Trends and Problems in Archaeological GIS Applications

MARKOS KATSIANIS*, SPYROS TSIPIDIS**

Department of History and Archaeology*, Department of Cadastre, Photogrammetry and Cartography**

Aristotle University of Thessaloniki
University Campus GR -541 24 Thessaloniki
GREECE

Abstract: - Archaeology counts two decades of GIS applications. In terms of theory and practice it is time to evaluate GIS methods and explore ideas about future advancements. Two distinct research trends have been developed in Archaeology until now: landscape studies and intra-site applications. Each field still bears unresolved problems. In this paper we attempt a description of the major problems within these fields from an archaeological viewpoint and try to categorize them under three important notions that in our view should become of central focus in future research: Ontology, Visualization and Time.

Key-Words: - GIS applications, Archaeology, Intra-site, Landscape, Ontology, Visualization, Time

1 Introduction

The use of Geographical Information Systems (GIS) in Archaeology already has a history of at least 20 years. GIS were regarded from the beginning revolutionary in terms of data management and spatial analysis. After a period of pioneering applications, Archaeology has entered a phase of critical evaluation of the method. GIS have gathered both lots of appraisals and criticisms on their role in archaeologists’ attempts to give meaning to the past. Many believe that their use should be confined in managing data, while others envisage an even more active role in archaeological interpretation. The question is not straightforward, as it will be attempted to be shown. The ensuing analysis will focus on the problems of GIS applications in archaeological investigation - leaving aside its role in Cultural Resource Management - and present some promising ways to face those problems.

2 Archaeology and GIS applications

The usability of GIS in Archaeology lies in the fact that all human activity has a spatial character. It is therefore essential for every analysis to take into account the spatial context and the spatial result of such activity. Until the advent of GIS, this was achieved through maps and plans at various scales of analysis, which provided a means of organizing data, but couldn’t support quantitative analysis or data integration between maps [15].

The features of GIS technology gave a fresh impetus to all kinds of analysis involved in archaeological studies. Despite the numerous applications that have been published since the outset of the method in archaeological research, GIS usage falls into two major categories that depend on the scale of analysis: landscape or regional studies and intra-site applications. The former have dominated the literature since the beginning and continue to do so. The latter have generally been considered inadequate and only recently have emerged as a prosperous field of study [21].

This dichotomy is related to the fact that GIS was first applied as a means of handling and analysing environmental data. As a powerful tool in this area the use of GIS in archaeological analysis provided the means of conducting a neutral, mathematically based, quantitative and data-rich analysis muchlike in the spirit of the so called “processual” archaeology of the 1960’s [12]. In this context, however, GIS have favoured functional and deterministic approaches and have not managed to incorporate more hermeneutic approaches that treat the archaeological material “as a set of dynamic, dialectical, unstable relations between objects, contexts and interpretations” proposed by current “post-processual” archaeological theory [10].

The reason for the inability of GIS to explore archaeological material in such way is their dependence on map representations of space [22]. These maps - as every map - favor a neutral, uni-dimensional, ahistorical and empty of social meaning representation of the world that is totally different to the way it is experienced in real life or understood via archaeological research [9]. In this sense, GIS limitations can lead to bias by having the questions
asked and the data collected adapted to the ensuing analysis. Conclusively, GIS technology poses many restrictions in the way Archaeology is conducted and reveals a gap between current archaeological theory and GIS methodology that manifests the inability of theory to integrate GIS in a productive manner [7]. So as to understand the problems of GIS applications in Archaeology a closer look on the two application sub-areas is required.

3 Landscape studies
Landscape studies have taken advantage of the analytical capabilities of GIS technology and produced applications that cover different aspects of landscape - human interaction. The somewhat exploratory case studies of the early 1990’s set the ground for current attempts to approach the landscape from different theoretical viewpoints and with a variety of analytical methods often borrowed from other application areas (i.e. location models, voronoi tessalations, proximity surfaces, network structuring, site-catchments, viewsheds and cost surfaces). However, their success has been debatable, mainly due to the tendency to reproduce already evident relationships or legitimize functionalist arguments for the explanation of human conduct. With the exception of a few GIS-aided archaeological surface surveys, few applications have managed to integrate the different analytical methods, so as to produce complete regional syntheses.

A major issue of GIS landscape applications lies in the explanatory means employed in such analyses. The lack of cognitive and cultural research orientations isn’t just a result of the choices made by the analyst. The facilities of GIS software are yet inadequate to support such analyses. The difficulty in modelling (or mapping) cultural and cognitive factors (i.e. visual perception, movement choices) prevents them from being included in a GIS analysis. The result is that only certain kinds of data are imported in GIS, especially those that favour environmental data [6]. In order to avoid environmental determinism, GIS landscape studies have to incorporate cognitive, ideational and cultural factors that affect the shaping of space. Moves towards this end have been made through the incorporation in GIS of visibility and cost-surface analysis, but their efficiency and analytical value is still under consideration [6].

In terms of landscape representation, the preference between the available GIS data models, either raster or vector, influence the input and the format of the data that support the ensuing analyses [24]. So far GIS applications have favoured the raster data model since most current studies employ Digital Terrain Models (DTMs) as the bases for their analyses. Their graphic interface can give a very realistic representation of values that otherwise would be very difficult to grasp and quantify by the analyst (i.e. slope). Sometimes, though, the creation of sophisticated outputs can distract attention form the actual validity of the project’s results. It has been reported that even in the most favourable conditions the accuracy of the modelled surface is “mediocre”. Furthermore, DTM’s are still lacking in their ability to be vested with features that model surface coverage such as trees, rocks etc. This can affect the results of ensuing analyses, as for example in the calculation of viewsheds from specific points across a landscape [16].

Finally, landscape reconstruction has inherent problems, because present surfaces are the product of constant change. These changes can have different rhythms from abrupt (i.e. flooding) to slow processes (i.e. erosion). If the interest lies in past landforms, then the need to find evidence of these changes and measure their effect on the present surface is fundamental. In most case-studies there is a noted lack of geomorphological evidence that ideally could support reconstruction attempts. For this reason, geoarchaeological investigation is essential for the gathering of the necessary data. However, even in data-rich cases this is not an easy task, because the landscape cannot be broken easily down to distinct features indicative of temporal changes. Finally, the modelling of diachronic change is difficult to visualise and the only methods so far have been through time-slices or their animated combination [8].

4 Intra-site studies
Although the given archaeological interest for utilization of GIS analytical capabilities in excavation research, the intra-site applications have been fragmented in three main interest areas: (1) excavation data management, (2) excavation feature representation and (3) spatial analysis of excavation finds and structures. The integration of all these three areas in a GIS system, ideally could lead to the formation of a functional archaeological excavation information system. In this section an approach on the major problematic issues concerning intra-site applications is attempted and briefly discussed.

A major problem that has hindered the use of GIS in excavation practice has been the difficulty to
model excavation objects and features in an all-encompassing data model with spatial character. Archaeological excavation generates numerous object types each with its own set of attributes. The classifications made are therefore extensive and difficult to model in conventional database systems [14]. Furthermore, they are normally changed or extended during excavation procedure or post-extraction study as new data come into light. Updating the database is another issue, since the process of archaeological interpretation goes through various stages until finalized for publication. Finally, the subjective nature of archaeological description and the problems in recording standardization make even more difficult the correlation of archaeological information between different excavations or even between trenches [17]. Given the fact that in a GIS environment thematic and spatial attributes have to be employed alongside, it is no wonder that most excavation management systems proved to be inadequate in the management of archaeological information in its totality.

An archaeological excavation “is a programme of intrusive fieldwork with defined research objectives, which examines, records and interprets archaeological deposits, features and structures and, as appropriate, retrieves artefacts, ecofacts and other remains within a specified area or site” [3]. The vertical orientation of the excavation process implicates the issue of depth (the third dimension) with a unique significance in archaeological analysis and interpretation. Following this statement, a representation of an excavation in a digital environment should include all three dimensions of space. 3D representation of excavation features is even more significant counting the fact that archaeological excavation could be regarded as a procedure that involves the destruction of past evidence. In this frame, 3D GIS can help the archaeologist visualise objects that no longer exist.

However, most of the current commercial GIS software packages handle spatial data in only two dimensions. The approaches, proposed so far for 3D visualization in GIS, present two major limitations prohibiting a functional excavation representation:

- poor graphic results of objects representing spatial entities
- complicated and time-consuming techniques for the creation of 3D objects

Strongly related with these issues are the limitations in effectively handling and analyzing the archaeological data in 3D space. Although spatial analysis of data in current commercial 2D based GIS has been efficient, the task of 3D functionality can be characterized as a complex issue due to the lack of supportive GIS theory. GIS functionality aspects such as 3D object manipulation, 3D geometry and topology are still not embedded in current GIS systems [23].

Additional requirements are posed in GIS functionality, since the investigation of material culture transformation through time is one of the primary goals of archaeological research. In order to “depict the history” of past structures or phenomena, archaeologists should have in mind several significant issues regarding SpatioTemporal Reasoning. Within this frame, an important factor refers to changes affecting the spatial characteristics of structures or phenomena. Some possible alterations of an archaeological feature or structure that could be met within this domain include functions such as its appearance or disappearance, increase or decrease, movement or boundary shifts. Changes may also refer to transformations that affect the thematic attributes of an object [2]. Giving a simple example, the transformation of Tate Modern to a museum from an industrial building, did not affect its geometric attributes but, on the other hand, altered significantly its character. The translation of all these concepts within a database framework as well as the exploration of new methodologies for visual representation of archaeological feature “change”, are currently missing from archaeological intra-site GIS approaches.

5 Research Orientations

Overall, archaeological GIS applications in their first twenty years have provided an invaluable tool in archaeological research. However, in both fields of application, landscape and intra-site Archaeology, numerous implications are yet to be solved. The existing problems in both sub-fields of archaeological inquiry - without being the only ones - present some similarities that enable their generalization under three notions: Ontology, Visualization and Time. These notions provide the research axes for future advancements in archaeological GIS applications.

Table 1. Overview of major problems in Archaeological GIS applications.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Landscape</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontology</td>
<td>Modeling of Cognitive and Cultural factors</td>
<td>Modelling of Excavation Information</td>
</tr>
<tr>
<td>Visualization</td>
<td>Raster/Vector integration DTM Improvement</td>
<td>3D Representation and Analysis</td>
</tr>
<tr>
<td>Time</td>
<td>Intangible Temporal alterations</td>
<td>Temporal Object Modifications</td>
</tr>
</tbody>
</table>
5.1 Ontology
Ontology “involves a system of concepts and categories which divide up the corresponding universe of discourse into objects, processes and relations in different sorts of ways” [19]. The complexity of archaeological observation proves to be very difficult to model in database terms as it presents:

- a broad variety of objects, concepts and actions to be represented that are related in a highly complex manner
- uncertainty on basic material properties, as for example colouring or chronology.
- the element of subjectivity, since no consensus exists among archaeologists about their strategies of investigation and their observation vocabulary.

Despite these restrictions, to which answers cannot easily be given, there are possibilities for improved GIS data models that could function as flexible means of organising information in both scales of archaeological inquiry. According to Hodder [10] these should:

- incorporate different types of information (picture, text, drawing, diagram)
- be extensible supporting re-adjustments upon research process
- emphasise the spatiotemporal characteristics of archaeological information
- be efficient as for the recuperation of data and their collation
- support the analysis of information in multiple and alternative levels depending on the research hypothesis

Object-oriented models are considered to describe the archaeological data better than the adopted relational model. Particular interest present the development of ontology models with spatio-temporal elements for the digital organisation of cultural material in museums, collections and lists promoted by the International Committee for Documentation (CIDOC) and the International Council of Museums (ICOM) [4].

The benefits of object-oriented or object-relational databases to archaeological practice are:

- improved performance in complicated data structures,
- more explicit semantics
- distinguishable identification of the entities described
- possibilities of system extensibility
- compatibility with existing geographic data models, especially vector representations

5.2 Visualization
Visualization (or more specifically Geographic Visualization in GIS terms) 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 GIScience” [5].

The effective incorporation and management of cultural and cognitive aspects of archaeological features within GIS archaeological analysis is closely related with the efficient visualization of this information. In this case, sophisticated symbologies, still missing from most commercial GIS, should be adopted representing the broad categories of qualitative information and stressing their special character.

In terms of representation, all three dimensions of space should be effectively embedded within GIS visualization environment emphasizing the 3D character of archaeological evidence and improving the digital representation of archaeological context. An effective 3D representation of landscape and intra-site content should primarily support in the first case, meaningful images about the exact landscape formation, and in the second, the creation of realistic 3D features, thus improving the accuracy of archaeological interpretive results. For this reason, the archaeological data should be available to observation from all horizontal and vertical viewpoints having their shape approximating the original feature relief. The combination of the material culture and the anthropogenic strata or landforms would also provide a helpful context for answering questions about temporal relationships between structures and human activities.

In effect, developments in GIS 3D data management should act together with the implementation of new theories supporting spatial analysis and statistics in 3D space. As during the last years there is a shift in 3D visualization techniques, especially within the developments of Virtual Reality, an important link is still missing between representation and manipulation of data in 3D space [20]. Research on GIS 3D data handling could provide a more effective exploration of the spatial relationships between the objects in 3D space resulting in a functional and accurate interpretation.
of archaeological phenomena and processes.

5.3 Time
As Bailey states, “contradictory notions of time are more or less explicit in archaeological thinking” [1]. In practice though, archaeology has maintained a linear, objective, and irreversible notion of time that provides the background for the organisation of material culture in temporal categories and the search for a perfect chronological cross-correlation of historical events [11]. This is evident in the vast majority of GIS studies that depict information in time-slices.

The last years more flexible archaeological approaches of time are advanced that adopt the elements of temporal scales and non-linearity [13]. In addition, spatio-temporal ontologies are developed and implemented within database systems [18].

With regard to GIS archaeological research, the subject of time should be approached within the frame of developing functional tools in order to manipulate the complicated spatiotemporal relationships between the various archaeological entities. These tools should incorporate elements of temporal topology and explore new ways of presenting or symbolizing archaeological variation through time, such as spatio-temporal zones or the space-time cube.

6 Conclusions
Conclusively, GIS are a very powerful tool of spatial analysis in Archaeology. As a tool however, it is value-laden and this has been obvious in the orientation of archaeological research. GIS can become a constitutive element of current archaeological theory, as long as research moves towards new applications and a clear distinction is made between objective explanation and interpretation through modeling.

Although the improvement of GIS technology will facilitate the implementation of more sophisticated analyses, the gap between archaeological and GIS theory will still negatively affect the successful incorporation of GIS in archaeological research. In order to overcome this problem, a shift in GIS research interest towards specific archaeological problems should take place, embodying archaeological methodology issues and theories and translating them to a body of archaeology-focused GIS tools. The systematic exploration of these functions within the domains of ontology, visualization and time can reveal new ways for the organization, analysis and representation of archaeological data. This can be reinforced by effectively using the experience of the current archaeological focused data, in order to record the needs of contemporary archaeological research, point the problematic issues of current analysis and declare the expectations of such a conjunction.

7 Acknowledgements
We would like to thank Prof. Kostas Kotsakis for his guidance through our research. The current paper is also supported by the “SEEArchWeb: An Interactive Web-based Presentation of Southeastern European Archaeology” project - a SOCRATES programme, with grant agreement number 110665-CP-1-2003-1-MINERVA-M. http://meteora.csd.auth.gr

References:


