Data visualization in archaeology

by P. Reilly

Archaeological field work produces vast amounts of three-dimensionally recorded data which can only be analysed using computers. Developments in data-visualization techniques are continually increasing the volume and complexity of data that can be studied meaningfully. In particular, three systems developed at the IBM United Kingdom Scientific Centre have been applied in a wide variety of archaeological situations: a graphics-database system called the Winchester Graphics System (WGS), IBM's IAX (Image Applications eXecutive) image processing system, and the WINchester SOlid Modelling system called WINSOM. It has been shown that these systems not only permit well-known problems to be answered in new and interesting ways but have freed archaeologists to explore previously undiscovered avenues of research. The techniques developed using these systems also have major implications for education and training.

To outsiders, archaeologists must seem to be a very odd breed of scientist; their garb tends to be outlandish, and they appear to have a very peculiar attitude toward their data. Consider the process of archaeological excavation—probably the most well-known aspect of archaeological enquiry. Excavations are carried out to examine the residues of past human activities, which may manifest themselves as the stains left by former posts or the foundations of ancient walls. It is an unfortunate irony that in order to reveal what lies below, the archaeological excavator must remove, and thereby destroy, what lies above. The anthropologist Sir Edmund Leach once observed that in an anthropological context, this would be rather like interviewing members from the society under study and then shooting them!

Not surprisingly, archaeologists are very self-conscious about this ethical dilemma. On the one hand, if they don't excavate they will be deprived of much of the data required to advance their discipline. On the other hand, they are exposed to the charge of vandalism. In order to come to terms with this problem, archaeologists in different countries have developed their own codes of practice. These codes try to ensure that each archaeological excavation has clearly-defined research objectives and that every archaeological formation uncovered is recorded in the finest detail.

The net result, of course, is an enormous mass of descriptive and locational information. To deal with an ever-growing glut of complex data, archaeologists have had to turn to machine-based data collection, storage, and processing. In recent years, some of the most significant advances have been made in the field of data visualization, where developments continue to expand the power and range of graphical modelling systems. These systems are used as passive presentational devices and, more recently, as active analytical tools.

Looking at excavated data

Paradoxically, although archaeological excavation can be characterized as an observational discipline, the archaeologist never actually *sees* the whole formation under examination. What is seen is only a series of veneers arbitrarily produced as the excavation proceeds. At any given time, part of the formation will have already been removed and part will remain out of view, buried beneath the exposed surface. It is necessary to integrate each of the separate perceptions of the formation to obtain a clear idea of the total picture. The computer provides a powerful analytical aid, in this respect, by allowing a virtual reconstruction of the features. The computer can be used at different levels of detail to reconstruct and analyse the shapes of the formations and the distributions of interesting categories of artefacts and ecofacts within them. In particular, the combination of a relational database management system linked to sophisticated graphics facilities provides an effective analytical aid. The Winchester Graphics System (WGS) developed at the IBM United Kingdom Scientific Centre is just such a tool.[1]

The data may be viewed from various positions.

In WGS, every record in the database contains a three-dimensional position coordinate, an orientation, and a potentially large set of additional attributes, including length, width, weight, and fabric. Records are retrieved from the database using standard relational database operations (e.g., JOIN, SELECT, UNION, DIFFERENCE, etc.). Any record can be logically associated to a wide range of coloured three-dimensionally definable markers and lines which can be displayed to enable the user to examine the spatial distributions of interest. Related distributions can be stored in separate picture segments and displayed or hidden in any combination. Some displays (e.g., the IBM 5080) also support smooth rotation, panning, and zooming of vector graphics. This ability to move about the different representations in real time enables the viewer to gain a much better impression of the component shapes. The data may be viewed from various positions and perspectives, many of which are unattainable in the real world.

The first archaeology project to demonstrate the potential benefits offered by the application of the WGS data exploration facilities was a collaborative project between the IBM United Kingdom Scientific Centre and the Faunal Remains Unit of the University of Southampton. The descriptions and three-dimensional positions of thousands of objects found in a rubbish pit uncovered at the mid-Saxon settlement of Hamwic were entered into WGS. By studying the shapes of layers and the distributions of selected objects in various combinations, the researchers were able to have a better understanding of the formation of the deposits. (See Figure 1.) This project also produced much interesting new information about the attitude of the Hamwic inhabitants toward rubbish and its disposal.[2,3] Probably the most exciting aspect of this work was the ability of the researcher to interact with the graphical models to enrich greatly the perception of the material under study. Often a WGS query would generate interesting new details in the graphics, and this would stimulate the researcher to refine the question being asked or lead to completely new avenues of enquiry. Furthermore, since all the data were immediately available in the system's database, questions and answers were produced very quickly.

Archaeologists working on the Bronze Age pits from Altheim in Bavaria, West Germany, also used a graphics-based approach. However, the software they adopted was intended for the purposes of crystallography, and the database facilities were rather crude in comparison to those of WGS. Nevertheless, these workers also appreciated the benefit of being able to reconstitute and re-examine their data in three dimensions.[4] Australian researchers have also employed the combination of a database and graphics to record and study a Bronze Age fortress, called El Qitar, in Northern Syria.[5]

More recent experiments using WGS have attempted to demonstrate that the simulation of properties such as transparency or opaqueness reveals interesting archaeological patterns in the data. Indeed, mimicking these properties was invaluable in the analysis of a Bronze Age midden from Potterne in Wiltshire, England. For example, by treating the representation of the Potterne excavations as being transparent and systematically highlighting only those contexts which contained material that could be dated, several distinct phases in the development of the rubbish dump were identified. By this means, it was possible to demonstrate that certain categories of chronologically diagnostic material were confined to clear vertical horizons. In contrast, common categories of objects, like bones, could not be dated directly, and their very ubiquity made it impossible to detect convincing structure in their distribution. However, an approach which proved very effective in dealing with this sort of problem was the application of what might be called an interactive animated sequence.

Slices through the midden excavation data were defined, and changes in the degree of bone fragmentation across the computed profiles were shown using color-coded shading. It was hoped that this would reveal trampled surfaces or deposits that had been rapidly built up. Since each profile was stored as an individual WGS picture segment, it proved possible to create a time-lapse-like animation by displaying and hiding each successive profile in rapid sequence.[6] However, since each *frame* in the *movie* was actually a separate vectorized picture, the viewer could continue to pan, zoom, or rotate the animated sequence to obtain optimum viewing aspects of specific features within the data.[7,8] This fluid interaction between the researcher and the data means that data exploration can proceed in an iterative fashion with very fast cycle times between original hypothesis, data examination, modified theory, new hypothesis, and so on.

Virtual excavations for training and evaluation studies

With sufficient recorded detail, it becomes practical to use a system like WGS to experiment with alternative excavation strategies. This is an invaluable way to determine whether it would be more efficient or cheaper to use another data collection method to obtain the same level of information. In other words, it is possible to *re-excavate* or *resurvey* the virtual archaeological formation within the constraints of the recorded detail.

Clearly, the ability to investigate the reliability of our recording and data processing procedures has major educational and training implications. In the case of the Saxon pit project mentioned previously, it was possible to simulate alternative excavation strategies. Thus, instead of excavating the whole pit and recording the precise three-dimensional position of each of more than 30 000 objects, different-sized samples (e.g., half-sections, quadrants, and columns) were re-excavated at this level of detail, through simulation, in order to determine whether similar information would be obtained by excavating only a portion of the total pit. The effects of adopting less precise recording criteria could also be simulated. Thus, instead of exploiting the exact three-dimensional position of each object, groups of objects could be aggregated by means of membership to a higher-level entity. Locations could be specified in terms of natural stratigraphic contexts (e.g., layers) or in terms of some arbitrarily-imposed system for partitioning space (e.g., spits or boxes). It is not hard to see the potential for using such systems in teaching archaeological techniques. The systems are particularly attractive in that they do not destroy the archaeological record. Students can gain experience without having to excavate features physically. They can gain insights into the costs and resources required for a successful excavation by contrasting the various computer scenarios of excavating the same features, using a range of different techniques.

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Looking at survey data

Modern-day archaeology is not confined to time-consuming and expensive excavations. It also includes other forms of field work such as aerial reconnaissance, geophysical prospecting, collecting artefacts from the plough-soil, and topographic surveys. These techniques also generate vast amounts of complex data.

Computer graphics are invaluable for enhancing very fine topographic details which are difficult or impossible to see on the ground. They are also indispensable in the analysis of remotely-sensed and geophysical data. It is not surprising, then, that it is fairly common these days to build computer models of earthwork surfaces on the basis of measured points. A computer-generated surface is, of course, much more flexible than the rigid physical topography that it represents. It has the distinct advantage of being amenable to enhancement using a variety of digital techniques. The simplest of these is to exaggerate readings so as to improve feature definition—that is, mounds are made higher and ditches are made deeper. However, one can then go further and create optimal lighting conditions for viewing the already enhanced features.[9,10] Clearly, the computer-generated model is a most useful tool for the analytical archaeologist.

Archaeologists involved in aerial reconnaissance know that some lighting conditions and ground cover are far more helpful than others when studying the morphology of particular types of earthworks. Existing modelling techniques enable archaeologists to reconnoiter their study areas under ideal conditions and not be affected by the vagaries of the weather or seasonal vegetation changes.

The same techniques are equally applicable to surveys that involve the measurement of properties which cannot be seen. Geophysical data, as collected for example during resistivity surveys, where probes are used to measure the resistance of buried soils, can be analysed in this way to reveal archaeological features. Going further, several types of data can be integrated. For instance, resistivity or surface-collected data could be mapped onto a topographic, or terrain, model to help establish whether there is any relationship between the surface details and the buried information.[10] Integrating different data types in one picture sometimes helps prevent archaeologists from falling into interpretive pitfalls. A comparison of Figure 2 with Figure 3 illustrates this point. These two figures show the same data, but from slightly different views. Figure 2 is a plan showing concentrations of modern pottery collected by fieldworkers in a parcel of land in Fairoak, Hampshire, England. These concentrations of material would normally be interpreted as *activity areas* or *sites*. However, when the local topography over which this material is distributed is also taken into account, our interpretation is radically altered. Instead of inferring the presence of the several sites suggested in Figure 2, we might now posit the presence of just one site at the crest of a slope, from which material has been carried down into nearby hollows to create spurious activity areas. Planners who have the responsibility of establishing adequate preservation priorities in their region will have a far better chance of realizing their objectives with such techniques.

Digital terrain modelling[11] and geographic information systems[12,13] have been identified as methods of great potential in both archaeological landscape studies and excavation analyses. The terrain-modelling approach is equally valid at the micro-topographical level and has proved useful in the examination and presentation of the three-dimensional soil silhouettes left by bodies buried in the royal Anglo-Saxon cemetery at Sutton Hoo, Suffolk.[14,15] (See Figure 4.)

Virtual surveys for training and evaluation studies

As in the case of excavation, simulation studies may permit archaeologists to assess the reliability of their recording methodologies for field surveys. For example, Fletcher and Spicer[16] have created a theoretical earthwork site in the form of a geometrically-defined surface whose topography is known exactly in an attempt to establish surveying standards. Using this standard earthwork, they simulate various surveying methods (e.g., by taking measurements on regular grids of points, at variable intervals along linear transacts, and from randomly distributed locations) to assess how closely the terrain model derived from their samples resembles the original surface.

An analogous idea has been developed in relation to the study of geophysical measurements, such as the magnetic and electrical properties of buried features.[17] Geophysical surveys are often plagued by spurious readings or noise through which it is difficult to discern details in the data. This noise can be filtered out using image-processing techniques, but as each filter is designed to operate on specific types of signals, it is necessary to determine which techniques are most suitable for removing characteristic noise problems. To this end, Scollar synthesized an ideal set of geophysical reading from an imaginary Roman fort, which was represented as a terrain model. He then deliberately added different types of noise and proceeded to experiment with various filtering procedures to reveal the pure data again.[18] In the future, we might expect artificial intelligence techniques to help less experienced practitioners choose the appropriate procedure to collect and process real survey data.

The combining of collected data and interpretations in one picture is a new development which might help investigators convey their interpretations of abstract data sets to nonspecialists. This is an idea being explored in the Mathrafal project,[19] where extensive earthworks associated with the medieval Welsh princes of Powys have attracted the attention of medieval historians and archaeologists.

Some 15 000 surface measurements were taken at Mathrafal using electronic distance measurers

Figure 1 Typical WGS output from Hamwic pit project. The distribution of burnt daub (orange) and bones (green dots) in one layer is shown against the soil profile (green wires) normally recorded by archaeologists.

Figure 2 Plan view of modern pottery distribution in Fairoak. The plan appears to show two or three focal points of activity. These activity areas are shown as high readings (i.e., red end of spectrum).

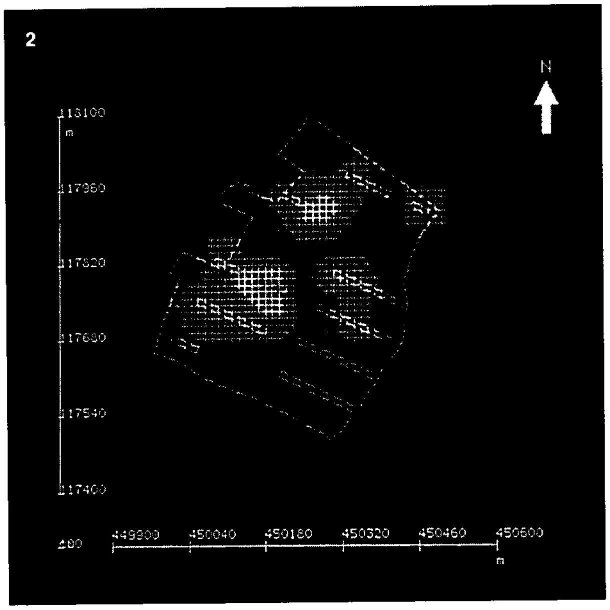


Figure 3 Oblique view of modern pottery distribution in Fairoak. With the exception of the one activity area on the crest of a slope, all the other so-called sites lie in a hollow. A trail of material runs down the slope into the hollow, suggesting that the concentrations there might be due to down-slope migration.

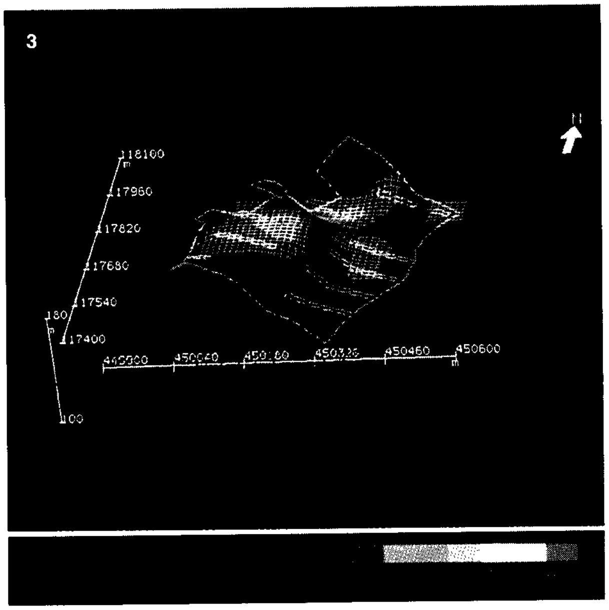


Figure 4 Sandman. The surface of the silhouette is modelled here using shaded patches.

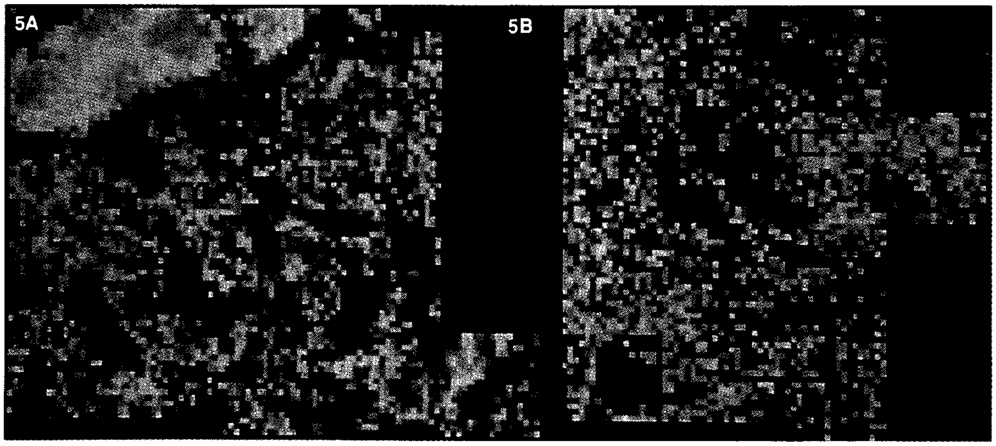


Figure 5 Raw geophysical data displayed as IAX images: (A) resistivity data; (B) magnetometer data

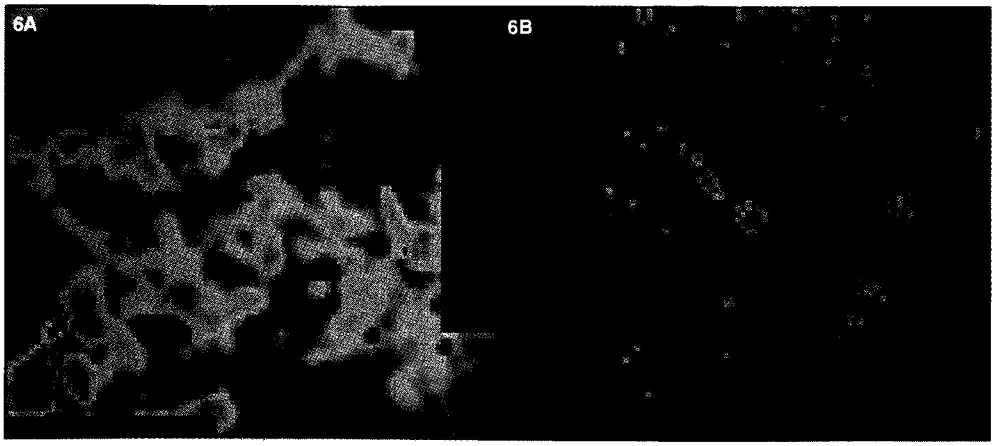
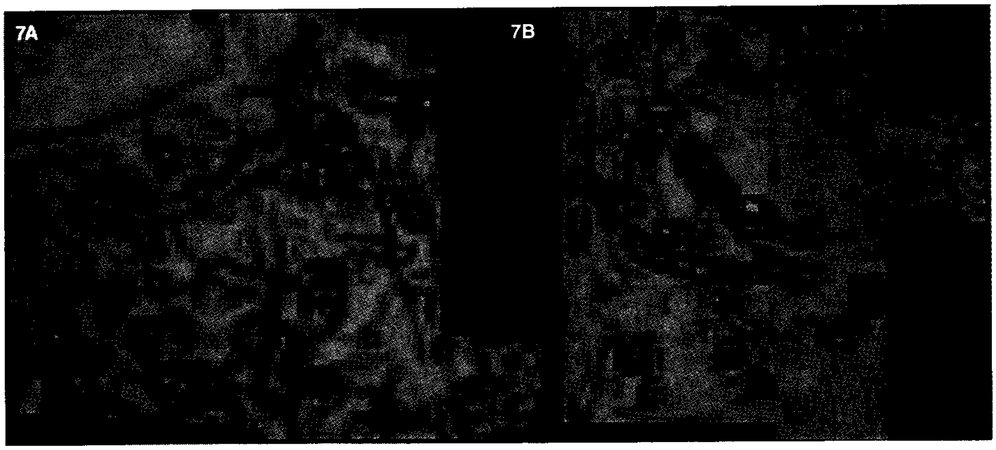


Figure 6 Geophysical data after median filtering to remove noise: (A) resistivity data; (B) magnetometer data

Figure 7 Geophysical data after edge detectors have been applied: (A) resistivity data; (B) magnetometer data



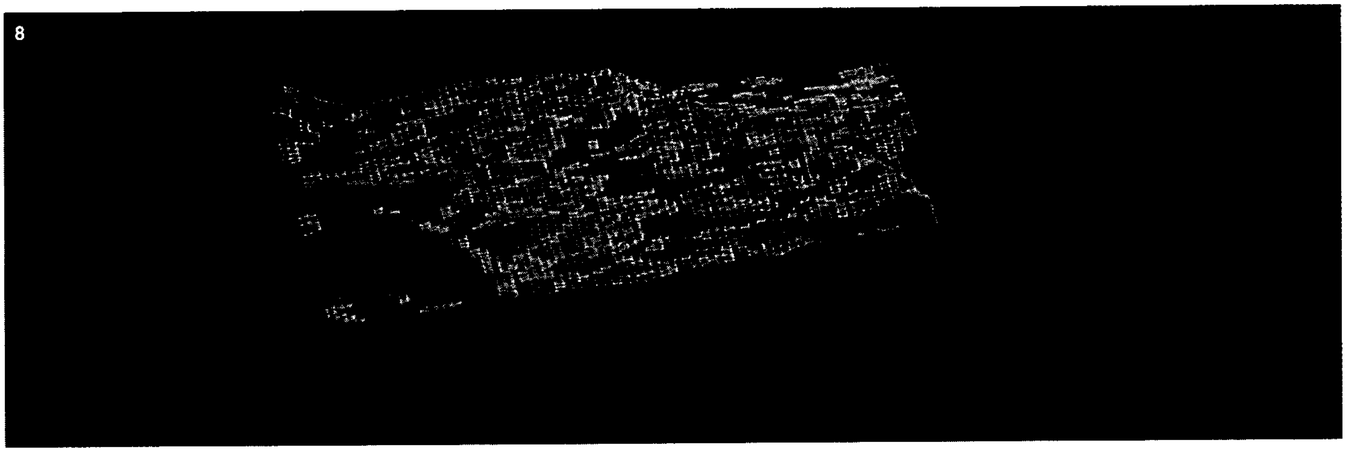


Figure 8 Resistivity data mapped onto terrain model of part of site. The edges of a large rectangular platform of ground, thought to be the remnants of a vegetable garden that existed on the site until comparatively modern times, were demarcated by strong linear anomalies in the resistivity data. These are the red contours near the ditch on the right-hand side of the picture.

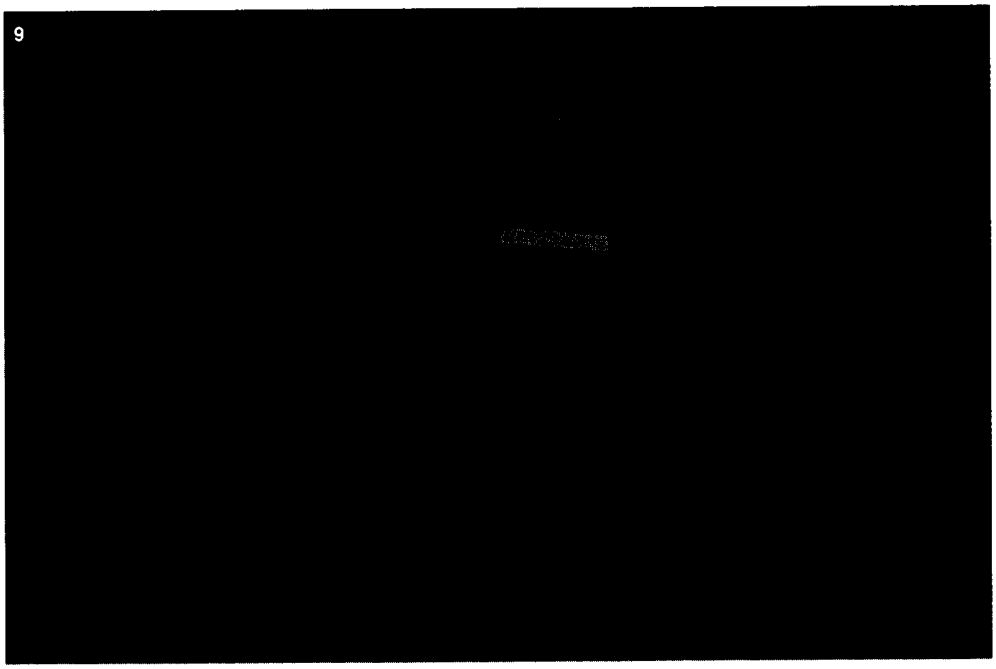


Figure 9 Mathrafal reconstruction. Several reconstructed details have been placed on the modelled surface of part of the Mathrafal site.

Figure 10 The Anglo-Saxon minster of Winchester. This wireframe representation of the solid model was produced using FastDraw. This form of representation is very easy and quick to generate, which means that the model construction phase is shortened considerably.

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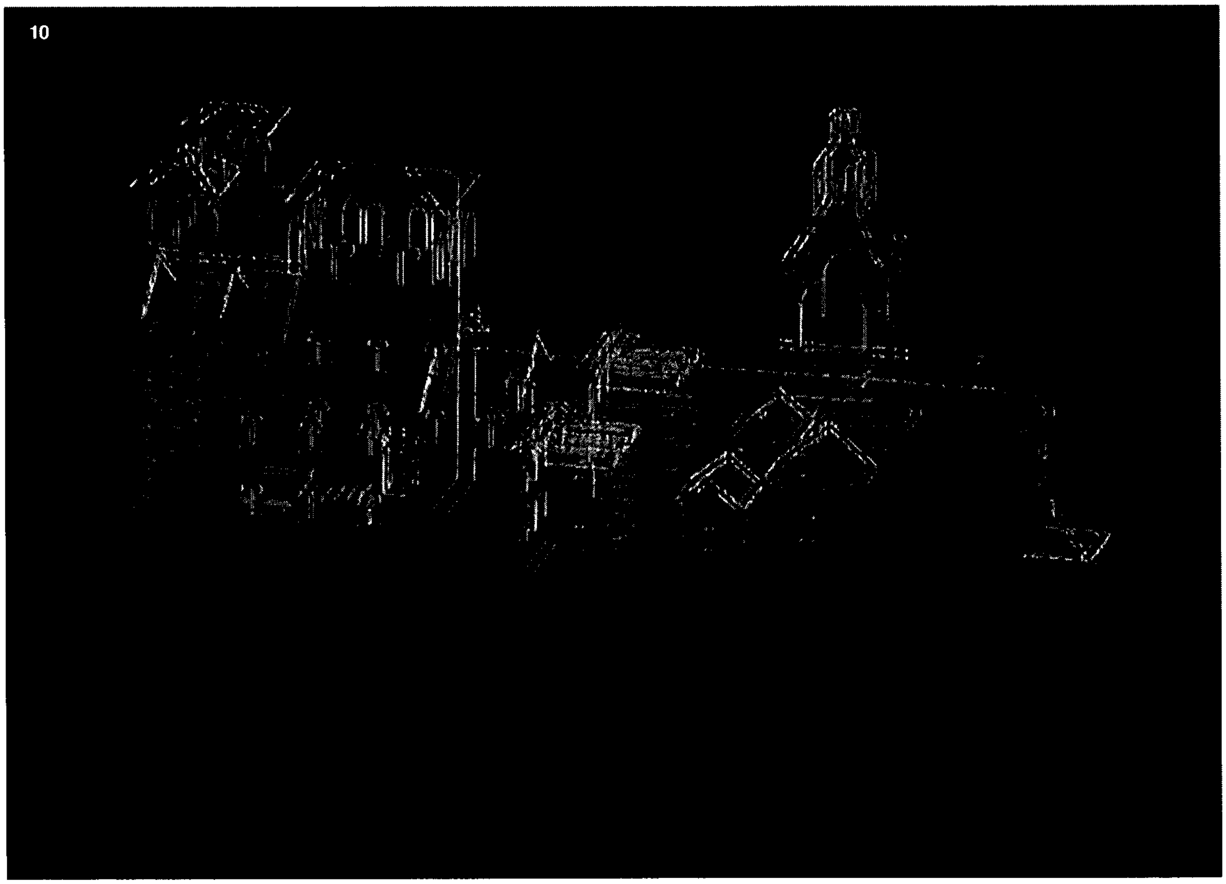

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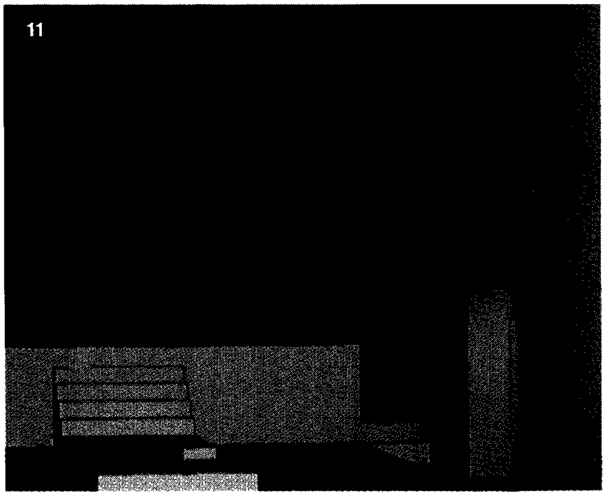

Figure 11 Interior view of the reconstructed Anglo-Saxon minster

Figure 12 Wall building

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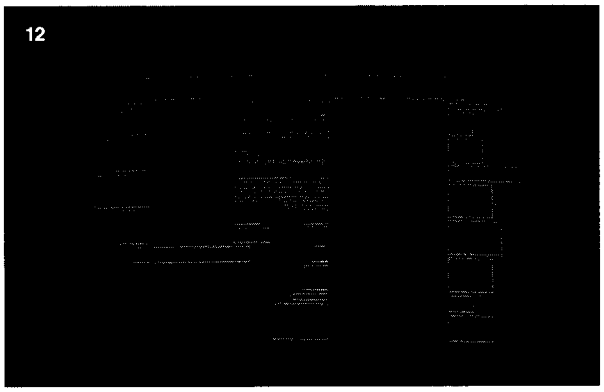

(EDMs), and a similar number of resistivity and magnetometer samples were also collected using suitable probes and data loggers. The EDM readings formed the basis of a WGS wire-framed face model of the Mathrafal earthworks, which have been examined using the real-time interaction facilities on an IBM 5080. Another version was built using the IBM UK Scientific Centre's WINchester SOlid Modelling system, WINSOM, which is based on principles of constructive solid geometry (CSG). While it is not yet possible to dynamically interact with a fully rendered WINSOM object, the CSG version of the Mathrafal terrain has some important advantages over its face-model counterpart. For example, the ray-casting facilities in WINSOM enable the researcher to model accurately those helpful highlights and shadows that are produced when the sun is in a particular position. In the past, when it has not been convenient to rely on providential natural lighting, archaeologists have actually resorted to shining banks of strong lights across an earthwork site at night in order to reveal interesting minor topographic features which might otherwise escape attention.

One can indicate the range and distribution of values of other data (e.g., magnetometer data) as shaded contours on both face and solid models. In this instance, the data obtained from the two Mathrafal geophysical surveys had already been processed using IBM's IAX system. (See Figures 5, 6, and 7.) This processing was necessary to remove a certain amount of noise and to enhance several intriguing features or anomalies.

This exercise brought to light, among other things, indications of what have been interpreted as a timber hall, a palisade, and two kilns. By assigning the enhanced geophysical readings suitable colour codes on the surface of the terrain models, it became possible to determine visually whether or not the features suggested in the different data sets tended to complement or contradict one another (Figure 8). For example, the edges of a large rectangular platform of ground, thought to be the remnants of a vegetable garden that existed on the site until comparatively modern times, were demarcated by strong linear anomalies in the resistivity data. These features are interpreted as former walls. In other cases, partial correlations between anomalies in the different data sets enabled problematic gaps to be filled and helped to resolve some problems of interpretation. A long linear anomaly traverses the breadth of the resistivity survey area, for instance. When the resistivity data was marked on the terrain model, it was realized that this anomaly marked the continuation of a path that could be traced along only a short section of its length by following a slight sunken linear feature on the surface. Sometimes, however, features detected in one set of data (e.g., the anomaly interpreted as the remains of a burnt-down palisade in the magnetometer survey) could not be correlated with any surface features.

After arriving at an interpretation, it is sometimes useful to encapsulate these ideas in a reconstruction, because such an exercise often reveals any shortcomings in a model. The modelling process tends to concentrate attention on those specific details that have been defined by the modeller. By using WINSOM, however, it is now also possible to fully integrate reconstructed details with the pre-existing model which is based on recorded data. This one operation allows the researcher to demonstrate in strong visual terms how the interpretation relates directly to the collected data. In the process of highlighting those well-understood aspects of the data, the analyst is confronted again with the problem of accounting for all those unexplained features which remain as formless humps and hollows or discolored patches on the surface of the terrain model (Figure 9). In other words, it stimulates the researcher to look for further information. This may involve the application of extra analytical experiments on the existing data, or it may require the formulation of a completely new research design to answer the outstanding questions.

Reconstructing and exhibiting archaeological material

Graphics have a major role in the area of reconstruction. It is not always feasible to generate the resources to build reconstructions on the scale of Knossos on Crete, or Jorvik in York. Nevertheless, it is often important to build such reconstructions in order to appreciate how the original architects manipulated space to create an impact with the buildings. Solid-modelling systems offer an important alternative method for exploring such questions. CSG techniques were first applied in an archaeological context by John Woodwark in a reconstruction of the temple precinct of Roman Bath and the Roman military bathhouse at Caerleon.[20,21] A little later, WINSOM was employed to build a reconstruction of the Saxon minster of Winchester which was demolished in 1092 to make way for the present cathedral.[2] (See Figures 10 and 11.) The Winchester project was more ambitious than its predecessors and involved the production of a two-minute animated tour of the

Saxon minster. This animated sequence, which was shown at the British Museum's 1987 *Archaeology in Britain* exhibition, required the generation of hundreds of views taken at increments along a route around and through the model.

The process of model building is helpful for expressing and conveying ideas about the original form of archaeological structures.

The process of model building is helpful for expressing and conveying ideas about the original form of archaeological structures. CSG reconstructions require the modeller to define explicitly each and every element in the model and their spatial relationship to one another. The definition of the model forces the researchers to reconsider the original data, which can focus attention on problem areas and gaps, thus causing them to observe, or record differently, certain types of evidence in a future investigation.

Solid modelling is increasing in importance in the reconstruction of artefacts. The modelling of surface properties is an obvious application area. One may contrast the aesthetic result of a decision to keep the patina on a bronze object in favor of exposing the bare metal, for example. Pieces of a broken object can be visualized on a computer before attempting any restoration. Again, the layout of showcases and exhibition lighting can be modelled before any work starts in the galleries. All these methods have the distinct advantage that the model produced can be easily repaired or modified if something is found wanting in the reconstruction.

It is not necessary to confine our attention purely to form. Processes may also be modelled. It is possible to distort shapes, for example. Given an object of known form, one can simulate the types of distortions required to produce another shape, thereby helping us understand what may have happened to a particular object.

Future trends: Hyperdocuments, artificial intelligence, and modelling

Undoubtedly, artificial intelligence will have a role to play in archaeological modelling and reconstruction.[22] Our understanding of building techniques is just one application area. A pilot study, at the IBM UK Scientific Centre, is attempting to develop a rule-based system which will take a stock of stones and decide where best to lay them in order to build a wall. The rules are written in the Prolog programming language, and the Graphical Data Display Manager (GDDM) is used to display the results.[23] (See Figure 12.) With such detailed computer models, we can hope to examine building techniques and—much more speculatively—help to restore ruined structures using the available debris. Others might wish to simulate the types of forces necessary to knock some buildings down. Such modelling would be particularly useful for testing hypotheses for explaining why certain structures collapsed. By making our assumptions explicit in the modelling systems, we may also be in a better position to critically study our own reasoning processes and thereby isolate and make good any faults thus revealed.

Although computer-aided techniques for data visualization and presentation are advancing rapidly, existing publishing practices severely hamper their wider application in information exchange. It is conceivable to envisage archaeological accounts being produced on mass-storage mediums such as videodisks. Some progress along these lines has already been made.[24,25] However, instead of referring to figures, the commentator in such a videodisk might employ sets of database operations and view parameters to demonstrate a particular phenomenon. This, of course, implies that the full data set should be made available together with a data management system, graphics facilities, and perhaps also a suitable statistical package, in a self-contained environment. Animated sequences, still photographs, and audio material might also be integrated into the product. A useful product would require a well-thought-out and standardized system of cross-referencing, which would allow the user to identify the various types of information associated with a particular fact, interpretation, or statement.

We should look forward to the everyday use of hyperdocuments of the kind just outlined. In the meantime, computer database systems, high-level graphics systems, and artificial intelligence techniques are already beginning to allow archaeologists to ask new types of questions and to look at their data from positions which were previously impossible.

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