3D GIS VISUALIZATION OF ARCHAEOLOGICAL EXCAVATION DATA

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Abstract

During the last decade the contribution of GIS technology in recording and analysis of archaeological data has been significant. Although, however, the information that archaeologists record has a deeply 3D character, the analyses within GIS packages rely upon a 2D abstraction of reality. The approaches proposed so far for 3D archaeological GISs reveal some important drawbacks such as: bad quality of produced graphic objects representing spatial entities, complicated and time-consuming techniques for the creation of 3D objects, inability of object manipulation in a true 3D GIS environment. In this paper, alternative methods of creating and analyzing 3D archaeological information are proposed; they are based on a commercial GIS package, with attempts to extend its options. The central aim is the realistic visualization of archaeological excavation data through 3D representations to help archaeologists have a reliable image of the excavation process and their interpretive results. In the first part, the spatial nature of archaeological research and the significance of the third dimension in excavation interpretation and analysis are introduced. In the second part, several techniques for 3D modeling and representation of the different data types are proposed, for: the excavation site and its greater landscape surroundings, geological layers captured during geological investigations, excavation units (the central spatial elements of the excavation process), finds (the material culture evidence within archaeological sites), plans and digital photographs of archaeological deposits (traced during excavation process). The procedure followed aims to facilitate a better data management of excavation context and provide useful insights during the interpretation process.

1. ARCHAEOLOGY, NEED FOR REALISTIC 3D REPRESENTATIONS

The large amount of data that is generated during archaeological excavations about spatial, thematic and temporal characteristics of the finds requires an appropriate environment for handling this information effectively. The work presented here constitutes part of a PhD research that is concerned with the geo-visualization of spatio-temporal archaeological information. Within this context the 3D aspect of space that is of concern here, apart from its obvious spatial importance, is a pre-requisite for dealing with time, since the 3D strata are records of temporal units, as described in the following. The current work combines the possibilities of GIS with true 3D visualization; the purpose is to “link” the options of both with the help of suitable programming and extend the capabilities of the working environment through an appropriate interface for the manipulation and visualization of the information.

1.1 The spatial nature of archaeological research

The issue of studying and interpreting the past is the main idea of archaeological research. For the implementation of these interpretations, archaeology has developed various analytical tools and techniques for the best study of cultural remains. The real problem (or challenge) of archaeology (unlike e.g. anthropology) relies on the limited information about the population in study that in many cases is represented by a small quantity of poor preserved structural and cultural remains. For this reason archaeologists record and describe the archaeological finds and their contexts in great detail.

The sophistication of archaeological recording practices verifies the spatial nature of archaeological research. One of the main phenomena studied in an excavation is the definition of the temporal phases of the use of space by past populations and the specification of their limits (in spatial and cultural terms). The methodologies that are followed towards this end are based generally on information about the exact location of the archaeological structures and artifacts, their orientation, the type of soil and its inclusions and their relation with their surroundings. The translation of these spatial relations in
archaeological terms and their linkage with ethno-historical information and other archaeological paradigms lead to the desired result of interpretation.

1.2 The 3D nature of archaeological data – visualization and analysis issues

An archaeological excavation is, in simple terms, a procedure of removing quantities of soil trying to uncover structures buried deep in the ground. This vertical orientation of the excavation procedure provides the issue of depth (the so called third dimension) with a unique significance as its contribution in all the stages of archaeological analysis and interpretation is profound. Following this statement in terms of visualization, a representation of an excavation should also include all three dimensions of space.

To determine the several issues that come out with this subject we first should examine the needs of the archaeological research in terms of visualization. In order to proceed in a safe and realistic interpretation of the data, an archaeologist should be able to have the observational control of every step of the excavation as well as a complete image about the exact shape of every structure that might affect his/her results. Unfortunately this cannot be done as the archaeological excavation could be seen as a procedure of continuous destruction of past evidence as the excavation process goes on. The only reference about the removed -during the excavation- objects can come from the descriptive and spatial information that was recorded during the excavation; the quality of this recording process affects the next steps of interpretation. The archaeological data should be able to be observed from all horizontal and vertical viewpoints and the shapes of the objects (for example a wall) should be the best possible, following the object’s relief. The effort should also focus on the combination of the different archaeological object types and information for the creation of meaningful maps in a GIS environment. So the detailed recording of the archaeological data is used as the information source for the possible representations within a GIS environment helping archaeologists visualise objects that no longer exist. In addition, the visualization should act together with the analytic capabilities that GIS software offers.

2. AN OVERVIEW OF 3D GIS REPRESENTATIONS

During the last years there is an increasing interest among many disciplines towards a three-dimensional reconstruction of the real world and analysis of complex phenomena occurring in 3D space. However most of the current commercial GIS software packages handle spatial data in only two dimensions. The limitation of the current GIS software in manipulating 3D data and the absence of the appropriate tools for such analysis, has led in a rapidly increasing research activity in 3D information (Stoter and Zlatanova, 2003). Although many efforts have been made in this direction and improvements are evident in 3D Visualization, important aspects of 3D Functionality (i.e. 3D Topology and Geometry) are still missing (Zlatanova et al., 2003).

The solutions offered for true 3D representation of objects could be classified in three main method categories: Constructive Solid Geometries, Volume Representations and Boundary Representations. Constructive Solid Geometry (CSG) has its origins in CAD technology and it adopts an approach of representing 3D objects as solids. A solid is a combination of primitives, or building blocks, such as rectangular blocks, cones, cylinders, spheres, tori, prisms, and so on (Shimada et al., 1998). Although solids are suitable for representing complex shaped objects, they cannot easily handle the complex relationships between the objects (Stoter and Zlatanova, 2003). In Volume Representations, the 3D space is divided into cubes of voxels that constitute three-dimensional pixels. Properties like mass, volume and surface area can be quickly computed as Boolean operations or voxel counts. This type of representations is suited for discrete objects or continuous distributions but require large volume of computer space (Jarroush and Even-Tzur, 2004). In Boundary Representations, the objects are defined as polyhedra bounded by planes or faces, where each face is comprised by connected points, lines, polygons or smaller polyhedra. By carefully collecting data about the faces of an object, this method can have really satisfactory results in representing complex real objects. However, the created objects are not treated as unique structures but as a combination of many sub-structures.

Regarding the type of the recorded archaeological information and the fact that there was not need for volume information (it was provided by the archaeological fieldwork records), the Boundary Representation method was chosen as the most suitable for the current application. The problem of linking the multi-structured objects created with the recorded information in the GIS package used (ArcGIS by ESRI), was solved by connecting the name of each layer imported in a map with standalone tables; this was done via Visual Basic programming code.
3. THE CURRENT APPROACH

The proposed methodologies for 3D GIS analysis in archaeological excavation research are applied in the prehistoric excavation of Paliambela, Greece. The site can be considered as a suitable field for such testing covering a long time span of human presence from early Neolithic to Byzantine period (ca. 6500 B.C to ca. 1500 A.D.). Trying to explore effective ways of representing the excavation of Paliambela the current approach is focusing on three main topics: 1) the construction of background maps, giving a useful image of the surrounding landscape and the site’s context, 2) the representation of archaeological artifacts and structures, that are the main objects of the archaeological interest, and 3) the representation of the basic archaeological excavation units.

3.1 Landscape Background

Having its theoretical background in human geography, the issue of cultural landscape has been broadly applied in archaeological research, especially after 1970 when “landscape archaeological studies” started to be an umbrella term for many different approaches to regional archaeological variation. These approaches are based on the assumption that the non-visible realm of landscape is a significant factor regarding human behaviour (Anschuetz et al., 2001), concerning long-term human-environmental interaction.

Although the Paliambela excavation is limited to a small and rather low hill, it is argued that the Neolithic site should be firstly introduced as a part of the greater surrounding landscape. For this purpose, various sources of information were used in order to represent the broader landscape of the site. Maps of the hill and the surrounding areas and topographic maps of the nearby village were digitized providing a good background for the placement of the archaeological information. Elevation data was captured from maps of the area (contour lines), and a DEM was created visualizing in 2.5D the landscape morphology including the site area (Fig. 1a). Several types of land use as well as road and hydrographic networks (streams) of the area were captured in order to fill in this landscape dataset and define the land properties. Future works are concentrated on capturing vegetation information in order to create an integrated image of the landscape that surrounds the archaeological site.

3.2 Excavation Background

In the first steps of an excavation it seems there is no obvious linkage between the -mostly fragmented- archaeological finds and structures uncovered within the several archaeological trenches. So, in these first steps the archaeologist’s interest is mainly focused on the “trench scale”. However, the scope of linking information and archaeological remains among the various trenches and within the entire excavation area is one of the major issues of archaeological research resulting in the definition and understanding of the extend of the site’s formation and structure. For this reason the creation of the site’s background was considered necessary, since the various spatial elements of the hill where the site is placed would offer a representation of the area on a “site scale”.

Figure 1. Landscape (a) and excavation (b) environment
First of all, a detailed DEM of the site area was constructed by interpolating both spot heights measured with Total-Station and contour lines provided by topographic maps, resulting in a much more detailed relief compared with the previous Landscape one (Fig. 1b). The contribution of some additional information was considered helpful for the construction of a meaningful site image. These are: the trench covers (the boundaries of the several trenches), the points where the extensive survey samples were taken and the top points where the geological research on the hill occurred. Although there are not yet archaeological structures to cover the whole site area and to populate this site image, the classification of the extensive survey points (in terms of temporal – historical period categories) and their distribution within the hill area resulted in a first understanding of the site’s formation.

3.3 Geological Stratigraphy

Although the geologic technique of boreholes is not the most suitable for revealing the thin, and most of the times “invisible” human-made sediments, the results of such a practice could provide the general stratigraphic formation of the site area. The 3D geologic layers (Fig. 2a) were produced with the help of the software package Environmental Visualization System (EVS), developed by CTech. Following a 3D Kriging interpolation, the boundaries (or external faces) of each geologic structure identified and classified by the geologists, were constructed. Each layer was then saved in a 3D shapefile format, using the special conversion module provided by EVS, and transferred in ArcGIS – ArcScene, where further analysis could take place.

![Figure 2. The stratigraphic formation of the area depicted as layers (a) and slices (b)](image)

Furthermore, it was possible to compose slices on the geologic layers (Fig. 2b) following the boundaries of each trench. This was very helpful as the archaeologists could have a synoptic image of the trench’s geologic formation, even before the start of the excavation process.

3.4 3D-like photographs

During the excavation, several digital photographs of the trenches are taken recording significant artifacts and following the main steps of the excavation procedure. Giving the general view of the whole trench and its spatial substitutes, the photographs are still useful information for the archaeologists helping their interpretive results. From our point of view, it was considered important to represent the “real” relief of the surface as well as the shape of the spatial elements depicted. For this task the pictures were georeferenced, orthorectified (orthoimages were produced with the appropriate photogrammetric procedures after a DEM of the respective area was generated) and consequently the pictures were draped over the DEM.

The methodology that was followed in order to have 3D-like shape images as described above, was based once again on the construction of a DEM of the area-trench covered by the images. To do this, a number of spot height points were needed. The estimation of the suitable number of such height points was based on a correlation between the area’s morphology and the spatial-archaeological significance of the structure. In cases where the surface was flat and regular, fewer points were taken with the total station and where significant elevation difference occurred more points were taken in order to follow the land relief. The archaeologists, being aware of the archaeological structures’ details, were assisting by indicating areas of archaeological interest where more points should be taken.
Moving one step forward, the structures that were depicted in the digital photographs were isolated and saved as different files in order to act independently from the original photo. In this way it was possible to visualize both “positive” (such as walls) and “negative” (such as pits) human made structures (with “positive” and “negative” referring to elevation values).

3.5 Excavation Units

As mentioned before, especially during the first steps of an excavation, the archaeological interest is focused on the “trench scale”. The basic archaeological analytical unit, for which most of the information is recorded, is the “excavation unit”. The excavation units are actually all the small pieces of land removed by the archaeologists in every step of the excavation. In Paliambela, the size of these units is not fixed; it is defined by the archaeologist by, mainly, looking at the stratigraphic formation of the trench. So the basic rule for the determination of an excavation unit is the structure of the human made stratigraphic layers with the contribution of the formation of the uncovered human-made structures within a trench. Of course such a stratigraphic layer cannot be defined and excavated at once but only partially as the excavation process goes on. So, each thin stratigraphic layer consists of a group of excavation units.

As excavation units act like containers of information affecting the whole understanding of the archaeological structure, it was considered necessary to represent them with the best possible way including all the three dimensions of space. Very helpful for this was the detailed spot height information that was recorded for each unit’s upper and lower surface. Importing this point (boring-like) information within EVS software, it was possible to create (as in geological layers) the external faces-boundaries of each unit (Fig. 4a and 4b) and import them in ArcScene, where the analytical capabilities of 3D Analyst could be used.

4. ANALYSIS

The main drawback of the contemporary efforts on 3D GIS is the lack of methodologies for dynamic manipulation and analysis of 3D objects. Although significant progress has occurred and is adopted by many current commercial GIS software with respect to 3D visualization, the important link between visualization and analysis in 3D space is still missing. As the purpose of this paper is not the definition of new approaches on 3D geometry and topology (the main unsolved aspects of 3D functionality), the discussion on the manipulation of the created archaeological structures will be restricted...
within the analytical capabilities that ArcGIS and 3DAnalyst offer with the contribution of programming tools such as Visual Basic (by Microsoft) and ArcObjects (by ESRI). In this way, it is possible to customize the default ArcGIS environment focusing on linking the created 2.5D and 3D data with all the related archaeological information stored in standalone tables. Some analytical examples helping in the interpretation of the archaeological data are mentioned below.

4.1 Querying the excavation Units and Finds

Utilizing the detailed information recorded for each excavation unit it was possible to proceed in the formulation of questions regarding the attributes and the characteristics of the archaeological units, helping in the classification, error detection and better interpretation of these structures. The units shown in the image below (Fig. 5a) belong to the same human-made stratigraphic layer and therefore they should have similar characteristics. As we can see, most of them belong to the “Sandy Clay Loam” soil type (light brown), but one of them breaks this homogeneity belonging to “Clay Loam” soil type (the reddish one). This could be an indication that this excavation unit was wrongly interpreted and classified in the field. Another example concerning the same group of units can be seen in the next image (Fig. 5b) where the different colors represent different levels of ceramic quantities within each unit (the closer to deep red, the more ceramic quantity the unit has).

4.2 Revealing the excavation image of a selected day

One of the first aims of the project was to provide the ability of visualizing the excavation status of any past moment. As the “date of recovery” is one of the first information recorded for every data (units or finds) in the field, it was possible to
provide the excavation “image” of every excavation day. Moreover, animations can be produced (and activated from within the GIS environment, as e.g. a Macromedia Flash movie object within an ArcScene document) showing the exact order with which each excavation unit was removed, representing every step of the excavation procedure (Fig. 6).

![Figure 6. Frame snapshots representing the excavation procedure](image)

4.3 Combining the different data types

By combining the different 2.5D and 3D data produced for the excavation, the application can offer better results in terms of visualization and interpretation. In the left image below (Fig. 7a), we can see a 2.5D plan (could also be a photo) representing a trench status on a definite time, where a pit is clearly seen. Making use of this plan, an archaeologist can just have a simple image of the trench. However, questions like: “how this pit was excavated?” or “what were the inclusions of this pit?” cannot be answered. To answer these questions the excavation units that constitute the pit as well as the finds recovered in these units were imported creating now a meaningful image of the pit and its inclusions (Fig. 7b).

![Figure 7. A pit in a 2.5D trench plan (a) and the same plan after importing the 3D units (b).](image)

5. CONCLUSIONS

The current approach focused mainly on the “realistic” visualization of the archaeological material using the – still limited – three-dimensional analytical capabilities of ESRI’s 3D Analyst software. The three dimensional excavation objects were produced with the contribution of EVS software (using the Boundary Representation method) and exported in ArcGIS environment where they could be effectively combined with other archaeological related information, with the help of programming code developed for this purpose. Since aspects such as 3D geometry and topology are limited in most
contemporary GIS packages, the spatial analysis of the created 2.5D and 3D objects was maintained by querying object attributes and classifying objects on the basis of attribute values. Based on this representation and analytical schema, it was possible to manipulate the archaeological information, helping in the interpretation of the archaeological excavation material. The current approach, still under development, hopes to facilitate a better data management of excavation context and -with the help of visualization- to provide useful insights during the excavation interpretation process; the extended GIS environment and the interface being built are expected to contribute to this purpose.

6. REFERENCES

- Stoter, J.E. and Zlatanova S., “3D GIS: where are we standing?”, Joint Workshop on Spatial, Temporal and Multi-Dimensional Data Modelling and Analysis, Québec, Canada, October 2003.
Spyros Tsipidis is a PhD candidate in the Faculty of Surveying Engineering of the Aristotle University of Thessaloniki, Greece. His PhD research, carried out in the area of Geo-Visualization, is concerned with the creation of a visualization environment for managing and visualizing spatio-temporal archaeological information. He holds a degree in Geography (University of the Aegean, Greece, 2001) and a MSc. in GIS and Spatial Analysis in Archaeology (Institute of Archaeology, UCL, United Kingdom, 2002). His professional experience includes: participation in archaeological excavations in Greece, excavation data analysis with databases / GIS, teaching of GIS packages in Public Training Institutes in Greece. He has participated in the past two Conferences on Computer Applications in Archaeology (2003 and 2004); in the latter he presented (together with co-author M. Katsianis) the paper: “Interactive interpretation of data and dynamic spatio-temporal visualization in excavation information systems”.