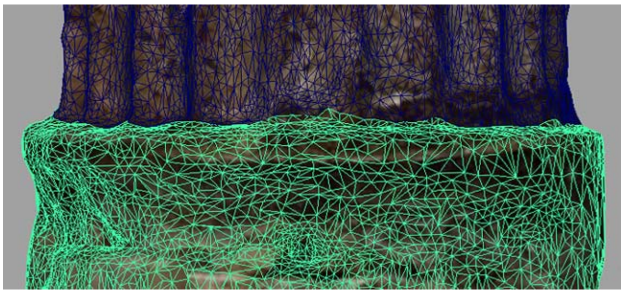

Figure 4: Segmentation of the whole geometry of the model by recognizing the transition among different elements with the help of texture and surface irregularities.

While the mesh is subdivided and the model segmented, the semantic structure of the find suggests the organization of single nodes and their naming (Figure 9).

After the segmentation phase, it is possible to re-build inner subdivision surfaces, in order to define the entire volume of each single element and node. This phase is strictly dependent on the ability of archaeologists to recognize morphological elements and constructive techniques and give volumetric interpretations.

In order to differentiate metric reconstructions from volumetric interpretations, it is necessary to use bright colors (for example bright red or yellow) that can easily be distinguished from other textures. In order to estimate the costs of these operations in terms of time, for finds that have a middle complexity (as the ones that are shown in the images of this paper), the segmentation and inner re-built of volumes usually requires one man-day per piece.

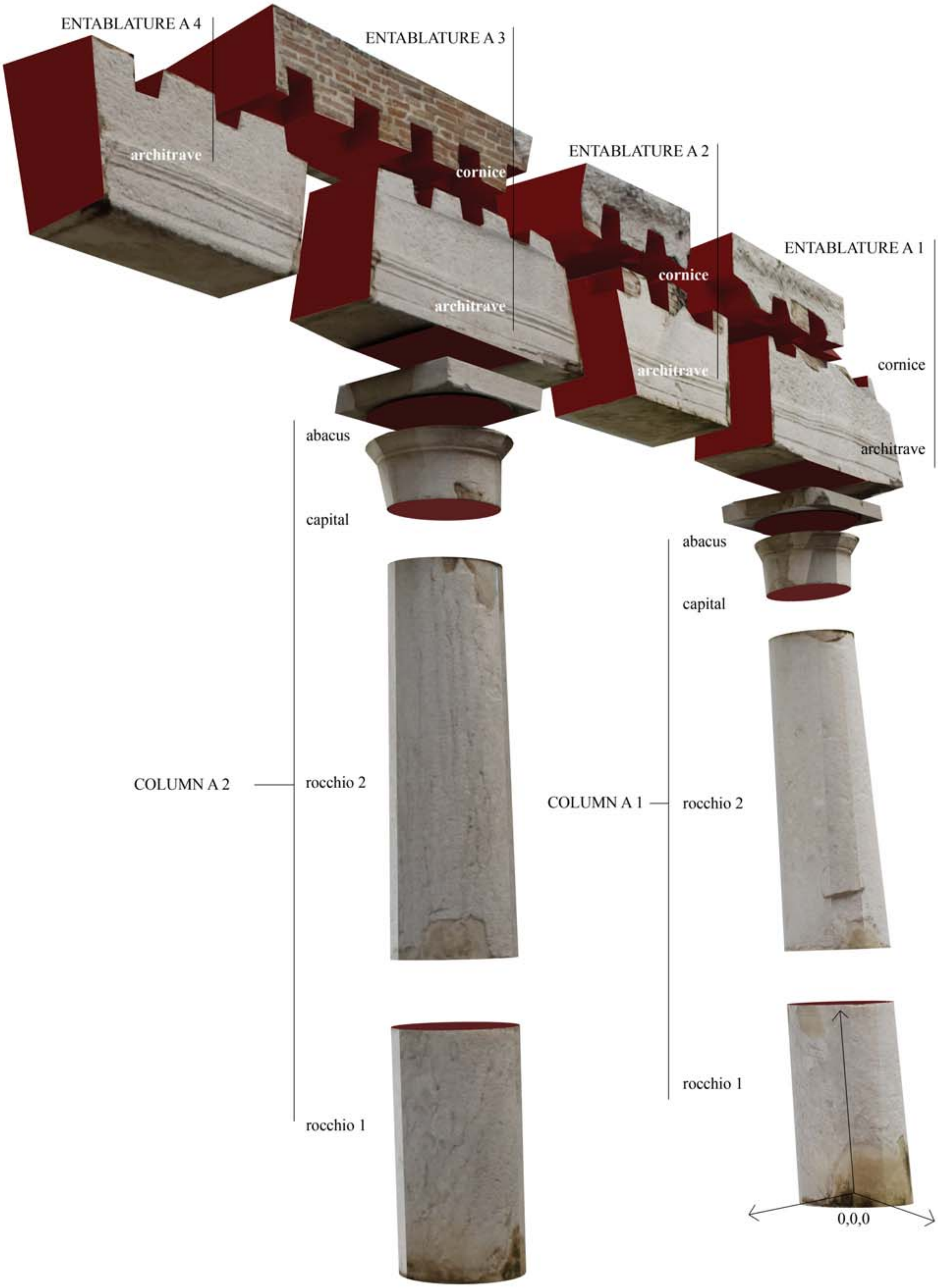

Figure 5: The segmentation process of the reconstructed 3D model, consisting of (i) identification of single elements, (ii) naming of the elements, (iii) identification of relations between them and (iv) definition of the volumes they subtend. All this information is stored in a database together with find's number, geo-location and other useful archaeological details.

5. VISUALIZATION AND GIS FUNCTIONALITIES

The survey of archaeological finds involves 3-dimentional considerations. Traditional 2-dimentional representations (such as orthogonal projections) do not constitute the right method to represent digital measurements, investigations and prepare protection policies, restoration interventions, etc.

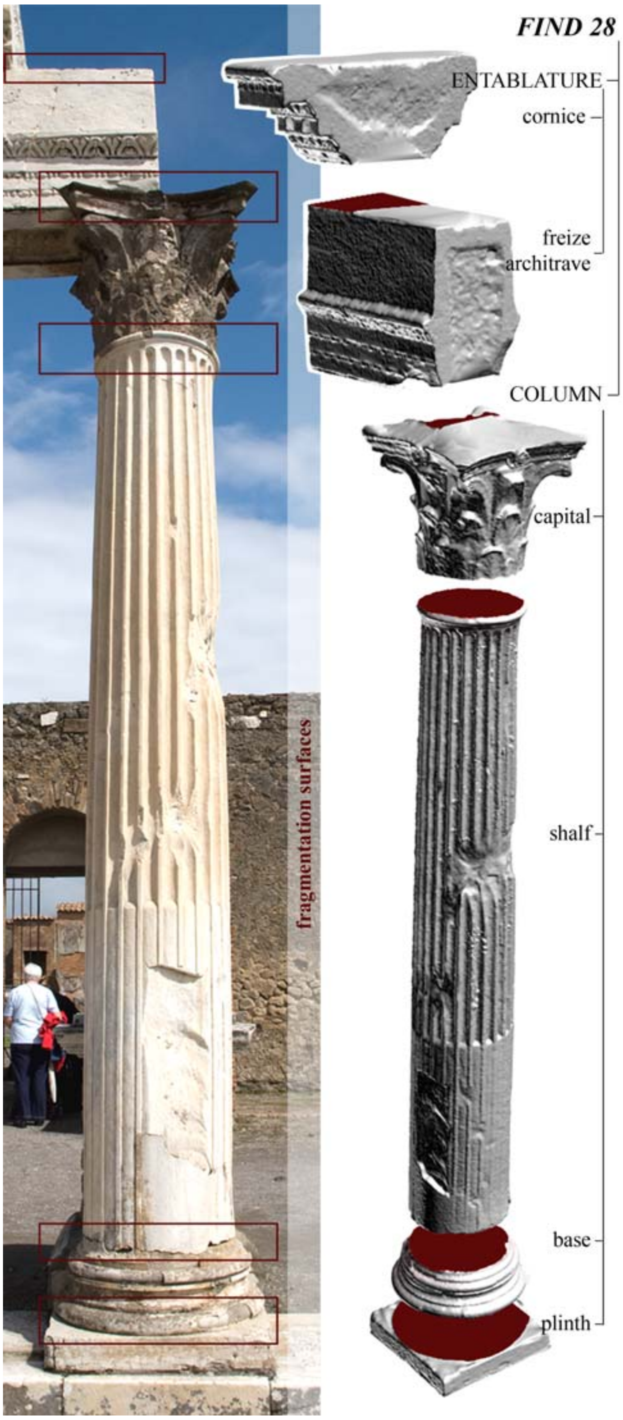

Figure 6: Left: recognition of discontinuities and identification of single elements. Right: segmentation and semantic organization of the fragmented 3D model. Additional surfaces (red areas) have been introduced in order to rebuild hidden volumes.

In order to preserve the 3rd dimension, survey data need to be represented, organized and managed using advanced repository of geometrical components. Those packages allow visualization, interaction with digital models and database queries.

This is not an easy problem, because current real-time systems have been planned for visualization, but not for non-expert interaction. To be considered a "3D repository", a system must be capable of handling data as more than a surface. It must handle geographical feature data, support query processing and spatial analysis in addition to dynamic user interaction according to three classes:

a) orientation and navigation;
b) selection and query;
c) manipulation and analysis.

In the developed methodology, textured 3D models, obtained using photogrammetry or active sensors and semantically segmented and classified, are displayed and queried using a rendering application based upon OpenSceneGraph (OSG). The OpenSceneGraph is an open-source high performance 3D graphics toolkit, used by application developers in fields such as animation, visual simulation, gaming, virtual reality, scientific visualization and modeling.

Figure 7: Example of segmentation and classification of the digitally modeled elements that constitute an archaeological find. The naming of single elements and classes they can be assembled to depends on considerations about the recognition of classical order rules, or building functions or materials. Extra information such as geo-location and object number can also be added.

Written entirely in standard C++ and OpenGL, it runs on all Windows platforms, OSX, GNU/Linux, IRIX, Solaris, HP-Ux, AIX and FreeBSD operating systems. Unlike other open-source solutions, such as VRML (Virtual Reality Modeling Language), for example, OpenSceneGraph allows to use OpenGL instruments not only to manage geometry, but also to correctly visualize texture and illuminate digital models. Using shaders that can be managed by common hardware (GPU of video board), these instruments are very useful in order to give much realism to 3D models. For example, some image-based models were textured using normal maps that don't modify the recovered geometry, but simply improve the visual appearance of the rendered surfaces by simulating small irregularities. OSG better supports the bump mapping approach than other visualization toolkits do. Anyway bump and normal maps were used only in cases where geometric irregularities were below a determined threshold, in order to precisely model the find but also visualize the small irregularities.

In addition to OpenGL instruments, OSG allows to customize the visualization of digital documentation. For our methodology, we have adopted the VISMAN visualization system, a version of OSG realized by CINECA (Inter University Consortium), in order to support the visualization of architectural and archaeological semantically segmented 3D models linked to external databases. Indeed the VISMAN framework allows to:

1. switch between models with different level of detail or pertaining to different historical periods but insisting over the same area;
2. insert IBR (Image Based Rendering) geometries;
3. add parts to the model (i.e. addition of sections built through the centuries);
4. connect to a relational multimedia database.

The latest feature has been a key point in the development, allowing the user to display dynamic content containing detailed data connected to a specific object in the scene. This connection is defined using a naming convention. Objects inside the nodes of the scene graph are given a specific prefix and a unique number. When the user interacts by clicking or passing the cursor over an object, an SQL query is performed and a pop-up window is used to show the retrieved data.

VISMAN is available as a standalone software, as well as a web browser plug-in.

In our methodology, semantic segmentation has been used to link huge data not only with archaeological finds, but also with their single sub-parts. The connection between the database and the single parts of an archaeological find upgrades the traditional 2D GIS to a 3D system. Digital models are geo-referenced (by point, line or area belonging to necessities), so that they also can be linked to 2D systems that are generally already available.

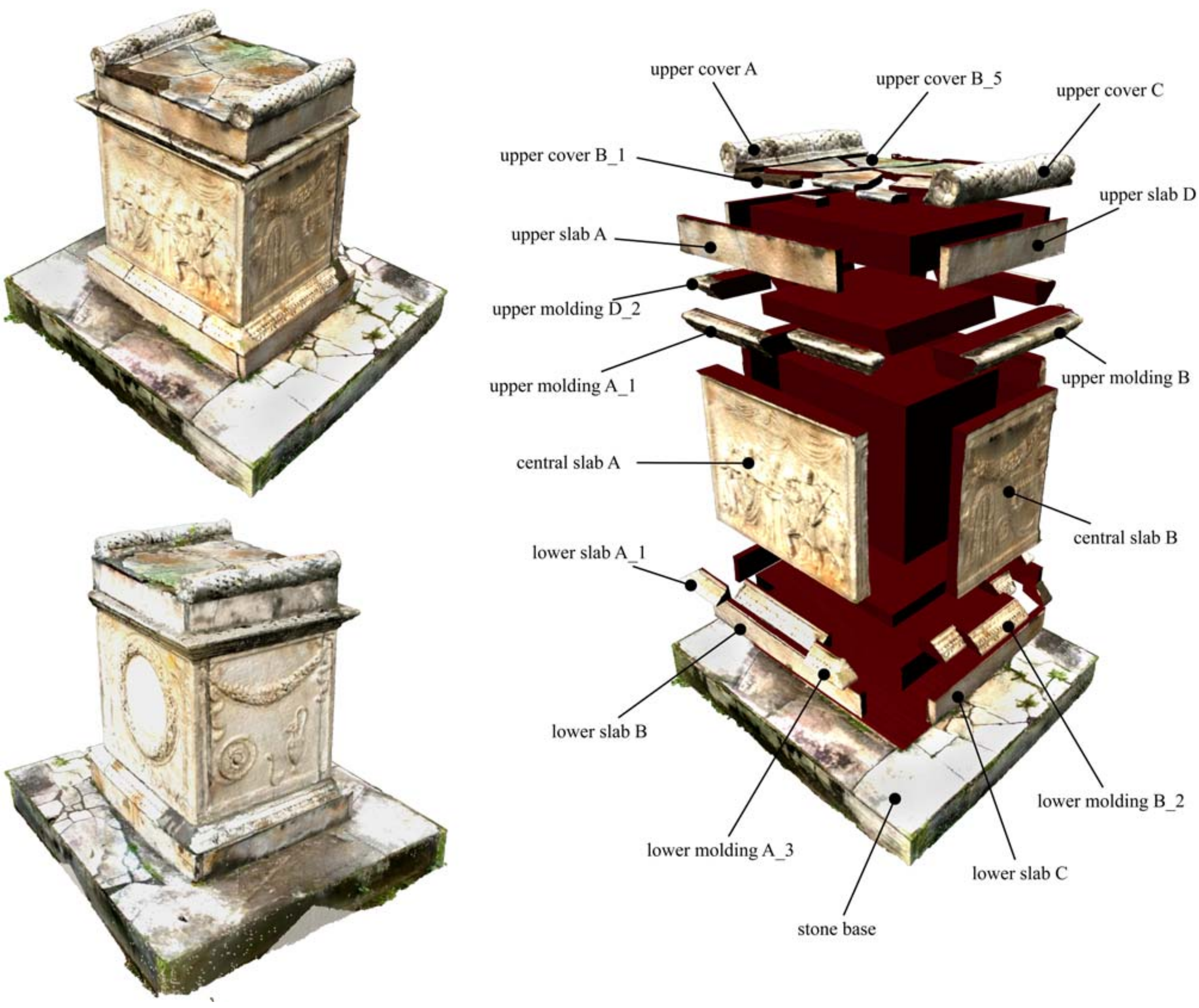

Figure 8: A range-based 3D model of an archaeological find (left) and the segmentation and definition of its sub parts (right). The linking to the archaeological database is done in a successive phase and queries can be done through a web-based interface.

Semantic fragmentation allows archaeologists to study every single element without context. This facilitates the recognition of wrong assembly. Furthermore, this classification is a useful instrument for the excavation administration that permits to check the consistency of the archaeological heritage and to program restoration and conservation interventions.
The link between 3D models and 2D documentation is bi-directional, so that it is possible to access data from models and vice-versa, using the same web based interface (Figure 10).
The system can therefore be easily linked with any kind of database available on web. The 3D advanced archaeological database has been conceived for different uses and a LOD technique is also implemented. Different LODs guarantee the maximum quality while observing finds that are near the observer, but also allow faster visualization of large finds, with a more effective use of resources.

6. CONSIDERATIONS AND CONCLUSIONS

In this work we presented how engineers and architects can contribute in the archaeological documentation and classification of finds and excavation sites with the current 3D modeling technologies and methodologies. The use of digital instruments to survey and represent 3D models requires abilities that often belong to the background of engineers and architects. On the other hand, the organization of data has to be leaded of course with the help and support of archaeologists and superintendences that can lead historical and archaeological analysis upon sites.
The large use of digital instruments to provide photorealistic 3D representations and to manage huge documentation requires that more and more interaction between the different communities involved in the heritage field must be reached and each specialist must do his/her job and deliver to others duties which are not in his/her background.
Our work has been leaded testing different technologies upon different kinds of finds, in order to supply accurate digital 3D models of archaeological objects. These tests have pointed out that nowadays a combined use of different technologies has to be adopted, in order to give satisfactory results in terms of metric accuracy, photo-realism, portability and reduced costs.
Semantic classification of archaeological finds is necessary in order to organize huge amount of documentation and to provide connections between models and data.
Future prospects could be singled out in the definition of standards for the creation of advanced 3D databases and the definition of precise roles of different working teams involved in this process.

Figure 9: Segmentation example of 3D image-based models and the definition of sub parts linked to the archaeological database.

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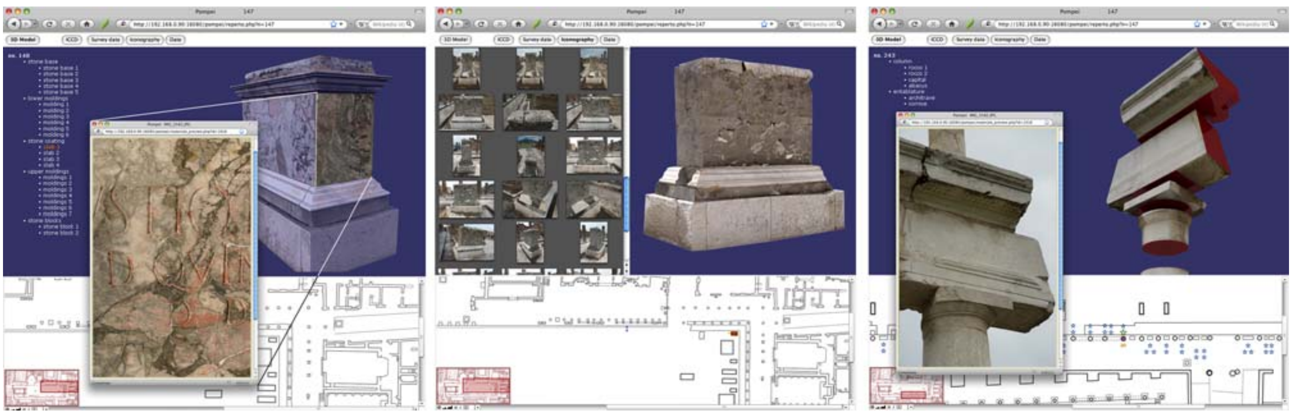

Figure 10: Web interface of the advance 3D archaeological repository. The fragmented 3D model represents an access to large kind of information stored in the archaeological database. The link between 3D models and database is bi-directional, therefore information can be retrieve selecting a part on the 3D model or accessing the database, but using the same web-based interface.