BRITISH MUSEUM

OCCASIONAL PAPER NUMBER 114

IMAGING THE PAST

ELECTRONIC IMAGING AND COMPUTER GRAPHICS IN MUSEUMS AND ARCHAEOLOGY

edited by Tony Higgins, Peter Main and Janet Lang

EXPANDING THE ARCHAEOLOGIST'S TOOLKIT: SCIENTIFIC VISUALISATION OF ARCHAEOLOGICAL DATA

Susan S. Lukesh

KEYWORDS: ARCHAEOLOGY, AUTOCAD, COMPUTER-AIDED DESIGN, COMPUTER GRAPHICS

INTRODUCTION

The archaeological excavation of a site uncovers architectural features and material remains, both man-made and organic, all of which play important roles in the interpretation of the site. In addition to the identification of organic remains, and the interpretation of artifact manufacture and use, archaeologists routinely use the *spatial patterning* and *coincidence* of different types of the remains (that is, artifacts, organic remains and architectural features) to draw conclusions on site and region use (Kroll and Price, 1991; Blankholm, 1991; Kotsakis, 1989; Colley *et al.*, 1988). From the early days of computer availability, the computers have provided support in the gathering and interpretation of archaeological data (Lock and Fletcher, 1991; Ross *et al.*, 1991; Plog and Carlson, 1989; Dibble and McPherron, 1988; Nelson *et al.*, 1987; Richards and Ryan, 1985). More recently, with the advent of sophisticated computer aided design (CAD) products, the mapping, drawing and three-dimensional reconstruction of sites has become possible (for example, Bower and Kolb, 1990; Williams, 1989; Raymond, 1989; Schiffer, 1982; for current work on archaeology and CAD see the *Newsletter of the Center for the Study of Architecture*). Nonetheless, while two-dimensional surface plots of material are commonplace, three-dimensional plotting and the illustration and *analysis* of three-dimensional spatial relationships in archaeology have only more recently come under consideration. Yet, as researchers in other disciplines recognise, the analysis of spatial relationships is crucial. Tom West, in *In the Mind's Eye*, writes that:

> Patterns in data are invisible until one can turn away from the individual data element, and focus instead on the "global structure of the field variables." In cases such as these, we can see a major shift from the individual values and indicators and toward the consideration of complex things that make sense only when you can look at the whole of a system with each individual part seen in relation to all other parts - in many respects an inherently visual frame of reference. These developments have come to be known as "scientific visualisation," an approach to handling data that began to be used in many different fields in the late 1980s.
>
> (West, 1991, p. 232)

The three-dimensionality of archaeology is obvious. Yet archaeologists have been forced to analyze and illustrate archaeological remains in an essentially two-dimensional world. Edward Tufte's words are especially appropriate to archaeology:

> The world is complex, dynamic, multidimensional; the paper is static, flat. How are we to represent the rich visual world of experience and measurement on mere flatland?
>
> (Tufte, 1990, p. 9)

This paper presents one approach to Tufte's question. We recognise that, while more answers will be developed and the rapidly expanding capabilities of hardware and software may soon make this step obsolete, each one is a useful building block.

During the course of excavation, records of objects recovered (material description and indication of find-spot) are maintained. The physical excavation of a site under controlled circumstances may proceed by establishing and following a standard grid pattern in regular vertical sections. Or, an investigation may proceed, as in places where either geographical features hinder such a scheme or the excavator elects a different approach, by the excavation of units whose definition is driven by either natural features or the site itself (e.g., excavation within hut walls, individual burials). Material that is recovered may be recorded by specific find-spot, that is, the absolute three-dimensional coordinates within the site. At other times, the volume of material (or at least specific material such as ceramic pot sherds) precludes establishing and recording the precise three-dimensional find-spot of each object. In these instances, material is recorded by its excavation unit (or survey plot) which itself has absolute coordinates within the site. In the first instance, each object, with its own set of three-dimensional coordinates, can be readily plotted on a three-dimensional model of the site (Figure 1). In the second, when the volume of recovered material prohibits recording the three-dimensional plot point of each object, three-dimensional plotting of these objects can only be addressed by plotting densities of materials per excavation unit.

We can easily see the value in the display of objects by find-spot across the site. How can we extend this to material found in volume and recorded only by excavation unit? Although I have been keeping detailed database records of artifact information for over twenty years (Lukesh, 1975a, 1982, 1984), and the determination and display of recovered material densities has been a goal of mine, until recently, hardware and software limitations made this impractical if not impossible. I am less interested in such a display for a site publication (although this has clear value) than I am in using the capabilities of graphics to tell us more about the site than the lists or summaries of material remains can reveal. In short, my goal has been graphical display and analysis of densities *to assist* in the interpretation of the site, rather than *to support* an otherwise derived interpretation of the site. Tufte's language again is useful:

> Modern data graphics can do much more than simply substitute for small statistical tables. At their best, graphics are instruments for reasoning about quantitative information. Often the most effective way to describe, explore and summarize a set of numbers - even a very large set - is to look at pictures of those numbers. Furthermore, of all methods for analyzing and communicating statistical information, well-designed data graphics are usually the simplest and at the same time the most powerful.
>
> (Tufte, 1983, Introduction)

We are all familiar with data maps which indicate intensities of population based on various factors. These are two-dimensional examples of the graphical analysis described here. Our information, on the other hand, is three-dimensional, since the vertical position of the material (i.e., its relationship with the stratigraphy of the site) is as important as the horizontal disposition. Data graphics which summarize and display millions of bits of information from a three-dimensional world on a two-dimensional printed page or screen are powerful tools which must be added to the standard repertoire of tools for the archaeologist.

Plotting information, either population densities across a country or artifact densities throughout a site is not simply to illustrate what is known, but to display data in such a fashion that more information and understanding are gained. A classic example of this, related by Tufte, is provided by Dr. John Snow who plotted the location of deaths from cholera in central London in 1854 and, seeing the proximity of the deaths to a specific water pump, knew immediately the relationship between the pump and the disease. As Tufte writes,

> Of course the link between the pump and the disease might have been revealed by computation and analysis without graphics, with some good luck and hard work. But, here at least, graphical analysis testifies about the data far more efficiently than calculation.
>
> (Tufte, 1983, p. 24)

If Snow had not plotted the water pumps as well as the locations of cholera deaths on his map of London the significance of the pattern of deaths would not have been obvious. So too the archaeologist will be dependent for insight on the *selection* of material and the *conjunction of other features* with the densities of these materials. If an archaeologist begins an analysis intending to study, for example, the distribution

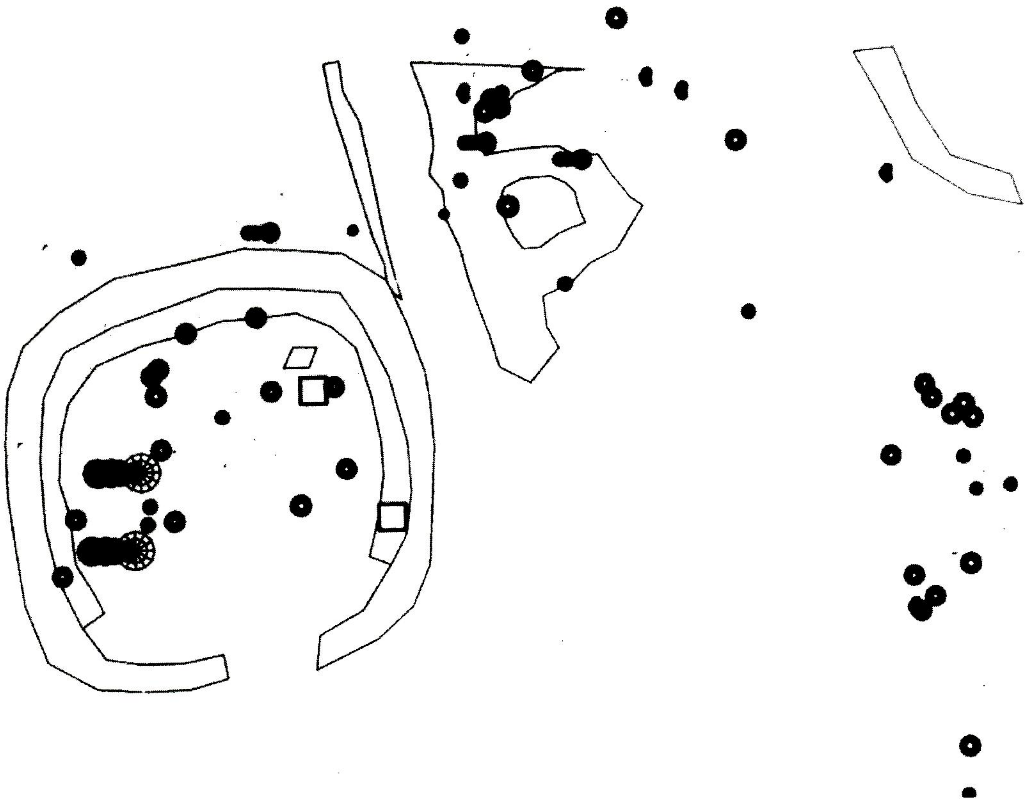


Figure 1. Hut walls (and inner bench) of one hut as well as miscellaneous other wall fragments plotted exactly as they were found. Also plotted precisely are icons, whose shapes and colours differentiate the objects recovered (e.g., spindle whorls, pieces of obsidian, and whole pots).

of stone moulds for bronze working, or even the distribution of the density of fragments of water pitchers, the task can be accomplished manually, although it is vastly improved with computer assistance. But if an archaeologist wishes to model the distributions of any and all materials, not knowing which ones may reveal meaningful spatial patterns, computer assistance is fundamental to the solution. Only with computer support can we easily and repeatedly select any material, or combinations of materials, and plot their relative densities in order to see the patterns of retrieval or recovery, if not actual use, of the materials across the site. Such modeling allows us to assess various hypotheses and develop additional ones to explain the patterns.

What is described here is a tool to aid in the interpretation of archaeological excavations through graphical analysis of the large volumes of data recovered during the course of an excavation. Current CAD products are designed in such a way that the plotting of individual find spots (e.g. Dibble and McPherron, 1988) and related three-dimensional structures becomes routine, as we saw in Figure 1. The software discussed here provides a solution to automated plotting of material densities when objects are recorded by unit excavated, rather than by the specific three-dimensional coordinates.[1]

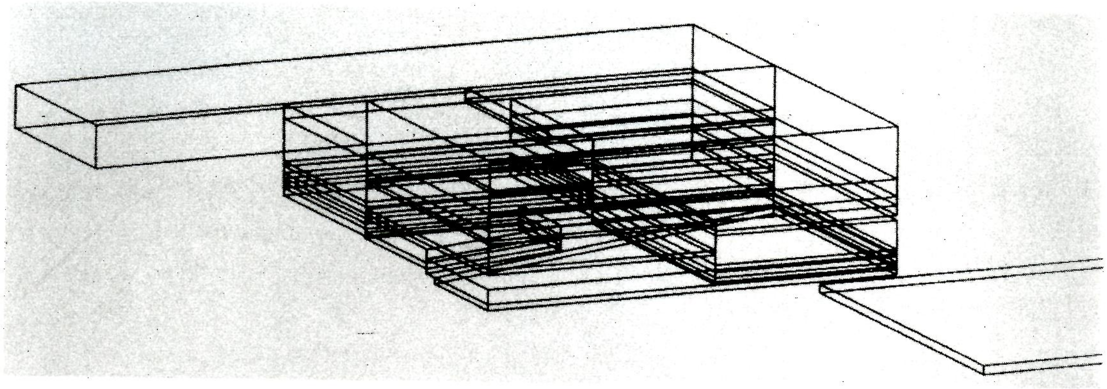


Figure 2. Three-dimensional excavation units only; icons, placed on different layers, are hidden in this example.

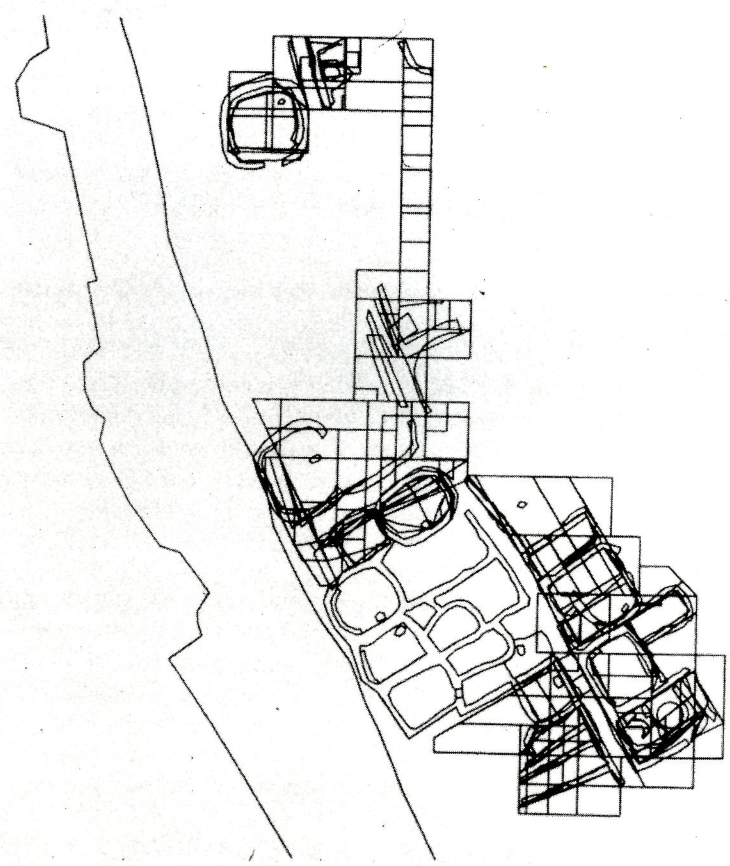


Figure 3. AutoCAD drawing of the city and hut walls with the drawings containing the excavation units.

BACKGROUND

On the sites on which I have worked (Holloway and Lukesh, 1991, 1992; Holloway *et al.* 1975, 1991), we excavate by a series of trenches which, while not following a standard grid plan, are nonetheless mapped by three-dimensional coordinates, relative to one fixed point on the site (Figure 2). They can thus be easily represented in a three-dimensional model of the site. Although our trenches begin as standard quadrilateral and cubic units, architectural features and natural geographical variations often require the excavation of non-standard units. Single objects such as grinder stones or moulds for bronze objects or whole vessels are mapped with the precise three-dimensional coordinates of their findspots (see Figure 1) but the large volume of fragmentary ceramic material requires us to record this material in groups associated with the unique identifier of the excavation unit from which they were recovered. Thus multiple objects are recorded for each excavation unit, but without precise find-spots within the excavation unit.

Analysis by density of material within excavation unit presupposes the ability to calculate the volume of each unit. When the excavation proceeds by standard grid, as described above, this calculation is trivial. With irregularly shaped excavation units, the simple calculation of volume presents an immediate obstacle to the analysis by density. We all know how to calculate area for rectangular, triangular and even regular 5-sided units. Much more difficult is the calculation of area (and thus volume) when the excavation unit is described by the contours of man-made or natural objects. Our excavations have such non-regular units, and cubic volume has been difficult to calculate. If we can only calculate volume for a portion of the site, analysis of materials based on density recovered cannot be realised.

In addition to the calculation of volume, however, analysis by density of materials recovered also requires that all material be recorded (or all examples of selected types, or all material within certain areas). The sites on which I have worked have allowed for the recording of all materials (which, on account of sheer size alone, many sites do not), but without the ability to readily calculate volumes of irregular excavation units, density analysis has been beyond reach.[2]

From the outset, we recognised that the tool developed had to be able to:

assist in the calculation of volume;

select material(s) to be displayed;

generate and display the corresponding density patterns.

These capabilities are dependent, firstly on the databases which inventory the material and on the ability of archaeologists to use them to select material or groups of material (e.g., all ceramic, all coarse ceramic, or all water jugs) from the databases. The selection of materials, in effect, allows the archaeologist to model different hypotheses of site use and material interaction. Secondly, the solution is dependent on graphic capabilities of other software. A tool which, in conjunction with architectural features and other fixed points, can display, rotate and slice excavation units while showing the relative densities of selected material, presents us with a powerful tool to test hypotheses and search for potentially significant material distributions.

DEVELOPMENT OF THE SOFTWARE

Although the idea of this software had been in mind for some time, it was not until recently that reasonably priced CAD products and equipment made it feasible and possible to begin development for archaeology. Without any modification of AutoCAD (the software used for this development), we found that it is possible to readily determine or approximate the cubic volume of any excavation unit (a prerequisite to determining density) and to display a three-dimensional model of the architectural features and the excavation units of the site (Figure 3). The overall problem that remained, and whose solution is described here, was to join density information from the artifact database to the AutoCAD model of excavation units (and architectural features) *and* display graphically the varying densities across the full site and at selected vertical sections.[3]

At the beginning, it was clear that there were two problems fundamental to the development of this product: firstly, the joining of records from separate database systems to the CAD product and the matching of the density records with the corresponding excavation unit; and secondly, the display of density in such a fashion that it easily demonstrates relative density and, if we chose to cut through the site (vertically or horizontally), that the display would be preserved. Not surprisingly, a number of other problems arose in the course of development some of which are described below.

For the first problem, we could not use the AutoCAD SQL Extension, which provides embedded SQL routines and drivers to link to a number of databases, since our long-standing databases were not written in one of the linkable databases. Instead, we needed to design interface programs to read a standard output file, a solution we knew would allow the option of 'linking' to almost any database. While AutoLisp allowed us to read the output file we prepared (one line sets of data per excavation unit), it is designed to read lists, or one 'data element' at a time.[4] Consequently, we developed a conversion program which parsed the file of multiple one line data records into a list of data elements. Rather than the end of a line signifying the end of a data record, a special delimiter indicates when the next record begins. Using the converted file enormously decreased processing time.

Since it is not possible to associate a fixed label to each excavation unit which AutoCAD would recognise regardless of drawing transformation, we chose to place each excavation unit on its own AutoCAD layer, allowing the layer name to carry the unique excavation unit identifier. This solution allows us to associate the density of the selected material(s) with each excavation unit by associating it with the AutoCAD layer carrying the unique excavation unit name.

Since we are interested in displaying densities of material, rather than specific find spots (a solution which would create its own density pattern), we needed a way to differentiate variations in density. Hatch patterns are routinely used in displaying different materials or densities of materials in two-dimensional sections. They are, however, unworkable in a true three-dimensional environment since they do not readily turn into a three-dimensional 'fill' through which we can slice.[5] For our solution, we turned to colour, which, as Tufte writes, "is a natural quantifier, with a perceptually continuous (in value and saturation) span of incredible fineness of distinction, at a precision comparable to most measurements" (Tufte, 1990, p.91).

Colour serves a variety of purposes, two of which we use in this software - to distinguish densities and to label. To display density differences, we reject the distinctions often employed in multi-coloured maps (where red, blue and yellow represent different values with no intuitively obvious degree of magnitude) and use a single colour whose 'lighter-to-darker' sequence reflects the parallel 'lower to higher' densities of recovered material.

In the second place, we use colour to label, differentiating mutually exclusive sets of data. In one instance, stratum 1 densities are displayed in red, stratum 2 in blue, and so on. In another, densities of materials in courtyards are in red hues, covered buildings in blue hues. Thus we encode these three-dimensional density maps to differentiate among classes of site use as well as among quantities of material.[5]

Returning to the consideration of density display, it is worth remarking that we do not, of course, display each unit's exact density. Rather, we divide the densities into a series of ranges, assign a colour-hue to each range and then change the colour of the layer, and hence the excavation unit on the layer, to that appropriate to its density. Just as a map of New York City which showed population densities might use a dense hatching to indicate most dense (e.g., 500,000 residents/sq. mile) and a light hatching to indicate the least dense, so we use shades of blue, for example, to indicate the relative densities of the selected material per cubic meter per excavation unit.

As the development of this software continued, we discovered another problem related to the ranges of densities of recovered artefacts to be displayed. Study of various population density maps has acquainted all of us with the fact that the choice of ranges of densities can significantly change one's impression of the map. For example, the first range may be from 0 to 1,000 or from 0 to 100,000. While the second choice is germane to a map of the United States, the first is more appropriate to a small town. An obvious selection of ranges is the simple division of the maximum density into the available number of ranges. It is then possible to assign the density of each unit to a specific range (and its associated colour-hue). We saw immediately, however, that with this method, when the maximum was represented by a single unit or two and was also far removed from the distribution of other densities, the resulting distribution showed clustering in only a few ranges, thus limiting the information conveyed. We addressed this in two ways.

First, we had already decided that density of zero would be represented differently from other lowest densities since the absence of material is often a significant fact. Thus, the total range which we break into subsets is not assumed to go from zero to the maximum, but rather from the lowest non-zero density to the maximum. This means that the lowest density range or subset is zero or empty, the next begins at the next lowest density and (when we have five ranges, for example, in addition to empty) continues for one fifth of the distance to the maximum and so forth. In this way, we do not arbitrarily divide the distribution into ranges where no units have densities, on the lower end. Yet, in instances where there are one or two high densities, outliers so to speak, we still can create a less than useful set of ranges, most of which are empty, toward the maximum end. Graphic distribution with this set of ranges could make most units look the same.

The solution to this problem, then, was to allow the user to determine the limits to each range, after viewing the default set of ranges. This ability to redefine the ranges allows us to focus on the point around which the distribution of material clusters. To help in determining the optimum set of ranges, we developed a simple graph showing the distribution of actual density ranges of the material selected so that the most useful set of ranges (although perhaps not the most intuitively obvious) can be selected. For optimum usefulness, once a preferred set of density ranges is selected for a specific situation, there is the ability to save it so that future analyses do not need to recreate it.[6]

The related requirement of slicing through the site and preserving the density of each sliced excavation unit can be solved with Release 11 (and higher) of AutoCAD and AME (Advanced Modelling Extension) Release1.0 (and higher) with its solid modelling capabilities which allow us to associate colour with a solid (here, the excavation unit). This colour is not simply reflected on the top, bottom and sides but throughout the core and so will withstand our slicing through the site to obtain a vertical (or horizontal) section of the excavation which exhibits the colour throughout the model of the site. While AutoCAD provides the ability to do exactly what I envisioned (Figure 4), as the site models grew in size (a natural condition as excavation continues over a number of years), with Release 12 of AutoCAD, the time required for slicing the site seemed to grow exponentially. Even moving the software to the Unix environment on a Silicon Graphics machine did not decrease the time appreciably, and it became clear that the algorithm used for slicing in AutoCAD Release 12 was the problem. One solution to this, we thought, was to cut the model of the site in advance and use this sliced model to 'colour' the site with whatever material we were studying. This would preclude slicing it each time. We discovered, unfortunately, that this approach could not work because of the way AutoCAD Release 12 actually treats the drawing when it cuts an object. In short, the cut object (the excavation unit in this instance) is placed on the current layer and thus loses the critical identifying information (layer name) that allows the software to associate density information with a specific excavation unit. With the cutting time prohibitive (after three seasons of excavation units in excess of 24 hours on a 486/50 MHz machine with 20 MB RAM), we began searching for alternatives.

One alternative may be to use other software to cut the model. But there is an alternative within AutoCAD - its ability to define a 'clipping plane'. This is a significantly faster approach but presents a more impressionistic view of the section in which individual excavation units are not as clearly defined. An example of this shows the section but does not allow the look at the sections that the actual slicing

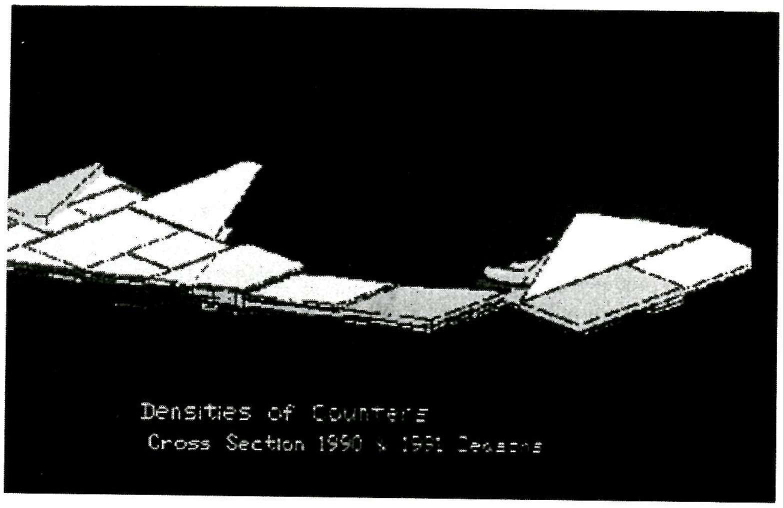


Figure 4. An example of the slice after densities of the objects (in this case, counters) are displayed in the elevation units. White indicates excavation units without any counters, while the light to darker blue indicates increasing densities (see Plate X). Once created, these 'slices' can be stored as AutoCAD slides for ready access and study. As can be seen, the inclusion of hut walls makes the resulting illustration very understandable. (See also Plate XVI).

approach does (Figure 5). Nonetheless, with this approach, 'named views' can be created, stored and made available whenever new material is used to 'colour' the site.

The latest release of AutoCAD, Release 13, appears to have solved the problems presented above. The algorithm for slicing through solids has been entirely rewritten and, on a 486/66 MHZ machine with 32 MB RAM, takes 5 minutes to slice through the site. The time for this slicing under Release 13 is not dependent on the overall size of the drawing but simply on the number of units through which the slice is made. This is a radical change from the prior release where the total number of solids in the drawing, regardless of the number actually sliced, affected the time.

In addition, when an excavation unit or solid is cut through it is no longer moved to the current layer. This means that the layer names remain associated with each excavation unit and standard cut versions of the site can be prepared against which various sets of densities can be plotted. Although the vastly improved speed of the slicing routine makes this a less necessary alternative, it will facilitate the display of densities of many sets of data against a common section.

Although it could not be reported at the conference, the original plan, to develop software which could easily and quickly be used to search the site for significant patterns of recovered material and to model various hypotheses of site use, is a definite success thanks to the most recent release of AutoCAD. What has this software made possible today? We can create and display, in both three or two dimensions, models of the site which include:

excavation units, coded to allow display of recovered material density information,

extant architecture (Figure 6), and,

icons which represent special finds located precisely where the finds were recovered on the site.

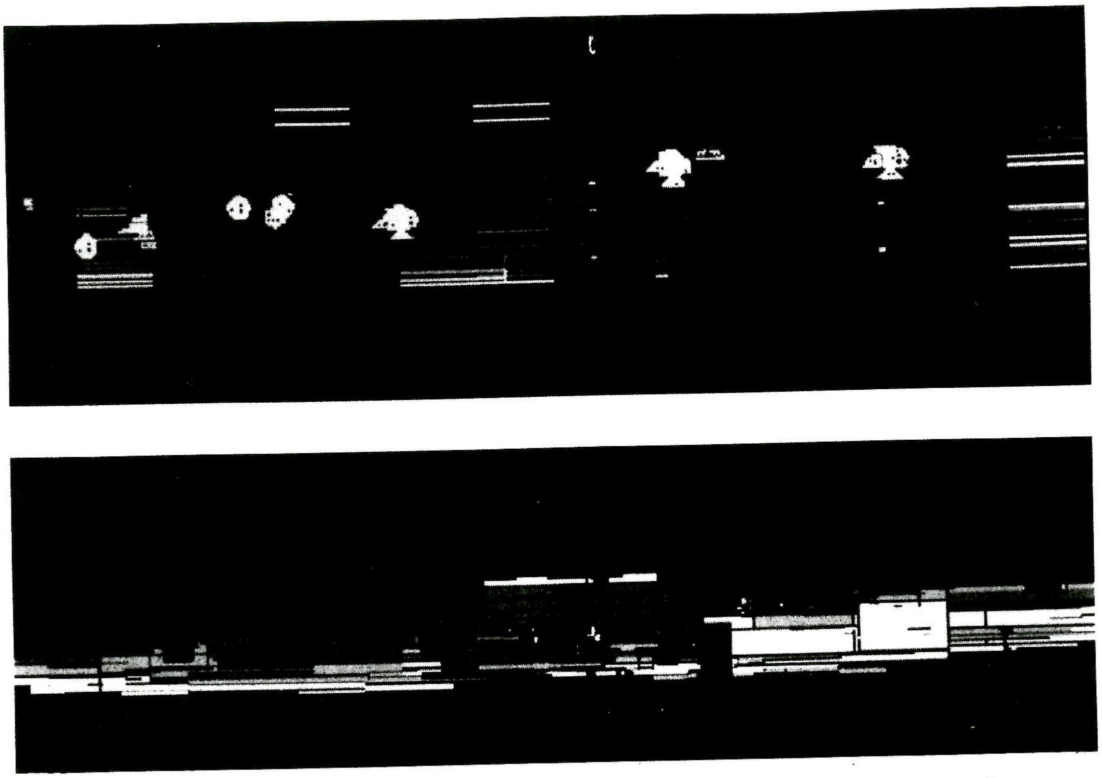


Figure 5. Two examples of a defined ‘clipping plane’. In the first (top), the units are unshaded, the outlines only carry the colour of the density; here the icons of pots stand out clearly. Once the units are shaded (bottom) it is far easier to see the differing densities, although the icons are no longer visible. Unlike the sliced example in Figure 4, however, it is more difficult to know exactly where this section is located in the site. (See also Plate XVI).

The capabilities we have built into this tool allow us model the display of data by determining the selection of materials, the selection of archaeological units, and the optimum distribution of ranges which display the most meaningful spatial distribution patterns. The software also allows the choice of colour hues most appropriate to the immediate hardware environment.

Other options we have available allow us to join multiple drawings for analysis to select units for analysis based on a variety of features (stratum, year of excavation, association with user-defined functions), to scale the z-axis (so that we can magnify and better understand the thin sections in which we often excavate) and, as mentioned above, to slice the site so that we can generate vertical and horizontal sections of the site, showing cross-sections of architectural features and density patterns at points we chose. In addition, standard AutoCAD features allow us to choose the viewpoint from which to see the site, as if walking around the site, and to zoom in on specific areas as though using a telescope.

CONCLUSION

Archaeology is not the only discipline to suffer the problem of data volume. Excavations may uncover hundreds of thousands of ceramic sherds, in addition to well-preserved pots, sculpture, simple items of

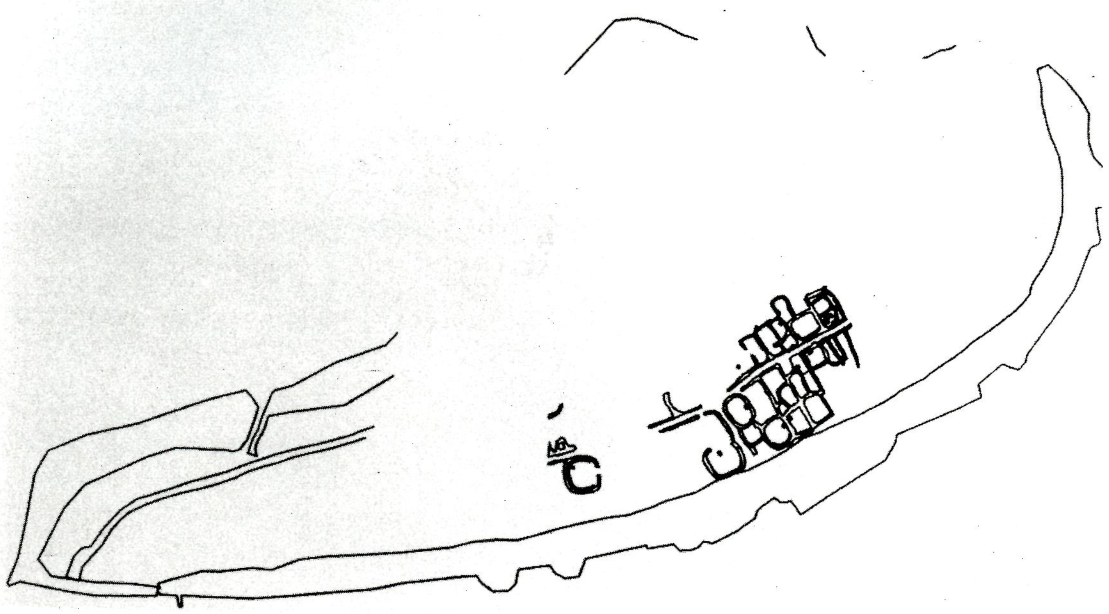


Figure 6. Two-dimensional view of the site showing the extent of the city wall and the hut walls excavated to date. This is a simple but excellent use of native AutoCAD capabilities assisted by the capture of data with an electronic theodolite and data recorder.

everyday use, organic remains and architectural features. There is the danger that the ceramic fragments, themselves assigned to categories of (apparently) greater and lesser importance, may be selectively recorded. Limitations of time and resources routinely preclude assessing all data and we must select, as best we can, what to record. The tool described here offers a way to organise, access and analyze large volumes of data across a site, providing an opportunity to include more information in the interpretation and assessment of our excavations.

First and foremost, this software provides an ability to plot, in three-dimensional space, densities of material recovered when individual find spots cannot be recorded. We have added, as well, the easy development of two-dimensional site plans and the ready availability of three-dimensional architectural features. Finally, the ability to reconstruct the buildings provides an additional useful tool for comprehending the extent and character of the site.

The heart of this, three-dimensional plotting of recovered material densities, is a new tool for archaeology. The software uses colour to impart as detailed a gradation of information as required and, combined with a three-dimensional model of the architectural features, provides a new way to look at archaeological information. With the ability to display patterns of site use across space and time, we are able to ask new, refined questions of the data. We then can prepare new models by selecting different materials, strata and functions of architectural features. The patterns presented may suggest new interpretations of materials and architectural features, which in turn may force us into another iteration of the process, which may yield still more insights.

Archaeology has long used tables of data and statistical tools such as multiple regression, clustering and scatter plots to study the distribution of material. The tool described allows us, as West wrote, to "look at the whole of a system with each individual part seen in relation to all other parts." (West, 1991, p. 232). Archaeology has traditionally made use of technology developed in other disciplines. We are still doing that, in a sense, by using an existing CAD package (AutoCAD) and developing a related system for our purpose. The solution is uniquely archaeological, but may be of use to other disciplines.

We as archaeologists, by the nature of our discipline, destroy the record we are trying to recover and interpret. We take the three-dimensional record of the hidden site and turn it into a two-dimensional linear record. What is described here is a one way to 'rebuild' the site with all the recovered material and the architectural features and to provide, in essence, a three-dimensional record. It is one answer to Tufte's question "How are we to represent the rich visual world of experience and measurement on mere flatland?" (Tufte, 1990, p. 9).

Susan S. Lukesh. Hofstra University, Hempstead, N.Y. 11550.

ACKNOWLEDGEMENTS

While the authorship of this article and the design of the software are my responsibility, the project could not have progressed without the programming skills of Kendall Chenoweth who is responsible for putting into concrete form what I could only imagine. All computing development was overseen by the then Chair of the Computer Science Department at Hofstra University, Dr. John Impagliazzo. The University has been most generous in providing the computing environment in which to build this software. I am grateful, as well, to Harrison Eiteljorg, II (Center for the Study of Architecture) without whose support and encouragement this project could not have progressed. The site on which this work is based is I Faraglioni, Ustica, Sicily (Holloway and Lukesh, 1991 and 1992)

NOTES

1. Another approach is offered in a paper which the authors shared with me (Main *et al.*, 1995). Their approach uses a method of plotting random dots three-dimensionally to display density, a method which obviates the requirement for colour. It is not clear, to this author at least, how sections of the site are prepared so that densities can be displayed across the face of a vertical section.
2. Total material recording has, however, allowed us to discover the absence of certain materials or decoration patterns, for example, across the site. And, total material recording has also permitted analysis using counts and percent of counts by unit, stratum, and other logical groupings of the excavation units. From this we have determined, for example, that certain decoration patterns are found much more frequently (based on percentage of materials) in one part of the excavation than another (Holloway *et al.*, 1991). Nonetheless, analysis of the sites based on densities of material recovered has eluded us up to now and it is this issue specifically which the software described addresses.
3. While certain CAD products allow the collection of database information, the long history of use of our databases - as well as the many other functions they support - made it undesirable to change all our programs to a new database simply to incorporate CAD. Instead, we chose to develop an interface. A user commencing the design of a data collection and analysis system might well investigate the database capabilities available within some CAD products.
4. AutoLisp was used rather than C because of its portability to other hardware environments. This same software runs on a Unix machine now with no modification to code.
5. Since different types of material are not mutually exclusive, we cannot use colour in one map to differentiate among, for example, coarse ceramics and fine ware, since both may well occur in the same unit.
6. Hardware environments change and with them the actual colours displayed. For this reason, we built in an option to adjust the choice of colours per range. These too can be saved and recalled. This is critical in order to assure that the best selection of varying hues (signifying differences in densities) continue to be available when changing hardware environments.

REFERENCES

Blankholm, H. P., 1991. *Intrasite Spatial Analysis in Theory and Practice*, Aarhus University Press, Aarhus.

Bower, J. and Kolb, M., 1990. "Recording ancient history", *CADENCE*, April 1990, pp. 61-63.

Colley, S.M., Todd, S.J.P., and Campling, N.R. 1988. "Three-dimensional computer graphics for archaeological data exploration: an example from Saxon Southampton", *Journal of Archaeological Science* 15, pp. 99-106.

Dibble, H.L. and McPherron, S.P., 1988. "On the computerization of archaeological projects", *Journal of Field Archaeology* 15, pp. 431-440.

Holloway, R.R., Joukowsky, M.S. and Lukesh, S.S., 1991. "La Muculufa, The Early Bronze Age sanctuary: The Early Bronze Age village (excavation 1982-83)", *Revue des Archeologiques et Historiens d'art de Louvain* 22, pp. 11-67.

Holloway, R.R. and Lukesh, S.S., 1991 "Ustica: report on the excavations of the Bronze Age site of Faraglioni, 1990", *Archaeologizer Anzeiger* for 1991, pp. 359-365.

Holloway, R.R. and Lukesh, S.S., 1992. "Ustica: report on the excavations of the Bronze Age site of Faraglioni, 1991", *Archaeologizer Anzeiger* for 1992, pp. 553-560.

Kotsakis, K., 1989. "RUNSECT: A computer program for the analysis of excavation data", *Journal of Field Archaeology* 16, pp. 369-375.

Kroll, E.M. and Price, T.D. (eds.), 1991. *The Interpretation of Archaeological Spatial Patterning*, Plenum Press.

Lock, G. and Fletcher, M., 1991. *Digging Numbers: Statistics for Archaeologists*, Oxford University Committee for Archaeology, Monograph No. 33, Oxford.

Lukesh, S.S., 1975a. "Excavation Recording at Buccino, South Italy", in *Computer Applications in Archaeology, 1975.* pp. 63-68, University of Birmingham, Birmingham.

Lukesh, S.S., 1975b. "The ceramics" in Holloway, R.R. *et al.*, "Buccino: The early Bronze Age village of Tufariello", *Journal of Field Archaeology*, 2(1/2), pp. 36-59.

Lukesh, S.S., 1982. "A databank for archaeological research" in *Computer Applications in Archaeology 1982*, pp. 33-55, University of Birmingham, Birmingham.

Lukesh, S.S., 1984. "A databank for excavation recording" in *Computer Applications in Archaeology 1984*, pp. 134-140, University of Birmingham, Birmingham.

Main, P.L., Spence, A.J. and Higgins, T., 1995. "Computer-aided design techniques for the graphical modelling of data from the prehistoric site of Runnymede, Berkshire" in *Computer Applications and Quantitative Methods in Archaeology 1994,* BAR International Series 600, pp. 235-243, Tempvs Reparatvm, Oxford.

Nelson, S.M., Plooster, M. and Ford, D.L., 1987. "An interactive computer graphic technique for identifying occupation surfaces in deep archaeological sites", *Journal of Field Archaeology* 14, pp. 353-358.

Plog, F. and Carlson, D., 1989. "Computer applications for the All American Pipeline Project", *Antiquity* 63, pp. 258-67.

Raymond, C., 1989. "Computer graphics help archaeologist 'reconstruct' a Micronesian ruin", *Chronicle of Higher Education* for May 2, 1989, A10-A12.

Richards, J.D. and Ryan, N.S., 1985. *Data Processing in Archaeology*, Cambridge University Press, Cambridge.

Ross, S., Moffett, J. and Henderson, J. (eds.) 1991. *Computing for Archaeologists*, Oxford University Committee for Archaeology, Monograph No. 18, 1991.

Schiffer, M.B. (ed.), 1982. "Archaeological applications of computer graphics" in *Advances in Archaeological Method and Theory 5*, pp. 179-216, Academic Press.

Tufte, E.R., 1983. *The Visual Display of Quantitative Information*, Graphics Press.

Tufte, E.R., 1990. *Envisioning Information*, Graphics Press.

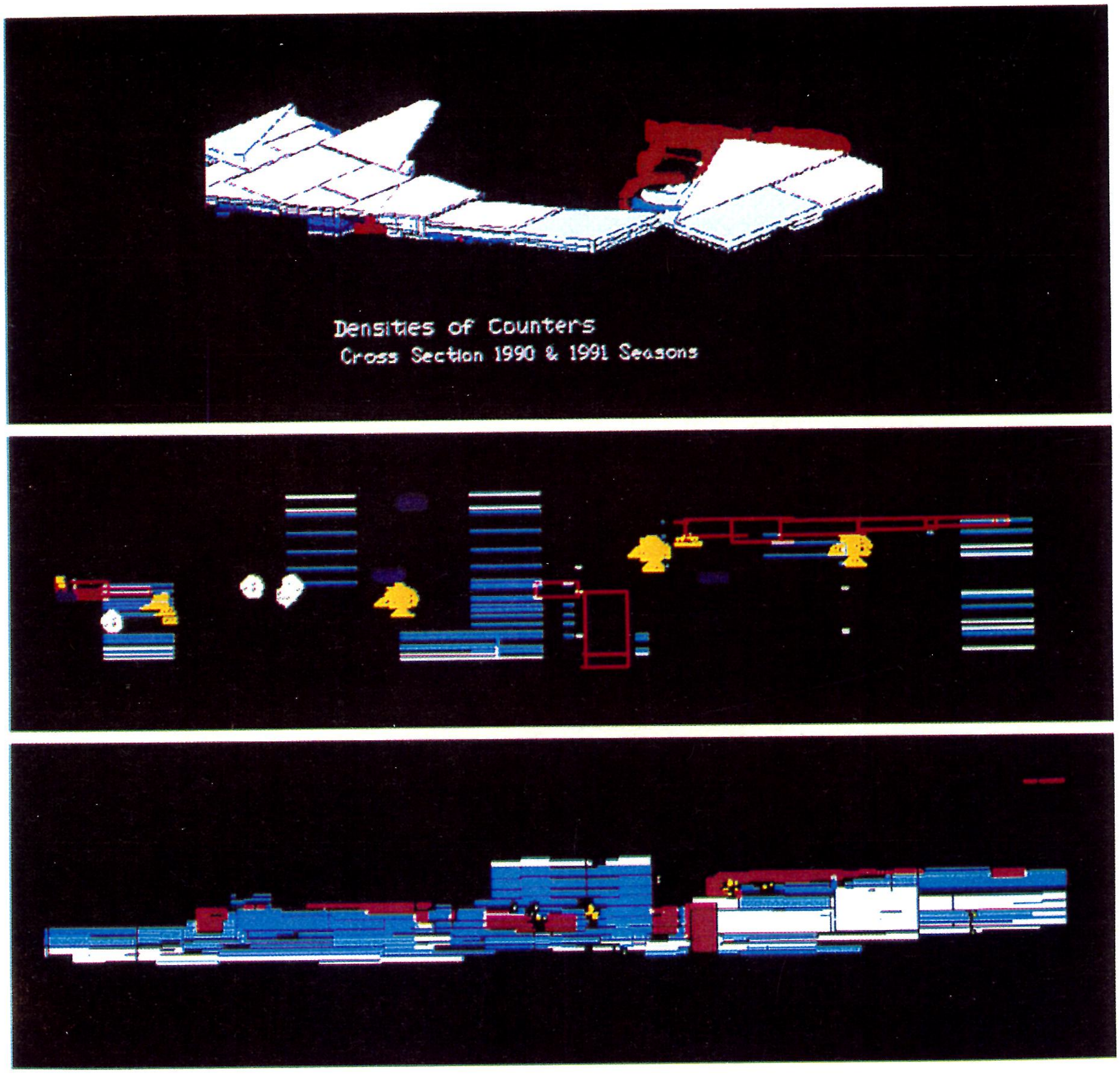
West, T.G., 1991. *In the Mind's Eye: Visual Thinkers, Gifted People with Learning Difficulties, Computer Images, and the Ironies of Creativity,* Prometheus Books.

Williams, W., 1989. "Exploring ancient civilizations: how to document an archaeological site with AutoCAD", *CADENCE* for September 1989, pp. 67-70.

AUTHOR BIOGRAPHY

Susan S. Lukesh is Associate Provost for Budget and Planning and Adjunct Associate Professor in the Anthropology Department at Hofstra University. She has worked in Southern Italy and Sicily since the early 1970s and, with her colleague Ross Holloway of Brown University, continues the excavations on Ustica, Sicily.

PLATE XVI



Densities of Counters
Cross Section 1990 & 1991 Seasons