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Integrating excavation recording, data management and object representation through GIS

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The excavation project of Paliambela Kolindros, Greece, in the past five years has developed a digital recording methodology through 2D photogrammetry that has resulted in the:

- systematic collection of excavation unit and artefact co-ordinates
- fast and detailed production of digital excavation plans and sections
- increase in the photographic documentation of the excavation process

However, these recording strategies have so far been distinguished from the rest of the excavation documentation, which has largely remained on paper. Despite previous attempts in computer applications development, the difficulty in handling the vast amount of excavation data in both analogue and digital form and the need for optimizing their study, have made necessary the use of an information system for the organization, management, representation and analysis of all kinds of archaeological evidence.

The Paliambela Excavation Information System is currently under development within the frame of two complementary PhD projects. The research is centered on the:

- critical appraisal of the excavation methodology employed
- integration of the recording techniques used within the new system's operational workflow
- effective description of excavation evidence in a data model
- realistic representation of excavation features in digital 3D space
- incorporation of the temporal properties of archaeological information

It is argued that in order to achieve a true integration of excavation data recording, management and representation, GIS technology should be in the core of such attempt. Therefore, the methodology employed is focused on the development of data models supported by GIS and the modification of existing GIS software in order to meet the archaeological research requirements.

Introduction

The Workshop on Past, Present and Future of Cultural heritage and New Technologies provides a timely occasion for a summary of the work carried out towards computer aided excavation documentation and an opportunity to express the theoretical and methodological implications that govern our attempt to develop a system for archaeological documentation and analysis. The paper belongs to the wider field of intra-site GIS applications that, despite recent developments, still remains a disproportional area of archaeological computer studies and largely detached from the theoretical discussion on the role of GIS applications in an interpretive framework of thought. Our contribution provides a case study for these matters and describes some ideas that stem from the experience gained, the problems encountered and the solutions emerged so far during the development stages of an excavation information system for the Paliambela Kolindros Archaeological project.

Excavation as Application Domain

The investigation of deep archaeological sites using stratigraphic excavation (HARRIS 1989) presents difficulties in both theoretical and practical levels. In the former case there is always the possibility to miss subtle distinctions between deposits, which can cause material contamination that is very difficult to verify at later stages. In the latter, deposits can be so thick and extensive that their treatment as a single recording unit presents difficulties in terms of material management or analysis (KOTSAKIS 1989).

Following the case of the excavation of Sitagroi, where "layers" were defined as recording units that follow either the existing stratigraphic distinctions or as arbitrary units that subdivide a larger depositional entity (RENFREW 1986), a system that combines elements of arbitrary and stratigraphic excavation has been developed at the excavations of the prehistoric site of Toumba Thessaloniki and consequent projects (KOTSAKIS 1989)[1]. The archaeologist tries to follow the extent and limits of each depositional layer, but in the process she/he is free to subdivide it in smaller excavation units, so as to carefully remove the deposit to its limits (Fig.1). The method provides further advantages, since it can monitor the differentiation (e.g. pottery sherd quantity) present within a stratigraphic deposit and provides a record of the archaeologist choices and strategies at various stages in his/her attempt to uncover a single deposit. In a sense then, the excavation methodology documents the steps taken by the archaeologist in his/her interaction with the site and uses the observations made, so as to infer the past processes that shaped the depositional record. It follows that the understanding of the past processes is mediated through the re-examination of the excavation process using the excavation archives produced.

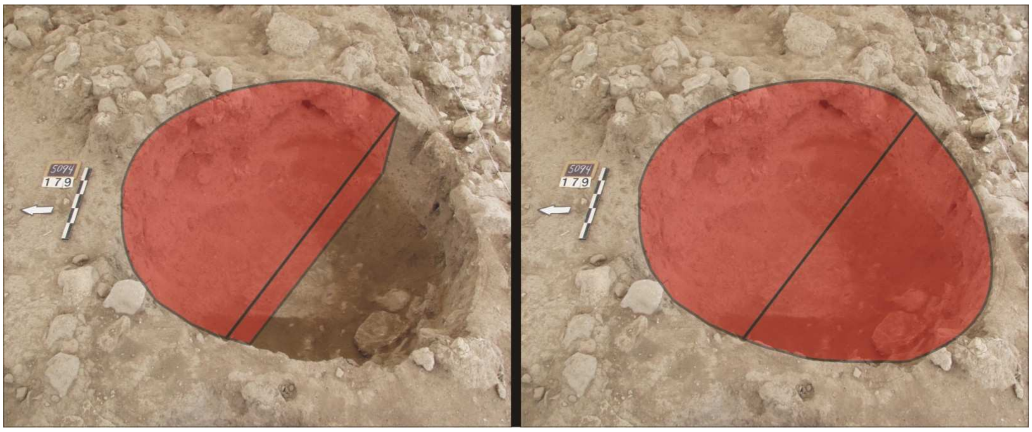

Fig. 1 - Excavation units used to excavate the depositional entity of a pit.

Thus, the documentation of each excavation unit is central to the recording methodology in Paliambela as it presents the smallest entity of observations during fieldwork. So as to record the observations about each unit, pre-printed forms are employed that allow both descriptive text in the form of excavation diary and specific fields about a number of related properties (such as work description, soil consistency, texture, inclusions, associated artefacts, samples and photographs). Furthermore, recording methodologies that use total station and 2D photogrammetry were introduced allowing the recording of excavation units, features and individual artefacts in national grid coordinates as well as the quick and accurate production of plan and section drawings (KOTSAKIS and HALSTEAD 2002)(Fig.2).

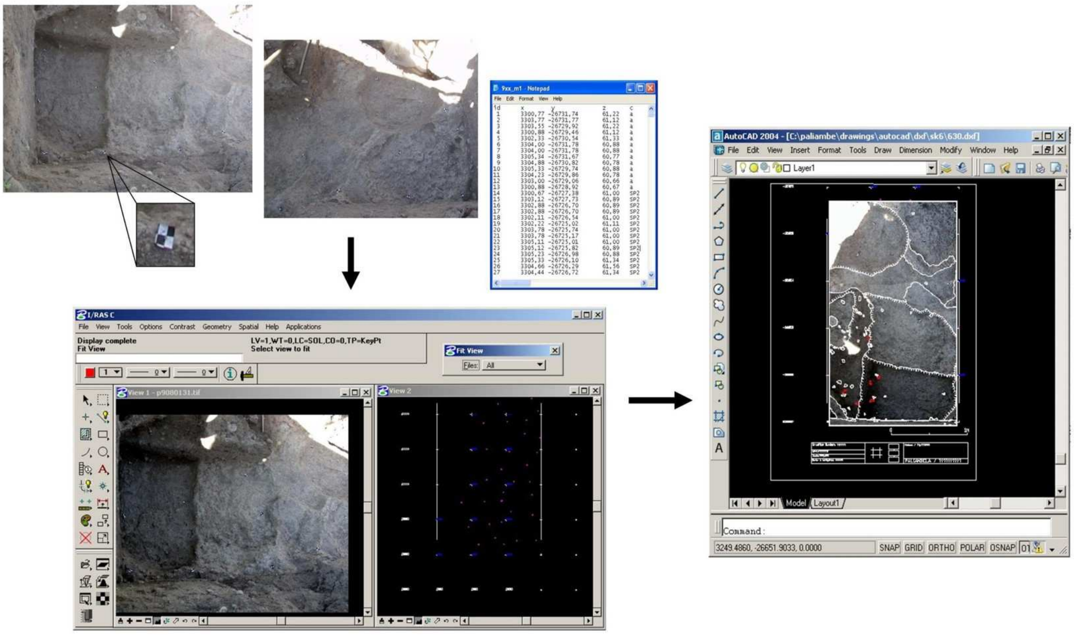

Fig. 2 - Plan drawing procedure in Paliambela: Digital pictures and control points are taken so as to provide a rectified result (left). Final result after vectorization in AutoCAD (right).

However, the method of subdividing a depositional entity presents implications in that spatial and attribute information about a single deposit is further compartmentalized making stratigraphic reconstruction a more difficult task. In addition, post-excavation study practices are linked to the fragmentation of the archive to its constituent elements (either the uncovered material or the excavation records) and their distribution among the specialists who will carry out individual studies. JONES (2002) suggests that this practice results in the disassociation of artefacts, contexts and initial observations and acts as a barrier for an interpretive engagement with the totality of the site. In an excavation that by virtue has a fragmented character this can present additional problems and delay the understanding of the stratigraphy.

In this background, intra-site computer applications, rather than providing structured filing capacities for the management of the excavation records (texts, drawings, photos etc), they should function as tools that can facilitate the constant re-evaluation to of the excavation process and the repeated investigation of the excavation records (LUCAS 2001). In effect, they should provide the means to re-associate contexts, objects and observations and equip the archaeologist with tools for exploring, linking and representing the excavation data.

Past Efforts

Computer applications with the aim of supporting the methodology outlined above have been employed since the late 1980s in an attempt to aid excavation recording and post-excavation analysis. The *Runsect* program and its successive version were designed so as to aid the correlation of stratigraphic units against the actual stratification recorded as a running section (KOTSAKIS 1989, VALASIADIS 1998). Data models for the excavation of Toumba Thessaloniki describing the domain of excavation were developed using the E-R model (HADZILAKOS and STOUMBOU 1996). Reconstruction attempts using *CAD* were also advanced and helped in the visual presentation of excavated features (KOTSAKIS et al. 1996) as well as in their correlation with artefacts and temporal phases (KOUSSOULAKOU and STYLIANIDIS 1999). Finally, artefact analysis was greatly enhanced through the use of statistical software packages such as *SPSS*, with an emphasis placed on population grouping based on typological criteria (Fig.3).

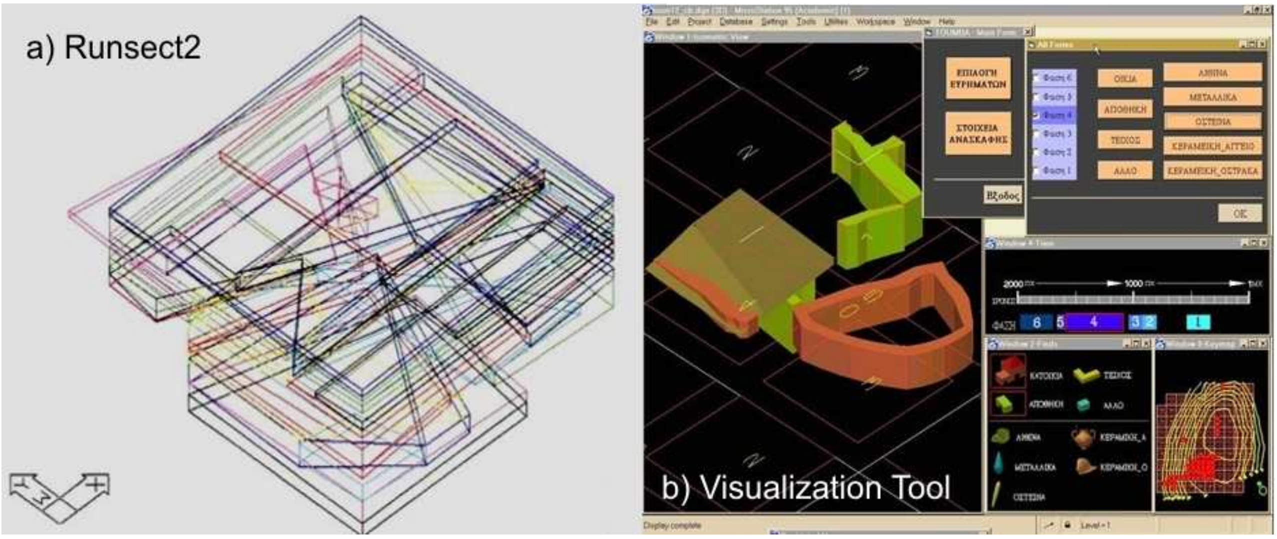

Fig. 3 - Past tools developed for the excavation of Toumba Thessaloniki. a) Unit representation tool (Runsect2), b) Temporal Visualization Tool

All these applications contributed to various stages of the excavation work and enhanced the functionality of the methodology used. In practice however, many unresolved issues still stand. Analogue pre-printed forms are still used for documentation during fieldwork. Isolated databases exist for diverse purposes (i.e. for bones, pottery etc.), without as yet being complemented within a single data management system or linked with tools for stratigraphic analysis. The plotting of features and units, although now in digital form, largely remains 2D, fragmented in separate files and unlinked to a database. Accordingly, artefact distribution is still very difficult to access or accurately measure.

It seems that the computer applications that were developed, despite their effectiveness in their specific tasks, make the design of a documentation system even more demanding. Our approach intends to make use of the developments at hand in order to solve the existing problems and provide an effective tool of interpretive reasoning.

Current Attempt

With regard to the interpretive theoretical framework, intra-site computer applications should be able to aid the archaeological reasoning process, in ways proposed within the recent discussion on excavation methodology (CHADWICK 1997, HODDER 1997, 1999, LUCAS 2001). In this sense, the main problems of intra-site applications can be summarised in the ability to correlate stratigraphic analysis with a structured database, the visual inspection of all excavation material in a visualization environment and the ability to correlate information using not only typological aspects, but also spatial and temporal restrictions. Towards this end, a project is currently being developed within the framework of the Paliambela Kolindros excavation project that tries to integrate advances made so far within a system that accommodates the recording, management, visualization and further analysis of excavation data.

PEREZ (2002) stresses the fact that computer applications in archaeology still lack system development methodologies that fit the theoretical implications of archaeological reasoning and cultural resource management. He favors context-aware modeling processes that allow the development of an information system which can validate both the theory of the application domain and the technology outlined in the computing domain. When designing an information system for an excavation three interrelated domains come into consideration:

- *Archaeology* in the frame of the theoretical and methodological aspects of interpretive reasoning
- *Database science* in the frame of structuring the archaeological record and
- *Cartography* in the frame of recording strategies and object representation

Through theorizing within the domains of Archaeology, Cartography and Database science, intra-site applications that can support archaeological thinking can be designed (Fig.4). It is proposed that in order to achieve a true integration of excavation data recording, management and representation, GIS technology should be in the core of such attempt.

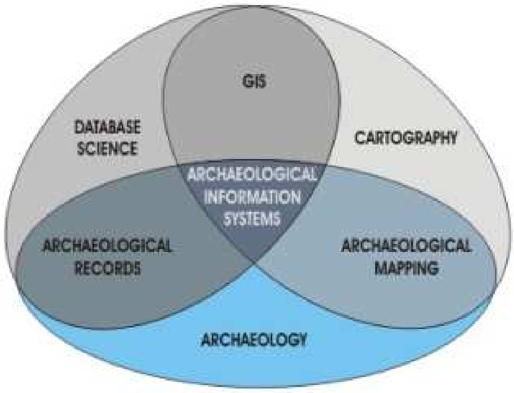

Fig. 4 - Modelling the application domains involved in intra-site applications.

Approach Description

The architecture of the Paliambela Archaeological Information System is based on object-oriented UML methodologies that integrate cartographic visualization procedures and GIS based implementation. UML (Unified Modelling Language) is a modelling methodology that allows the iterative and incremental modelling of an application through a series of diagrammatic depictions. It is used both to analyze the application domain and design the proposed system (DENNIS et al. 2001). Geovizualization is defined "*as a loosely bounded domain that addresses the visual exploration, analysis, synthesis, and presentation of geospatial data by integrating approaches from disciplines including cartography, scientific visualisation, image analysis, information visualisation, exploratory data analysis, and GISscience*" (DYKES et al. 2005). Finally, as system platform, *ArcGIS* by ESRI is used, being an industry standard and presenting abilities for customization.

System development is organized along five axes that present issues associated with one or more of the aforementioned domains:

- excavation methodology analysis,
- conceptual modeling of archaeological data,
- recording methodology integration,
- realistic representation of excavation features,
- temporal properties of archaeological information

Excavation methodology analysis

Considerably helpful has been the UML approach in the process of analyzing current practices so as to gather system requirements and implementation directions. UML can assist a structured and detailed analysis of the excavation domain that incorporates not only what is documented, but also how the archaeological reasoning process correlates data and further observations during later analyses stages. The means to perform the analysis are a series of use-case scenarios that provide the description of the excavation process and the specialists' study during post-excavation time. The fragmented character of archaeological study as described by JONES (2002) is the reality in many archaeological investigations involving a number of specialists. Through the use-cases it was realised that whereas recording and documentation during excavation are structured, in later stages of study both material analysis and synthesis are performed in a highly fragmented manner that is quite difficult to model using use-cases. It seems then that a system with the capacity to change this practice without constraining the specialists' analyses, should present a basic level of documentation and the ability to further structure the database according to the interpretive process and the new observations made by the specialists' studies. Based on this idea, use-case scenarios at a medium-high level of abstraction are employed, so as to provide the system users (actors) and describe basic aspects of their interaction with the system.

Conceptual modeling of archaeological data

Individual databases and recording forms are analyzed in order to provide the elements of the system's data model (Fig.5). Also, specialists have been interviewed or asked to fill in questionnaires in order to describe their domain of interest, their workflow process and their probable queries. The results were employed in a long process of constructing draft graphical models that would help in the identification of the object concepts (classes) and their properties (roles, relationships and methods). This work is supplemented by the search for relating data patterns produced for other domains or even archaeological systems (HADZILAKOS and STOUMBOU 1996, CRIPPS et al. 2004, DOERR 2001). Through their use it is possible not only to better understand the available data that exist in an excavation, but to realize that the existing differences between investigation methodologies aren't always an obstacle but a set of potential solutions.

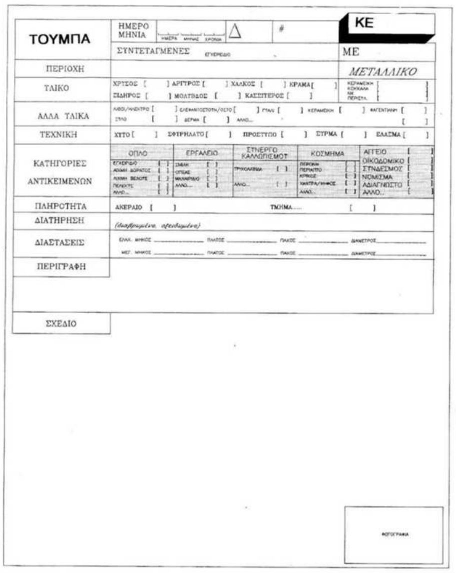


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Fig.5 - Individual databases and recording forms (in this case a recording form from the excavation of Toumba Thessaloniki) are analyzed in order to provide the elements of the class diagram of the system.

In this sense, conceptual modeling can be a real tool in archaeological theory as it provides a documented understanding of the archaeological reasoning process that can be effectively used to bridge out differences on excavation practices. It also helps on the understanding of the technology needed in order to realize an information system. In the case of Paliambela, a step forward was realized in terms of previous propositions (HADZILAKOS and STOUMBOU 1996) as the stage of domain analysis has made clear the need for the implementation of elements of object-orientation within the database schema so as to make use of characteristics, such as class inheritance, polymorphism and stereotyping (STEFANAKIS 2003). In terms of application design software, *MS Visio* has been employed for the drawing of the system's data model as it presents export capabilities to *ArcGIS GeoDatabase*.

Recording methodology integration

Strongly related is the attempt to integrate the recording techniques used within the new system's operational workflow. As noted, the recording methodology appears well structured and compatible with the excavation methodology used. However, the transition to a digital system changes many of the original goals and adds the need for better communication with GIS. Plans and sections are not produced therefore only for enhanced graphical outputs, but for the need to be incorporated as digital objects within a GIS environment. The role of the recording methodology is being redefined, so as to minimize operational changes and take full possibilities of the designed system.

In this framework, the digital picture and drawing archives are re-organized along the lines of nomenclature, file management, layering etc. Rules are set for on-site recording and drawing processing. The task of digitization is simplified as it can now be performed straight into a GIS environment without many intervening stages. Alongside, previously collected data are transformed into suitable formats, while analog textual data are being transcribed into digital format through input forms.

Realistic representation of excavation features

The incorporation of realistic visualizations of Paliambela excavation and its features was considered an important task from the early stages of the project. Whereas archaeologists experience excavation space and interpret at the trowel's edge, the attempt to infer past actions that shaped the depositional record requires the ability to review their interference with the site (MERLO 2003).

Using the experience of past representation efforts described earlier, visualization in a 3D environment was decided upon, treating archaeological features as 3D objects, supporting the vertical orientation character of excavation process and reinforcing the creation of "realistic" abstractions of archaeological features and contexts[2]. However, reviewing the approaches proposed so far for 3D archaeological GISs, some important drawbacks were encountered such as the restricted quality of the graphic objects produced, the complicated and time-consuming techniques for the creation of 3D objects, as well as the inability of object manipulation in a true 3D GIS environment supporting 3D functionality (ZLATANOVA et al., 2003).

Consequently, alternative methods for creating and manipulating 3D archaeological information were adopted. As the volume information about each excavation unit is systematically counted in the field, 3D volume representation methods using voxels (JARROUSH and EVEN-TZUR, 2004) were excluded from our methodology and boundary representation techniques were adopted, beneficially combining computer space requirements and 3D object output quality. The proposed methodology for the construction of 3D objects is based on a combination of photogrammetry techniques and the effective usage of specialized geological software. More specifically, following *Environmental Visualization System's* (*EVS* by CTech) 3D Kriging interpolation, the boundaries (or external faces) of each unit were constructed and then exported in a 3D shapefile format, using the special conversion module provided by the software (TSIPIDIS et al. 2005). The derived objects can be imported and manipulated in *ArcGIS*, while their options for analysis can be enhanced through programming. (Fig.6).

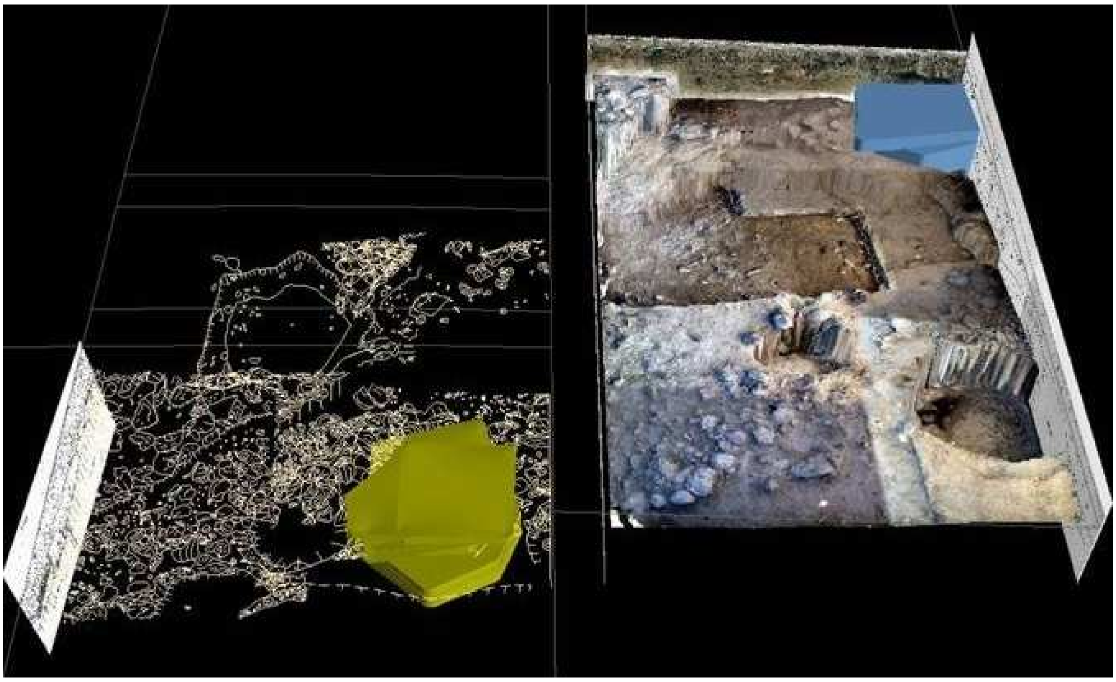

Fig. 6 - Integrated 3D visualization of excavation units, features, plans and sections

Unit visualization was complemented by the transformation of the plans and sections and the exploration of point 3D symbology so as to incorporate features and artefacts within the same 3D environment. Photographs depicting various stages during the excavation were georeferenced, orthorectified and draped over DEMs (TSIPIDIS et al. 2005). Finally, the construction of background landscape maps of the site area, was additionally undertaken, as it can provide a better understanding of its settings and allow the correlation of intra-site information with observations from the wider area (e.g. Geomorphological studies) (Fig.7).

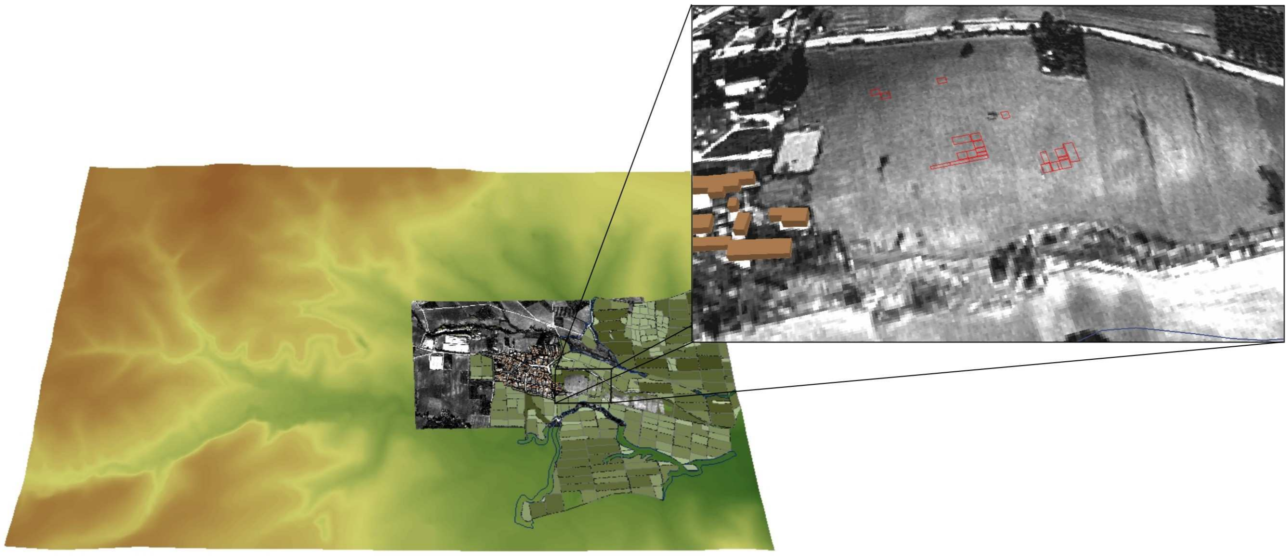

Fig. 7 - DTM of the surrounding landscape with digitized features. Detail of the site area with excavation trenches.

The representation of the plan and sections as surfaces combined with the units as 3D objects and the artefacts as 3D points has strengthened the issue of efficient excavation visualization. The next step is the functional incorporation of the visualization environment within the excavation system. In order to overcome strict depiction manners of visualization, the design of an interface that targets the interactive exploration of relationships among data and provides tools for analysis across space and time (HOWARD & MACEACHREN 1996) is proposed by programmatically extending *ArcGIS* software capabilities (ITS 2004). By linking the represented objects with their attributes and providing tools for the on-screen exploration and analysis of the data, the interface is acting as the medium between the database system and the visualization environment. The principles of the interface design are defined by focusing on the needs of the archaeologist - user during his/her modelled interaction with the system. Within this context, the interface is formed by constructing specialized tools for excavation features analysis (such as attribute viewing, grouping, buffering and querying procedures) in a manageable environment.

Temporal properties of archaeological information

Quoting BAILEY, "*contradictory notions of time are more or less explicit in archaeological thinking*" (1983). In excavation though, archaeology has maintained a linear, objective, and irreversible notion of time that provides the backbone for the organization of material culture in temporal classifications and the search for a perfect chronological cross-correlation of historical events (KARLSSON 2001). This is evident in the vast majority of GIS studies that depict information in time-slices. The last years more flexible archaeological and computing approaches to time are advanced and adopt the elements of temporal scales and non-linearity (CASTLEFORD 1992, OLIVIER 2001). In addition, ontologies and implementation procedures are developed for spatio-temporal database systems (SELLIS et al. 2003), while alternative visualization procedures that depict variation through time, such as spatio-temporal zones or the space-time cube, are explored (KRAAK & KOUSSOULAKOU 2005).

Archaeological data are not dynamic in the sense used for temporal data representing constantly changing events in the present. Rather, they represent temporal moments or durations that have to be organized in a relative or absolute manner (CONSTANTINIDIS in press). Their particularity lies in that their temporal attributes are related to the interpretive goals of the archaeologist. An archaeological artefact can thus have different sets of temporal values according to the context of interpretive discourse. In a sense then temporality in archaeological description can be considered as multilinear. Extending the observations made about the temporal categories used in an archaeological excavation by KOUSSOULAKOU and STYLIANIDIS (1999) we have identified six temporal paths when describing archaeological data.

1. Excavation time: the time of present discovery (e.g. 25/5/2005)
2. Database time: the time of creation as an object in the information system (e.g. 20050525184100)
3. Stratigraphic time: the relative temporal distinction between deposits (e.g. layer 2)
4. Archaeological time: the cultural temporal categorization assigned to the object (e.g. Late Neolithic)
5. Site phase time: the relative chronological framework within an excavation (e.g. phase IV)
6. Absolute time: the absolute chronology of an object (e.g. 4500-4300 B.C.)

All or some of these temporal paths apply to every excavation object depending on the interpretive objectives. Their incorporation in a database system can be achieved through time-stamping either as points in time or durations. Finally, in terms of representation the subject of time is approached within the development of functional tools in order to manipulate the complicated spatiotemporal relationships between the various archaeological entities (see KOUSSOULAKOU et al., in press) (Fig.8).

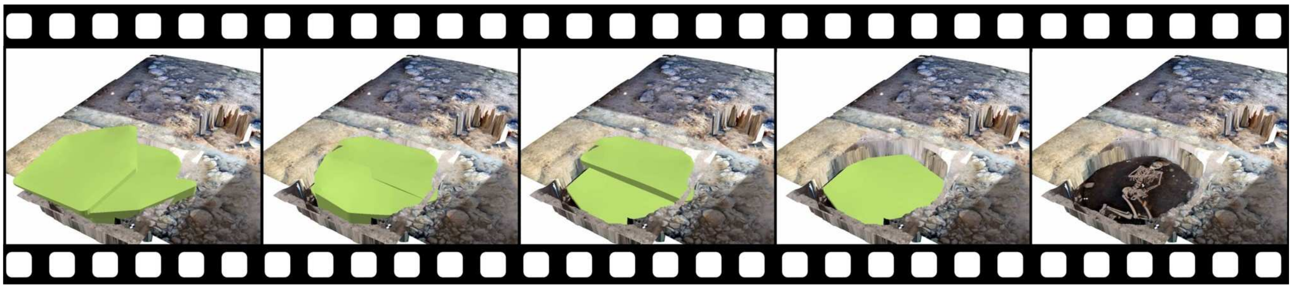

Fig. 8 - Snapshot series representing the removal of a pit-grave deposit using excavation units.

Conclusions

The attempt to develop an archaeological information system gives the opportunity to address a set of interesting issues in all domains involved. In the domain of Archaeology it provides a way of putting theory into practice by analyzing excavation and study processes and by attempting to standardize the vocabulary used for archaeological description. With regard to Database Science it contributes to the themes of data interoperability, spatiotemporal database reasoning and data pattern development. Finally, in the field of Cartography it facilitates a different perspective to problems of multidimensional representation of objects and analysis.

The development of the information system in Paliambela will continue on the basis of the presented problematic and following the methodology outlined. The next steps in terms of system design are related to the specification of the data model in terms of classes, attributes and methods, the initiation of the interface design and the further elaboration on the workflow process within the system.

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[1] This method has become a standard excavation procedure in most prehistoric sites in Northern Greece.

[2] The issue of the Harris Matrix diagrammatic representation of the excavation units (Harris 1989) is seen of limited practicality in the methodology used in Paliambela as it presupposes the validity of the archaeologists' interpretation during digging. In our view, the representation of excavation features and layers in 3D space will permit the re-evaluation of the stratigraphic observations as it will allow their comparison with the actual stratigraphy recorded and depicted as a section. Certainly, observations related to the Harris Matrix are still useful in terms of mapping topological (and thus temporal) relations between units, features and deposits within the database.