A New Technique for Recording Archaeological Excavations: Research Progress Report

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Abstract

Currently, 3D modelling is used in archaeology for modelling terrains and artefacts, and for virtual reconstructions of buildings and complexes. It is the opinion of the author that the most significant impact of 3D modelling on archaeology is yet to be realised and will be in a different application, that of modelling excavations. This paper is a preliminary report on part of a doctoral research project on the use of high resolution 3D modelling as a means of recording excavations as a quicker, more accurate alternative to drawing.

Key words: 3D, modelling, virtual reality, VR, excavations

1. Introduction

Three-dimensional modelling using computers is not new to archaeology. From early work using terrestrial photogrammetry techniques and Computer Aided Design (CAD) software for recording old buildings, 3D modelling in archaeology has advanced to be used in startling ways. Digital Elevation Models (DEM's) are commonly used to visualise archaeological sites or landscapes. Geographical Information Systems (GIS) are being used for cost surface and viewshed analyses of 3D landscapes. Many examples exist of virtual reconstructions of ancient buildings or ritual complexes created in 3D graphics software (e.g. Forte and Siliotti 1997). The latest Virtual Reality (VR) display environments allow the viewer to immerse themselves in 3D archaeological models (Vote et al., this volume). Somewhat different from the above, another current application is the precise modelling of artefacts in 3D, allowing the creation of virtual collections or museums on the Internet (e.g. Jeffrey Clark, CAA2000 presentation).

The author would argue, however, that the greatest impact of 3D modelling on archaeology has yet to be realised. When 3D modelling becomes the standard technique for recording excavations it will quite literally change the way excavating archaeologists go about their work.

In discussing the use of VR in archaeology, Gillings (in Barcelo et al. 2000:59) states:

> "… the notion of VR models as comprising little more than ingenious "end-products" needs to be challenged. Techniques must be embedded at all levels of archaeological investigation, serving not only as sophisticated visual summaries, but also as primary recording methods, heuristic devices, and display and communication mechanisms."

And,

> "… (there is) the need to develop and adapt a number of routine field and laboratory based methodologies that can be integrated into current archaeological practise."

While we might challenge Gillings by pointing to examples which are much more than high-tech "illustrations", we would be missing his main point, that of the need for greater integration of VR, or 3D modelling, into general archaeological practise. However, we should not be surprised to find ourselves at this juncture when we reflect on how the technology has evolved.

In a market lead by 3D display (especially computer gaming) it is the aspect of display, currently so accessible and widespread, that has been the first to be exploited by archaeologists. It is only now, in the subsequent developmental stages of the general field of 3D imaging, that acquisition devices for 3D data are starting to become widely available, and at which point we can begin to consider their potential impact and their integration into archaeology. This research, then, considers these 3D acquisition devices and how we might use 3D modelling as a standard tool in an integrated archaeological recording system. The author's proposal is that archaeologists should use 3D modelling as a means of making the primary record of an excavation in place of the traditional techniques of drawing and photography. Note that the emphasis here is on high resolution, high accuracy, data-dense models of small excavated areas, complementary to, and for integration with, DEM's and GIS models of entire sites or landscapes.

2. Drawing, photography and 3D modelling

Drawing, as a means of recording an area that has been excavated, can be criticised on a number of levels. Photography also has its disadvantages. Below, we briefly discuss the shortcomings of drawing and photography, and the relative merits of 3D modelling.

2.1. Subjectivity

Drawing is subjective and interpretive. When drawing, consciously or not, we choose what data we feel is relevant and effectively ignore the rest. Yet the excavating archaeologist has the responsibility to record for posterity all the evidence which he/she is in the process of dismantling. To choose to illustrate some aspects and not others are to ignore the possible needs of future archaeologists for the sake of expediency. In an effort to record the missing data we supplement the drawings by photography, which may be fast and simple, but which has its own limitations, *viz* perspective.

The use of high resolution, data-dense modelling effectively combines the best features of drawing and photography; the spatial organisation (conveying the benefits of orthogonal drawings, but with the advantage of being able to choose from an infinite number of projections) and the high detail and colour information of photographs. It becomes possible, for example, to examine the colour information in a 3D model (given that it was colour referenced at the time of capture) and realise, in post-excavation, the ideas of James M. Newhard (CAA2000 presentation) on digital determination of Munsell colour.

2.2. Accuracy

The accuracy of drawings can, or perhaps, should always be viewed with scepticism because of the substantial potential for error. Typically, when drawing a feature we map the coordinates of a number of prominent points of the feature and join them by freehand drawing. The sources of error are many. The thickness of a pencil line on a 1:20 scale drawing (if we allow it to be 1mm) scales up to 2 cm. The freehand parts of a drawing may at least double the error. If we are drawing by quadrates, errors can creep in with each placement of the frame. Further error may creep in when the drawings are collectively re-mapped, re-scaled and inked.

The fact that many of the data points have been gathered by total station with millimetre precision should not delude us as to the accuracy of the entire drawing. We are, in effect, expending considerable effort in fusing data which are poorly compatible in terms of their accuracy.

At this point some may argue that these criticisms are not relevant since we all know the limitations of drawings and work within them. Yet this assumes we share some common, though unquantified, estimate of the reliability of the drawings. It is surely preferable to use a system of recording for our primary record of an excavation which offers greater accuracy with less effort. 3D modelling seems to offer just this.

2.3. Quality

The quality of drawings, essentially their effectiveness in communicating good information, is related to the levels of skill of the person making the drawing. Surely, a system of recording, which produces results of uniformly high quality, must be preferred.

2.4. Speed

Clearly, drawing is slow. In theory we have an obligation to record everything, but in practise we are constrained by limited time and human resources. A means of recording which is quicker, and achievable by a single person, enables us to record much more and/or in much less time. The latter is obviously of great benefit where field time is limited, especially in rescue archaeology, where time can be literally measured in terms of (usually large sums of) money.

Then there are those sites which are particularly difficult to record by drawing. From personal experience at Le Cheslé, an Iron Age fort in southern Belgium, the making of plans and elevations of the steeply-sloped fort wall have been incredibly difficult and slow, requiring constant re-levelling for each successive quadrate as work proceeded down the steep slope (itself, a difficult and slow process under the circumstances). The task would have been much simpler and faster if we had been able to "scan" a 3D acquisition device across the slope.

2.5. Visual interpretation

Archaeologists are practised and adept at interpreting the 3D world from 2D plans and elevations. Yet most will admit that a 3D model is easier to interpret and often gives them a "new perspective". Further, there are situations where plans and elevations are not so illuminating. In the above example of the wall of the Iron Age fort, the choice of point-of-view for the elevation was not simple since two-thirds of the way up the wall, the slope turned to the right as it wrapped around the bastion of the portal. The elevation thus shows much of the upper part of the wall in almost profile view. Another good example is the large group of Neolithic flint mines at Spienne in southern Belgium. A plan of the surface would simply show a large number of circular mine entrances. For any single mine we might make any number of different section views, no single view adequately describing the highly irregular shape of the main chamber. Obviously, viewing and interpreting these two examples would be much easier using a 3D model on computer, especially with the active stereo-viewing technology using Liquid Crystal Shutter (LCS) eye-wear which has been available for at least a decade.

2.6. Utility of data

While speed of recording is a great attraction of 3D modelling, an equally attractive feature is the subsequent utility of the recorded data.

When starting from a 3D model, the considerable time spent in post-excavation in reworking records and diagrams is dramatically reduced and the preparation of reports greatly facilitated. Having criticised drawing above, I will be the first to defend it when publishing on paper. A line drawing to illustrate a particular point, needs display only the data relevant to that point and not other distracting, obfuscating or irrelevant data. It is a relatively simple process to create such line drawings from 3D models. For example, to create a plan view from a 3D model, one selects a vertical viewpoint, changes to an orthogonal projection of the model, and processes the resultant image by thresholding, binarisation and gradient filter for a line-drawn plan of the excavation, in a matter of a couple of minutes.

Photographs, too, have a place in paper publications. Yet a 3D model will supply 2D images too, and with the flexibility of choosing your particular point of view. And further, by simply changing the projection of the model on the computer screen from perspective to orthogonal, an orthophoto has been created.

However, when considering the utility of the data of a 3D model, by far the greatest potential benefit is its ability to be integrated with other digital data. Once we have modelled, for example, the walls and floor of an excavated trench and geo-referenced a number of points, we can accurately place the high resolution, data-dense model into our less data-dense DEM site plan. Such a composite model can be used with GIS, itself, a much simpler and useful means of managing site records than folders of drawings and albums of photographs. Further, GIS allows effective integration of other forms of digitised data by its ability to link to multimedia databases, e.g. to Stratigraphic Unit datasheets, to finds databases

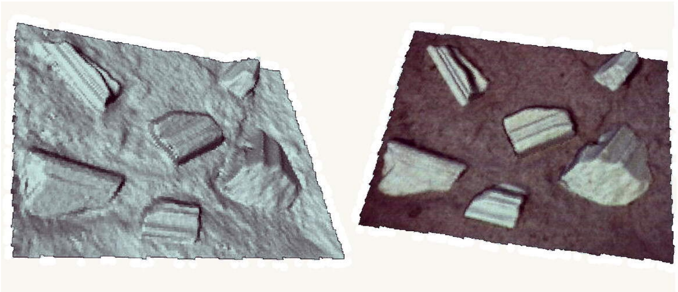

Figure 1: 3D models of a simulated surface of an excavation (approx 70 x 70cm) created by Eyetronics ShapeSnatcher; rendered surface model (left) and textured model in black and white (right).

which include weights and measures, pictures or 3D models of the finds, reports from analytical labs, etc, etc. In effect, by scanning excavations onto the computer at high resolution, we have perhaps the last step required to realise a "total recording system" for excavations.

3. Capturing 3D data

There is an ever-increasing number of devices on the market for recording in 3D. They use a variety of range-finding technologies including stereo-photogrammetry[1], active stereometry (e.g. laser line triangulation), passive stereometry (structured light techniques) and "time-of-flight" methods (e.g. sonar and scanned laser-distance-measuring devices). They have been designed with different applications in mind ranging from metrology and reverse-engineering to a simple means of incorporating complex 3D shapes into computer games. In considering which devices are suitable for our specific application the following five criteria have been applied:

1. *Speed.* Clearly, we want to be able to model the excavation in less time than it would take us to draw it.
2. *Accuracy.* We want a model which is at least as accurate as our drawing would be.
3. *Ease of Use.* A device and its software should be simple and intuitive to use, and not require us to employ a specialist for the recording work.
4. *Suitability for Use in the Field.* The device must be sufficiently portable and robust for use in the typical situations in which we conduct our excavations.
5. *Cost.* If our hope is that the majority of archaeologists will use such a device to record their excavations, they must obviously be able to affordable it.

On applying these criteria to the devices currently on the market we find that almost all, with the exception of stereo-photogrammetry, are quick and accurate. The majority are simple to use, though there are a few whose metrological applications sees them sold with quite complex (though comprehensive) software, making them less user-friendly.

It is their suitability for use in the field which eliminates most devices from consideration for our use. Many systems are large, designed to be fixed in place in the corner of a laboratory or workshop, and certainly not moved around an excavation site. There are also a number of small systems for use on the desktop but which have such small coverage or field of view (e.g. 20 cm) as to render them ineffective for our application.

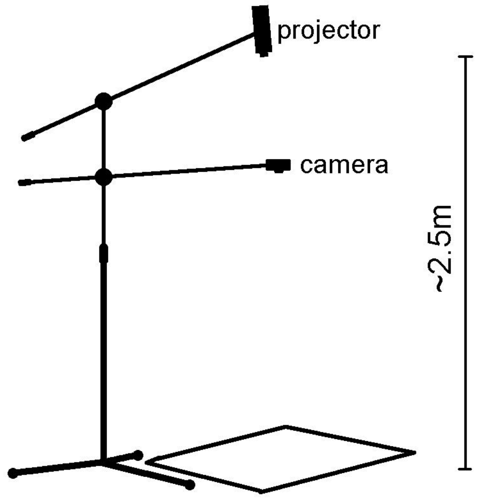

Figure 2: Proposed light-weight portable frame for mounting camera and "projector" for capturing images for 3D modelling by Eyetronics ShapeSnatcher.

4. 3D Acquisition devices

After applying four of the five criteria we are left with perhaps four systems, each deserving at least a little discussion, including that of the final criterion of cost.

4.1. ShapeSnatcher

ShapeSnatcher from Eyetronics is a system using the Structured Light principle. It comes as a program on a CD, packaged with a photographic slide and a small (approximately 20 cm high) calibration box. Other equipments required are a computer, a slide projector and a camera (video or digital still cameras are preferred). The slide is in fact a clear field carrying a very fine, black-lined grid which, using the projector, casts the grid pattern onto the subject. The subject is photographed and then, without moving camera or projector, a second photo is taken of the calibration box placed in front of the subject.

Starting with the calibration image, the software searches for the grid against the known background of the calibration box, and the relevant geometry of the camera-projector system is calculated and saved as a calibration file. The software then addresses the image of the subject, detecting the grid and, with reference to the calibration file, calculating the 3D positions of the grid nodes which become the apices of the resultant wireframe model. Texture data is taken from between the grid lines in the original image and interpolated for those parts obscured by the grid lines. The resulting 3D "patch" can be merged with other patches using an supplementary program, ShapeMatcher. Figure 1 shows a 3D model created by ShapeSnatcher, of some "mocked-up" archaeology (it was done in winter) of some pieces of early sixteenth century Flemish sculpture[2] placed in sand. It was created from three photographs by Eyetronics.

One of the advantages of ShapeSnatcher is that the components required for capturing the unprocessed images are simple and inexpensive. It would be easy to fabricate a more compact "light source and lens" substitute for the slide projector, which might even be battery-powered. Further, a frame such as that in figure 2, based on a microphone stand, not only makes the system portable and easy to relocate but, since it fixes the positions of the “projector” and camera, only one calibration image is required for each group of images taken with the one configuration of the system.

A further advantage of ShapeSnatcher is its versatility, by virtue of the fact that it is scalable. By using different projector lenses and/or grids of different coarseness (available from Eyetronics), the system can be used on a range of subject sizes, including small finds.

The greatest “advantage” or, perhaps, attraction of this system is its cost. At 200,000 Belgian Francs (very roughly US$4500) commercial price, this is by far the cheapest of the systems contemplated here (I understand that there is a special price for educational institutions).

The system is not without drawbacks though. ShapeSnatcher is slower than scanned laser line systems (see below), though faster than manual drawing. The process often requires user input to make refinements to the proposed model. Since it is essentially an optical system, sharp focus and depth of field are issues requiring constant attention when setting up and photographing. Also, since contrast between grid line and subject is fundamental to the detection process, working in anything but the most muted of ambient light gives problems. In practise, I suspect that the best resort is to take photographs at night. Another, perhaps lesser, disadvantage is that the modelling process is performed away from the excavation, so quick reference to the excavation to clarify details is not as simple as if we were creating a model on the spot, as would be the case using ModelMaker (see below).

In the final balance, ShapeSnatcher is quicker than drawing, it gives a good 3D model with colour texture and it is very affordable.

4.2. Metric 3D reconstruction

Eyetronics is also in the process of commercialising a system described by Pollefeys et al. (1998, 2000) whereby a number of photographs of a subject, taken without any record of position or camera parameters, can be used to create a 3D model.

In essence, the process begins by identifying a small number of homologous points in each photograph which are then used to calculate a first approximation of the projective framework (the spatial relationship between subject and points at which the photographs were taken). After a step of further refinement it is then possible to search for correspondences between the images for virtually every point in the images, giving a rigid spatial framework from which a 3D model can be computed using triangulation.

The strong point of this system is that one needs only a digital camera to gather the raw data in the field. Though not of great importance to our application, another interesting feature is that 3D models can be constructed of subjects which no longer exist, as long as there are a few extant photographs.

The drawbacks of this system are the potential for blind spots, the computing power required (I gather it is not possible on today’s average desktop computer), the modelling time, and the fact that the modelling is done (probably) off-site. This system is not yet commercially available so we cannot comment on its price.

While I have reservations as to the practicality of this system for modelling excavations, it would seem that this system has enormous potential for modelling entire sites. It would be very interesting indeed to see it applied to aerial photography.

Note: In the two techniques described above the texture map for the rendered model is derived from the original images which have been captured with a point source of illumination. This means that the texture map itself will display highlights and shadows. The following device collects colour information as it scans across the surface of the subject, giving a texture map of (approximately) uniform illumination. In some modelling situations such uniformity is clearly preferable.

4.3. ModelMaker

ModelMaker from 3D Scanners employs laser stripe triangulation as its range-finding technique. Unlike other similar systems which scan the laser stripe across the subject, ModelMaker requires the user to move the unit by hand across and around the subject. The laser unit is mounted on an articulated arm, each joint of which is fitted with sensors measuring flexion and rotation which allow the computer to track the position and orientation of the laser unit. The great advantage of this device is that, while the laser stripe is only some 25 mm or 45 mm wide (depending on the model used), a much larger field can be scanned, limited only by the length of the arm (which comes in a range of lengths). Another great advantage is that, having no fixed point of view, the device can capture data in what would be blind spots to other systems.

There are essentially two disadvantages of this system. As it is sold, it is not really appropriate to take into the field, however, I feel that it may be possible to adapt it to this end. The greater disadvantage is its cost; at approximately UK£ 58,000 it hardly falls within the budget of most archaeologists.

4.4. FastSCAN

FastSCAN from Polhemus also uses laser stripe triangulation for range-finding and, like ModelMaker, the scanning is done by the operator sweeping the unit across and around the subject by hand. The location and orientation of the FastSCAN handpiece is determined by a magnetic tracking system operating between the handset and a small, fixed-position tracking unit.

The advantages are that it seems that the system is portable and robust (I have not yet used it), and well-suited for use on archaeological sites. It claims to be very accurate and very fast, and should deal with the majority of blind spots that we might encounter. Its coverage is 3 m from the fixed position tracking unit, though there is an optional unit available with 10 m range. Multiple handsets can be used simultaneously with the one tracking unit.

The one failure of this system is that it does not capture colour information to enable texturing the model with real colour data. As such, I would not normally have considered it for discussion, except that I feel that it would be a device similar to this, but one which captures colour data, which would be ideal for the excavating archaeologist. An additional shortcoming of the device is that its magnetic tracking system may be affected by proximity to metals, compromising its utility in some situations. The price of this device is approximately US$40,000.

5. Conclusions

The author considers that a high resolution, data-dense 3D model is a better primary record of an excavation than traditional drawings supplemented by photography. The arguments are that 3D modelling is faster and more accurate, and that it includes more data, whose digital format confers greater utility and potential for integration with other data.

Of the many currently available systems, application of the five criteria of speed, accuracy, ease of use, suitability for the field and cost, finds most of them clearly inappropriate for our use. Of the few remaining systems ShapeSnatcher from Eyetronics is currently the best in the light of its "performance for cost". Another system, FastSCAN from Polhemus, while currently lacking colour detection, perhaps points to a future, "ideal" 3D scanning device.

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Documents available on the World Wide Web:

Eyetronics ShapeSnatcher: www.eyetronics.com

3D Scanners ModelMaker: www.3dscanners.com

Polhemus FastSCAN: www.polhemus.com/fastscan.htm

Notes

1 Stereo-photogrammetry will not be considered in this paper since, in general, it is too slow and the resultant model too simple for the application under consideration. Note that for modelling simple rectilinear features, such as foundations of buildings, whose morphology can be adequately described by a small number of 3D points, stereo-photogrammetry may well be a viable 3D modelling technique.

2 From the Cathedrale de SS. Michael et Gudula in Brussels, Belgium - excavated by Professor P. Bonenfant, Université Libre de Bruxelles.