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Prehistoric archaeology

GIS and intra-site spatial analysis

Andrea D'Andrea[1], Rosalia Gallotti[2]

Introduction

Intra-site spatial analyses have long been one of the most important methodologies for the study of the formation of paleosurfaces in prehistoric deposits, whose reconstruction undoubtedly plays a decisive role in the validation of subsequent deductive analyses (Texier 2000). An important contribution to the interpretation of prehistoric sites is provided by spatial analyses conducted in contexts explored extensively using the stratigraphic method. The systematic recording of the spatial distribution of finds, be they artefacts, animal bones, or any other archaeological evidence, helps to recognize functional units corresponding to areas set aside for work, butchering, waste dumping, etc.

The spatial distribution of finds in an Early Pleistocene site frequented by humans is rarely the result of an undisturbed and non-selective abandonment. In general, this distribution is largely determined by post-depositional disturbance phenomena, whether anthropogenic or not, which always need to be taken into account in any spatial interpretation.

One of the most difficult problems to solve is the difficulty of recognizing the sequence of these phenomena, which often occur simultaneously, and are hence hard to differentiate in an overall analysis. Furthermore, especially in the case of very rich layers produced by long-lasting human occupation, the increase and/or overlapping of zones of activity over periods of time that are hard to define limit the possibility of recognizing clear-cut distribution trends, thus undermining the significance of their subsequent chronological and socio-economic interpretation (Yellen 1977; Djindjian 1999).

In the case of an Early Pleistocene deposit, the observation of spatial distribution is hence limited to the recognition of post-depositional phenomena, anthropogenic or not, of characteristic associations of archaeological remains, and, if possible, of structures connected to the exploitation of the site (Whallon 1974; Johnson 1976; Binford 1978).

In consideration of the multiplicity of the above-listed factors, multidimensional analyses presently appear to be the most advanced techniques of spatial investigation, and have the better chance of solving problems of such complexity (Johnson 1976; Kintigh and Ammermann 1982; Simek 1984; Whallon 1984; Djindjian 1988, 1999). In the case of very rich paleosurfaces such as those of Garba IV D and Gombore I B, and, in general, the Oldowan and Acheulian sites of East Africa, it is impossible to conduct such analy-

1. Centro Interdipartimentale di Servizio di Archeologia, Università degli Studi di Napoli "L'Orientale", Vicoletto I, Santa Maria ad Agnone 8, 80139 Naples, Italy. dandrea@iuo.it. 2. Archaeological Mission Melka Kunture, Largo Tito Betuzio Barra 4, 71022 Ascoli Satriano (FG), Italy. rosaliagallotti@tin.it.

ses manually; the use of computers becomes necessary to attempt to reconstruct the process of their formation over time.

The last decade has seen a remarkable increase in the use of computational techniques in very different areas of archaeological research. These techniques range from classic statistical analyses to virtual simulations and the diffusion of data and results through the Internet (D'Andrea and Niccolucci 2000). Among them, GIS (Geographical Information Systems) programs have gained special favour, first as systems for the global management of stratigraphic archaeological data, then as fundamental tools for the interpretation of archaeological contexts. They have been long employed for inter-site analyses in archaeological landscape studies. In recent years, many applications aimed at the interpretation of prehistoric deposits have been developed (Thomas *et al.* 1996; Vullo *et al.* 1999; D'Andrea *et al.* 2000; Nigro *et al.* 2001, 2003). In this intra-site field of application, GIS has often proved decisive in the identification of the process of spatial aggregation of archaeological data through previously inconceivable modes of contextual and/or selective treatment of spatial-temporal variables.

The close connection between the spatial location of the evidence and the analytical study of each individual find makes the use of computer spatial-analysis technologies especially useful in conjunction with GIS. If the spatial distribution of evidence reflects the functional organization of an investigated surface, quantitative statistical techniques can be very useful for the classification of finds, the analysis of the overall evidence, and the detection of specific associative patterns. GIS applications allow the visualization of different distribution levels for specific categories of objects; more importantly, they can highlight "latent structures" in the distribution of artefacts. The topological features of GIS can be used to create derived maps representing frequency analyses, or obtain density values. Along with the so-called "indexing of phenomena", the production of information derived from the integration of thematic data is one of the principal characteristics and functions of GIS. Through the interrogation of spatial or alpha-numerical variables contained in an archive, elementary spatial units can be recognized that are useful for the definition of functional areas. Within each unit, each category (faunal remains, lithic artefacts, etc.), or all the objects together, can be counted to facilitate comparisons between areas with different surfaces and characteristics.

Djiandjian has recently reported on the employment of statistical methodologies in the processing of intra-site spatial data in an article (1999) dealing with the state of the art of quantitative techniques, and particularly multidimensional analyses, which are especially well suited to the study of associations of artefacts belonging to different categories and distributed in several superimposed levels. The use of statistical methods in the study of prehistoric deposits allows researchers to go beyond the simple observation of object distribution to attain an overall reading of archaeological contexts through the recognition of significant spatial patterns. Besides allowing the visualization of specific thematic selections of data, these systems can also filter data to remove disturbing elements or noise from the statistical corpus. In other words, thanks to its flexibility, GIS can be used to verify alternative hypotheses simply by adding or removing data, or using quantitative classification techniques. By visualizing multiple spatial variables simultaneously, it is possible to recognize specific connections between data. Thanks to their filtering capabilities, multivariate statistical methods play a decisive role especially in cases when the presence of significant post-depositional noise does not allow associations and patterns to be clearly distinguished by simple direct observation.

Although the use of GIS appears today to be indispensable, not just to improve and enable the management of excavation data but also to produce combined maps, the use of spatial analysis technology for intra-site investigations has not yet found wide application in archaeological research. In spite of the usefulness of intra-site spatial analyses for the observation and recognition of latent structures, this is still a relatively new field.

Although many considerations would warrant an increase in the employment of GIS for intra-site analyses, there are many risks involved in the conversion of spatial data to a digital format, unless the nature of the reproduced information is correctly understood. The logical and physical structure of the application should be accurately planned to make up for the limitations imposed by “electronic translation”. Special care should be taken in the planning of the application’s alpha-numeric archives and the programming of its vectorial graphics. If the objective of GIS is to simplify information management and produce derived thematic maps, the chosen GIS application needs to be correctly planned and implemented. However, since the description and organization of information levels includes no explicit interpretation or explanation of the nature of associations between investigated objects, the point of departure for the deduction, reconstruction and explanation of spatial phenomena must be the structuring of spatial entities and the descriptive variables associated with them.

So far, intra-site GIS has been applied to the study of Early African prehistory only in the Swartkans quarry in South Africa, and in the Acheulian deposit of Olorgesailie in Kenya (Thomas *et al.* 1996). In both cases, the use was prompted by the need to shed light on the phenomena leading to the formation of archaeological and/or paleoanthropological deposits. In particular, the case of Swartkrans can be regarded as a model for the investigation of all South African quarries where the interpretation of deposits and of the contextual relationship between fossils and lithic artefacts is extremely problematic. The project, a joint effort of the Palaeoanthropology Unit for Research and Exploration of the University of Witwatersrand and the Developed Spatial Technologies Department of the University of Arkansas, was aimed at the creation of a three-dimensional system able to cope with the chronostratigraphical problems common to all South African fossiliferous quarries. It also aimed to investigate the connections between archaeological objects through simulated reconstruction of old excavations by Brain, whose data were converted to a digital format allowing all human, geological and fossil remains to be archived and visualized in three dimensions (Nigro *et al.* 2003). The system developed for the study of the Swartkrans quarry is certainly one of the most significant and innovative experiments in the use of GIS for intra-site analysis of paleosurfaces and three-dimensional investigations of archaeological sites.

Similar considerations prompted our adoption of a GIS for the management and processing of spatial and alpha-numerical data concerning the paleosurfaces of Garba IV D and Gombore I B. The adoption of this analytical tool has resulted in a new basis for the investigation of the history of these sites.

Intra-site analysis of the Oldowan sites of Garba IV D and Gombore I B by means of a GIS application

The Oldowan paleosurfaces of Gombore I B and Garba IV D were explored extensively, the former over an area of about 230 square metres, the latter over an area of about 110 square metres. They yielded an enormous quantity of lithic objects and faunal remains, 12401 from Garba IV D and 10411 from Gombore I B respectively.

Due both to the extent of the investigated areas and the number of finds, spatial statistical techniques were indispensable for the interpretation of these deposits. Equally indispensable was the adoption of a GIS to highlight possible correlations between the spatial distribution of the objects and the analytical study of each individual find.

The logical and physical structure employed in the description and organization of information levels reflected the following research aims:

- conversion of paper archives to digital format;
- location and two- and three-dimensional visualization of all the finds;
- processing of archaeological entities as spatial variables;
- spatial interrogations (topographical selections, filtering out of post-depositional noise) to attempt to reconstruct possible natural and/or anthropogenic post-depositional processes that transformed the original deposits, and the modes and phases of the frequentation of the sites through the thematic break-down of spatial distribution and the creation of individual or combined plans and thematic sections;
- statistical inference of spatial data (frequency matrixes, density analyses) to highlight significant associations and connections between specific categories of materials that were potential indicators of the presence of functional areas.

The first step was to convert alpha-numerical data on paper (excavation files and object descriptions) to digital format. The information was processed in such a way as to be compatible with computerized management of the excavation archives and inventory. The basic documentation gathered during our fieldwork consisted of a catalogue of each lithic artefact or bone, plans, and a series of archives containing a more detailed study of lithic artefacts.

Microsoft Access® was used to create the archives. It was chosen mainly for its simplicity of use for the creation of tables and templates, and especially because it allows the use of personalized dictionaries facilitating data entry and assuring, at the same time, the homogeneity of archived data. The data were archived in a relational format to allow different types of interrogations of the database, especially the use of queries to group and count data, an operation that proved essential for subsequent statistical analyses. To ensure consistency of stored information, a template was created where the data of certain fields were normalized by means of a thesaurus available as a drop-down menu.

After the conversion of alpha-numeric archives on paper, we proceeded to computerize the existing plans of the investigated paleosurfaces. The logical structure, later implemented using the software MapInfo Professional®, was conceived to avoid any subjective interpretation in the organization of spatial data. Spatial entities and variables were entered as they were recorded during the excavation, without projecting any interpretative content upon them during the physical structuring of the GIS. The computerization of these data was not merely to provide a correct geometric and topological definition of the finds, and to simplify their searching and selection; it was also necessary to heighten their informative content through the interactive development of multiple views, and/or views derived from the original maps (selective plans, thematic plans, etc.).

The excavation of the paleosurfaces of Garba IV and Gombore I had been conducted by superimposing a grid formed of squares of 1 m on the surface of the excavation, within which each single find had been correctly positioned. This grid was imported into MapInfo Professional®, geo-referenced on non-terrestrial coordinates using a metric scale, and vectorized. This reticule, besides serving as a reference grid to reconstruct the spatial distribution of the objects, also provided a fundamental basis for statistical inferences. The same reference system was used for the subsequently imported excavation plans.

Some zones, especially at Level D of Garba IV, were characterized by high concentrations of materials, with some vertical accumulations. During the investigation, several plans of these zones had been drawn up to document the successive stages of removal of the paleosurfaces. The importation of these superimposed plans into the GIS posed a problem, since these objects did not actually lie on distinct horizontal planes.

Furthermore, while it would have been possible to visualize the vertical accumulation of lithic and faunal remains, doing the same for unmodified pebbles appeared rather problematic. This was because they had been simply indicated in the plans, but not classified in the general inventory, and no depth measurements were hence available for them; their distribution over the paleosurfaces could therefore only be visualized in two-dimensions. To attempt to organize the plans so as to reflect these superimpositions and provide an image of the vertical position of non-modified pebbles within layers, every single archaeological object was vectorized using a digitizer, or on-screen, and positioned in a given layer on the basis of the removal phase to which it belonged.

The result is a superimposition of different information levels that is exclusively visual, i.e., does not reflect actual attributes of the objects. In other words, the objects contained in a level did not necessarily lie at the same depth, but were certainly positioned below objects in the overlying level, and above those in the underlying level. Thus, for some areas of the excavation as many as six different layers were created, in each one of which the objects were represented using a different line style, as a visual means to highlight superimposition. Unmodified pebbles, since they cannot be processed through an associated database, were vectorized in distinct levels to guarantee the visibility of each find in the plan without losing the possibility of representing the vertical distribution of the total finds. A different graphic pattern was used for unmodified pebbles to distinguish them from the other finds, but using the same line styles as the other finds to signal their position in superimposed layers (Fig. 1).

After the digital and vectorial conversion of the excavation plans, we proceeded to link the data in the Microsoft Access® database with the graphic objects described in MapInfo Professional®. During vectorization, each object in the database was assigned an inventory number. The Access tables were then imported into the GIS. Since each find entered in the alpha-numeric archive and the vectorial archive was distinguished univocally by its inventory number, it was possible, using an SQL ("Standard Query Language") command, to establish one to one relationships between the information in the tables of the database and the vectorial planes. The absence of a code for unmodified pebbles, as mentioned above, did not allow the pebbles shown in the GIS with the database to be linked (Fig. 2).

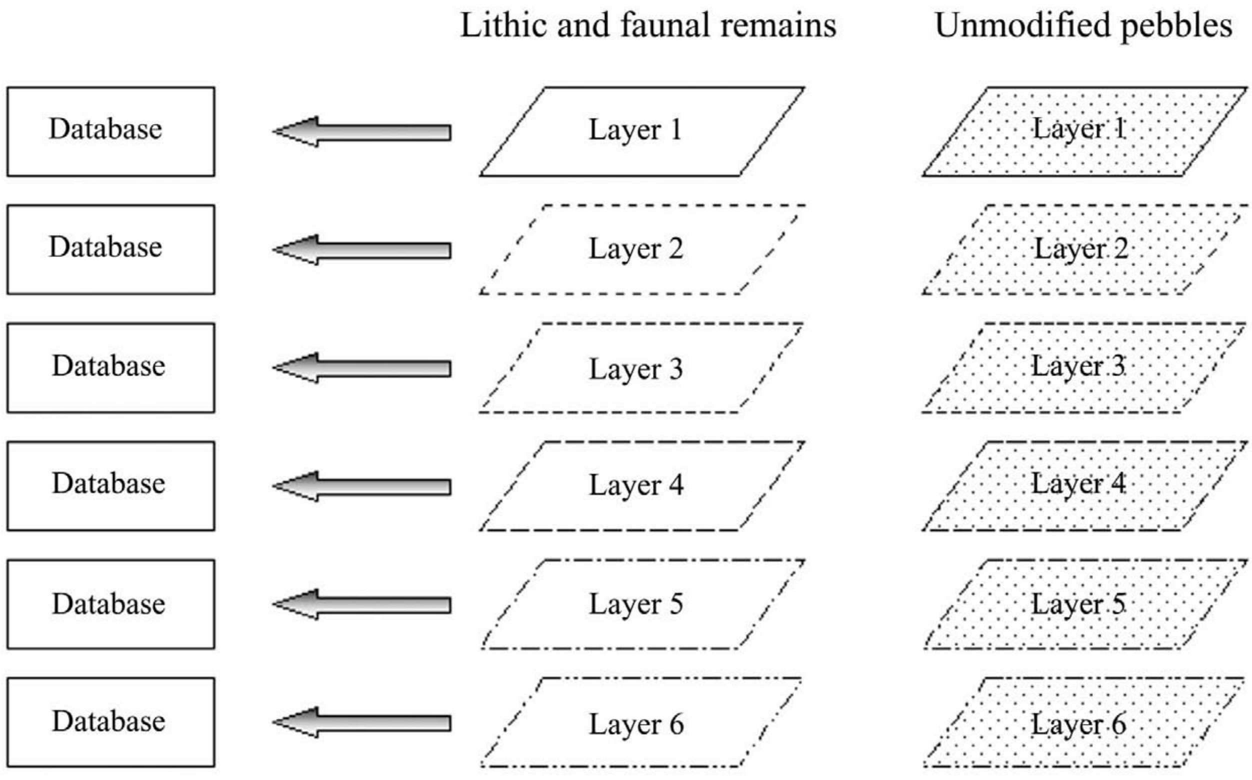

Fig. 1. Schematic model of the computerized reproduction of the excavation plans.

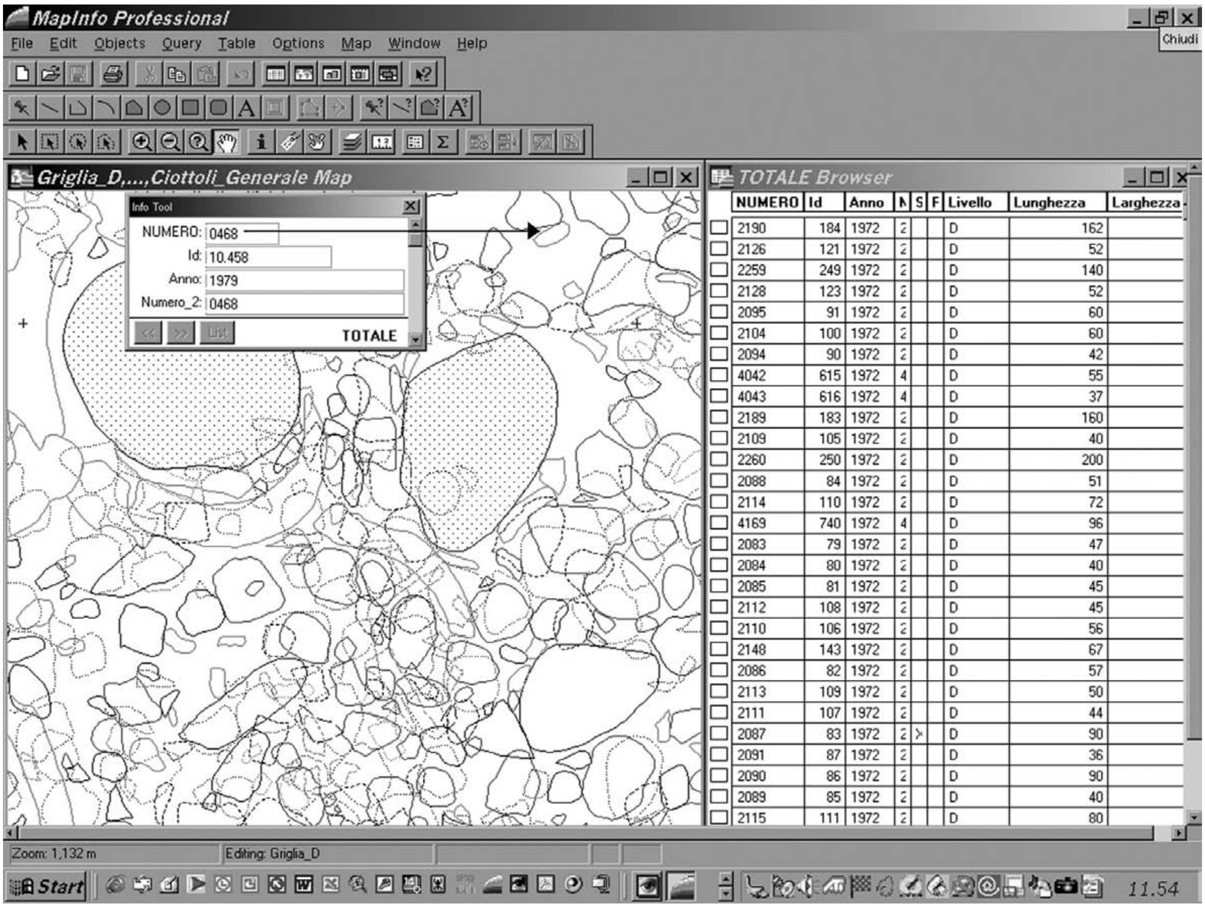

Fig. 2. Link between the database and graphical objects in MapInfo Professional®.

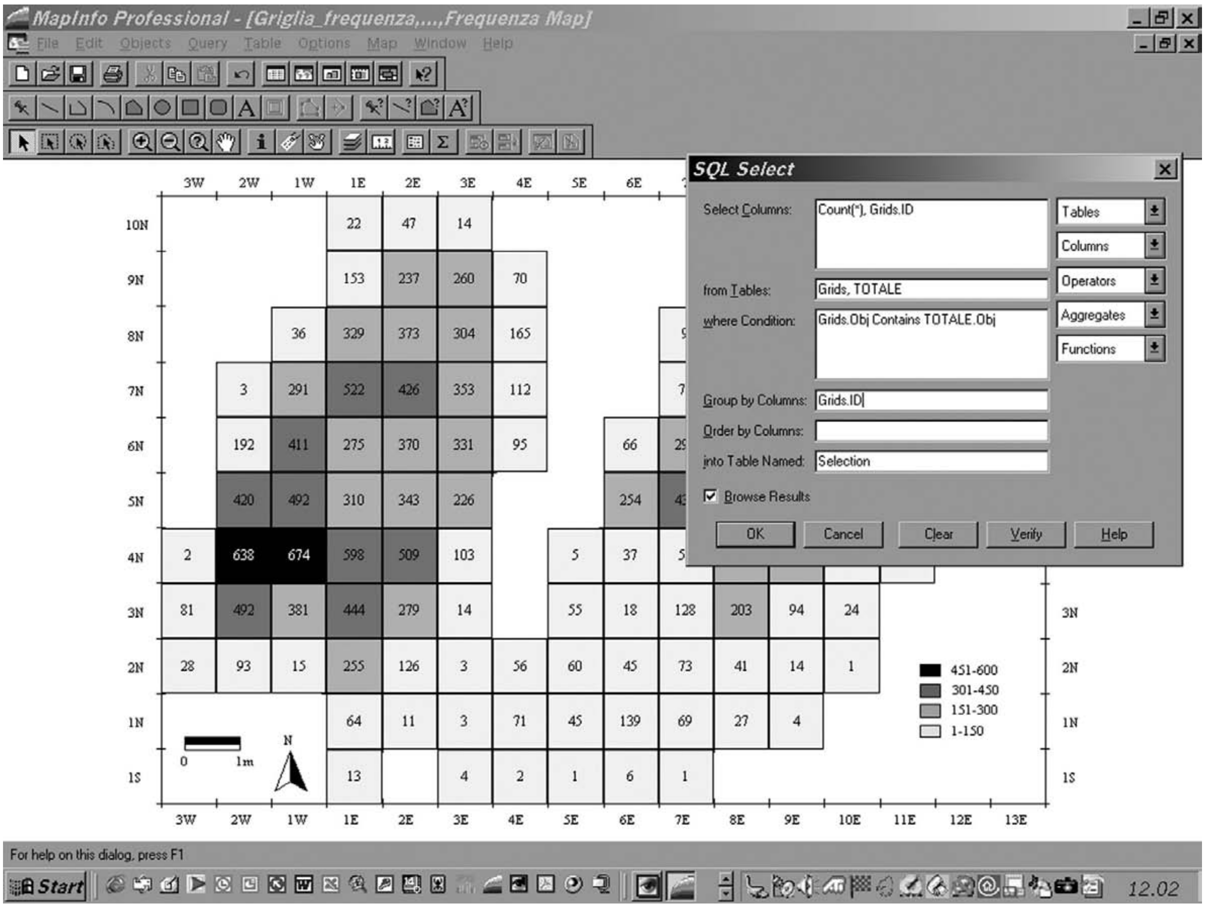

Fig. 3. Frequency plans by square metre created through a SQL interrogation based on the topology of informative levels.

By combining alpha-numeric and graphic information, it is possible to carry out any kind of interrogation and selection of the fields in the database. The themes thus created are then saved in new tables. Through simple modes of selection, it is possible to interrogate alpha-numerical data and visualize the corresponding graphic objects. It was thus possible to generate numerous thematic maps to visualize the evidence found on the paleosurface, considered both individually and in association with other types of information, e.g., comparing the spatial distributions of two or more variables.

In spite of the valuable contribution of these thematic plans to the highlighting of associations, the very high number of finds makes it difficult to obtain accurate readings of their distribution. This is why frequency maps and density maps were created to represent certain concentrations or dispersals in detail.

In the case of frequency maps, the remains were grouped and counted per square (i.e., using the square method, see Hodder and Orton 1976) using an SQL procedure based on the topological overlay of the 1m by 1m excavation grid, or a finer-meshed one (50 cm by 50 cm) for thematic levels. This procedure allows automatic calculation of the number of objects whose centroid falls within each square. The maps thus obtained contain the total number of objects for each category of finds, grouped and counted per square metre. It should be remarked, however, that the frequency count was limited to entirely excavated squares, since in partially excavated ones the number of finds could have been incomplete, with a distorting effect on the overall calculation (Fig. 3).

Frequencies in these maps are expressed by ranges of standard values. As a consequence, they provide a numerical image of density phenomena which, being schematic and adapted to the grid, does not fully reflect their real limits. To provide a more “naturalistic” rendering of object concentrations, free from the constraints of the grid, density plans were created. The points corresponding to the centroid of each object

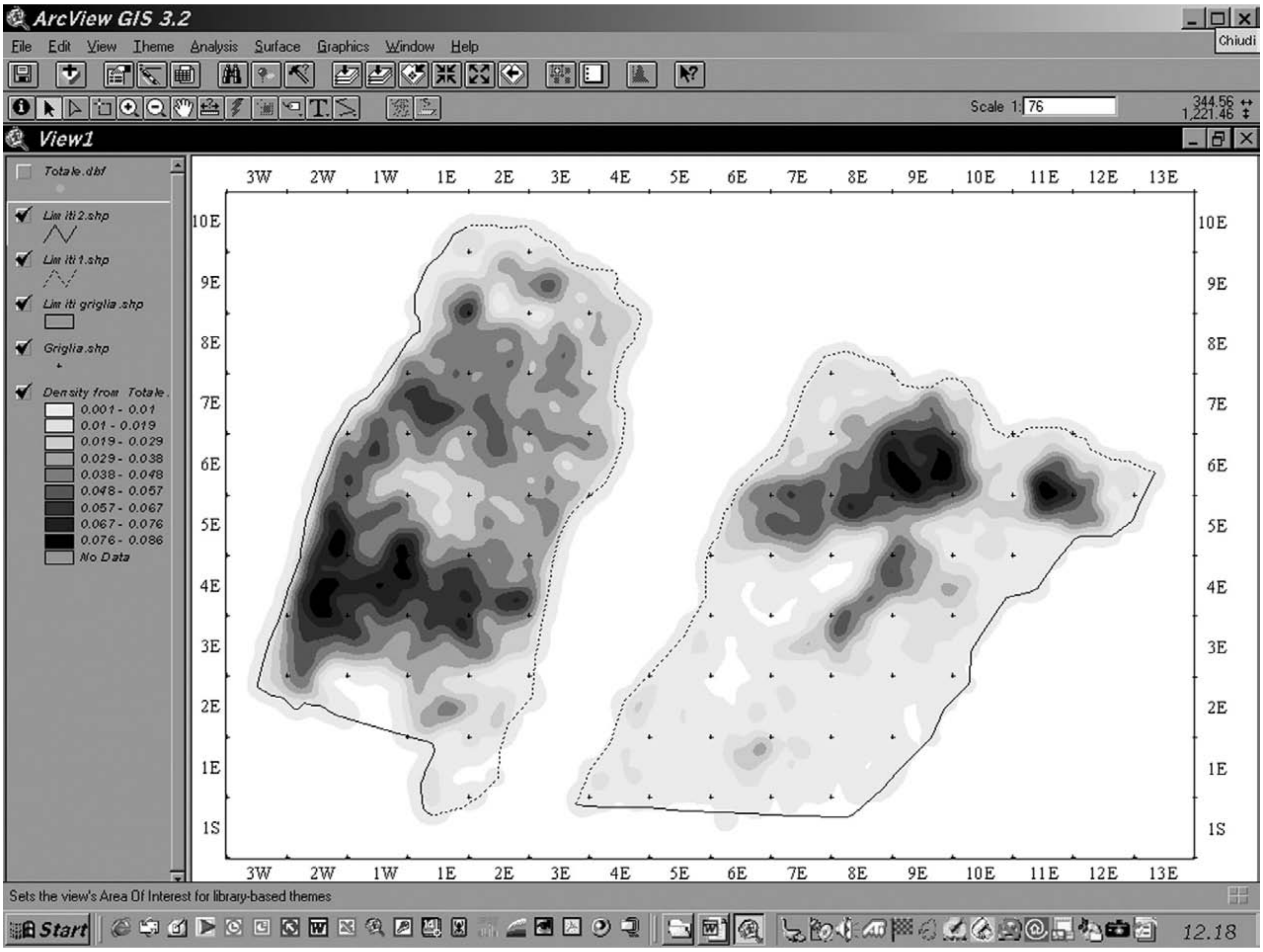

Fig. 4. Density plan created in ArcView® using the Spatial Analyst module.

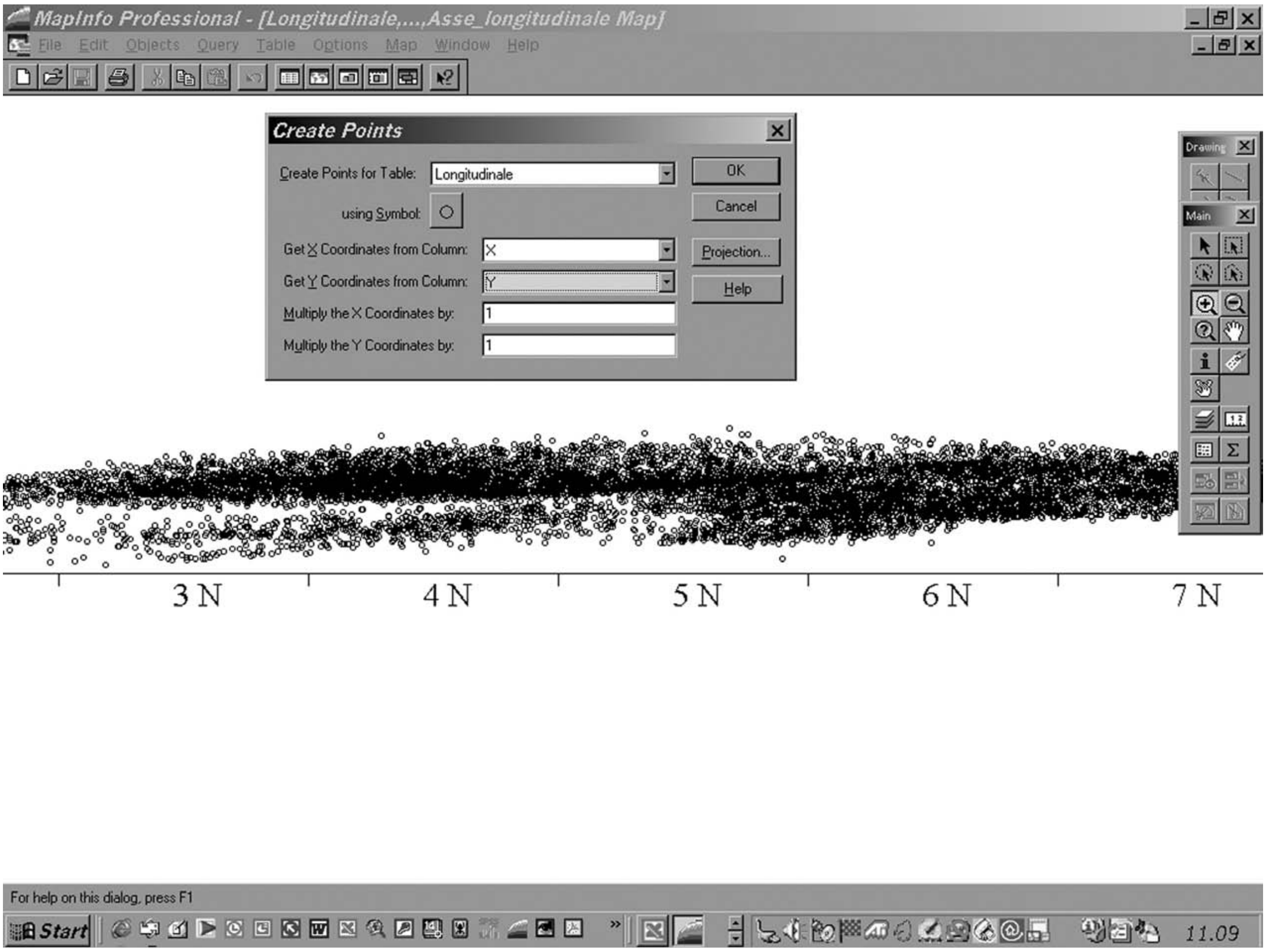

Fig. 5. "*Create points*" function to obtain a north/south section of Level D.

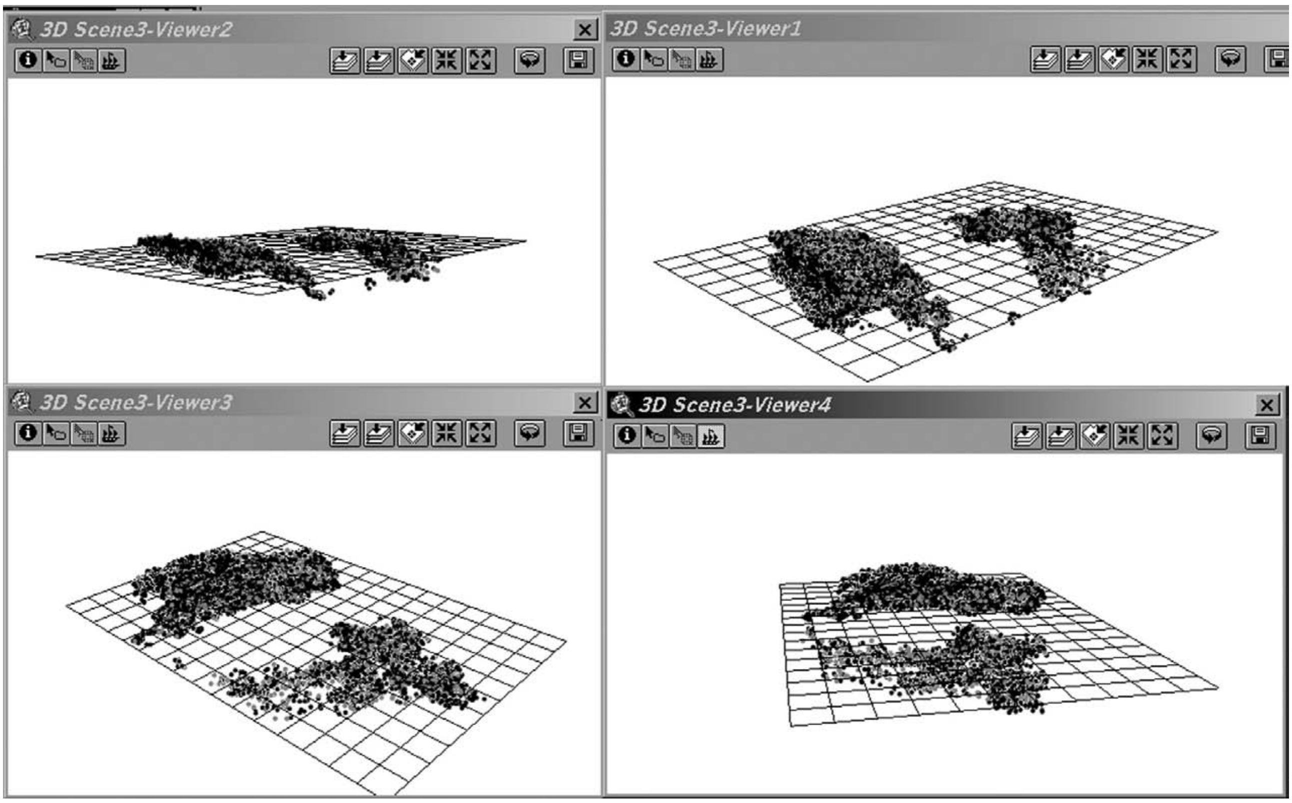

Fig. 6. Different axonometric views of Level D.

were exported to ArcView, where the density plans were generated using this application's spatial analysis module ("Spatial Analyst"). The density function calculates the quantity of points in a level on a continuous surface. Thus, the occurrence, and, especially, the nearness of points is highlighted through the generation of a new map of density values beginning from a given point. Values are expressed through density curves quantified on the basis on a k-nearest neighbour distance calculated beginning from the centroid of the objects (Fig. 4). Each density plan is combined with a frequency plan to extrapolate both naturalistic and numerical parameters from the interpretation of spatial distributions.

The use of specific topological functions applied to the spatial distribution of individual finds has allowed the calculation of north/south and east/west sections of the excavation using the MapInfo Professional® software. This application allowed the reconstruction of information about the section that, due to the high number of finds, would not have been reproducible manually. The *x* and *y* coordinates of the centroid of each object were calculated. To these values was added the measurement of the depth of each object, except for the unmodified pebbles, whose depth had not been measured. By ranging the values of *x* or *y*, respectively, on the abscissa for east/west and north/south sections, and those of depth on the ordinate, it was possible, using the program's "*create points*" function (Fig. 5), to create sections and axonometric view (Fig. 6) for any portion or extension of the excavated area (D'Andrea *et al.* 2000, 2002a, b; Gallotti and Piperno 2003).

So far, we have conducted two- and three-dimensional spatial analyses only of paleosurface D of the Garba IV site. The depth of a limited number of lithic and faunal remains on this paleosurface was not recorded due to difficulties encountered during the early stages of the excavation in the lower half of the Eastern Sector in clearly distinguishing Level D from Level C along the eastern margin of the excavation, near an area affected by erosion (see Piperno *et al.* in this volume). Out of a total of 12401 remains found in Level D, the depth of 776 were not recorded; these were all located in Eastern Sector, within squares 7E/3-5N, 6E/2-6N, 5E/1-4N, 4E/1-2N.

Finally, only a two-dimensional spatial analysis has been up to now conducted for the Gombore IB paleosurface. The main plans obtained for both sites with this GIS application are presented in Volume II.