

X-Bones: A New Approach to Recording Skeletons in 3D

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Abstract

Of the many types of find recorded by archaeologists, human skeletons are amongst the most difficult to record and visualize due to their innate complexity and homogeneous appearance. Questions of legitimate inference are also brought into play when interpolative assumptions are made based on a limited set of observations. Furthermore, attempts to represent them in real 3D relation to other entities are generally hampered by extremely complex linear data masking individual features.

Challenges presented by the excavation of a large Roman burial pit in Gloucester, gave Oxford Archaeology the opportunity to rethink its recording process and a new methodology with associated Open Source software was designed in order to autogenerate 3D schematic skeletons. Whilst the output should only be understood as a contextualizing spatial framework for further analysis, its simplicity and database compatibility make it an extremely useful analysis tool which can be used in conjunction with more traditional recording and digitizing methods.

1 Introduction

A Roman mass burial pit excavated recently in Gloucester illustrated well the problems found when attempting to record skeletons with a very complex relationship to one another. The positioning of the skeletons followed no predetermined pattern, with often incomplete bodies being placed one on top of the other, creating a palimpsest of human remains. Here the usual techniques of TST survey in combination with georectified photography were employed. Although ideal for the production of a 2D plan indicating the spatial positioning of the skeletons, it soon became apparent, that in this particular case, representing the 3D element of the information was at least as important as the production of a 2D plan. TST survey contained all the required information but because of the complexities of the burials, despite being able to distinguish one skeleton from another, it was almost impossible to visually identify any particular part of the skeleton merely by reference to the spatial positioning of the rest of the body. The desire to create a means by which the three dimensional aspect of the data could easily be visually interpreted was the catalyst for the instigation of a proposed new survey methodology, dubbed 'X-Bones'. The following paper outlines the challenges faced in recording complex spatial skeletal data and the development of the X-Bones method.

2 Osteological Background

There are principally two types of burial that are encountered in archaeological contexts: discrete inhumations and mass deposits of individuals. Excavation and recording of these broadly aims to explore burial and post-burial processes and maximise the biological information that may be gained from the examination of the remains. For discrete inhumations this includes creating a visual record of burial position (for example, supine, prone, extended, flexed, etc.), relation of the individual to any associated artefacts and any other remains of the funerary rite (for example, coffin nails), and the relationship of the grave to other burials. The often organised nature of these contexts usually means that two dimensional plans and photos provide a satisfactory record as a basis for their interpretation.

Mass deposits of individuals may be encountered as disarticulated, articulated, or semi articulated remains and they may be horizontally and/or vertically positioned, complete and/or fragmented and are usually commingled or superimposed upon one another. Individuals may have been deposited during one single episode, or over a period of time. Examples where such deposits may be encountered include post-medieval cemeteries where there is considerable inter-cutting between graves and deposits of charnel as a result of intense burial activity. Mass graves (defined here as a number of individuals contained within a single grave cut (Sutherland 2000:36)) are another example and may be encountered as a single earth cut feature (for example, a pit or a vertical shaft), a natural feature (for example, a cave) or a structure (for example, a chambered tomb).

The 'three-dimensional chaos' (Wright 2003:1) presented by these contexts poses a number of problems for both the archaeologist and osteologist. These primarily relate to the fact that, because of the very nature of the deposit, skeletons and/or bones must usually be removed one by one, often before a sufficient amount has

been excavated to allow full appreciation of the spatial relationships (from all angles) between them, other than that indicated in two dimensional photographs, sketches and plans.

An appreciation of spatial relationships from all angles is essential for a number of reasons. Wright (2003:2), on excavating mass burials in forensic contexts, discusses these. The main points are summarised thus:

1. Analysis of a deposit from all angles helps to demonstrate whether individuals were disposed of in an orderly or disorderly fashion.
2. Understanding spatial relationships is key to exploring whether individuals were deposited in a single episode or over a number of different episodes. Burial over a number of episodes may be identified by establishing the presence of a matrix between individuals. Identifying such a matrix may not be obvious during excavation.
3. Methods of disposal may be explored by identifying shapes of clusters of bodies and the arrangement of bodies within clusters. For example, this may indicate whether bodies were dumped in batches, such as being tipped in from a cart or, in more recent contexts, a truck.
4. Artefacts may be localised. For example, this may indicate whether they had originally been attached to a piece of since decomposed clothing, or whether they had been placed next to the individual.
5. Three dimensional viewing may determine whether the burial context had been disturbed by later activity. It may indicate whether bodies had been partially removed by the association of incomplete skeletons with later features that cut into the original grave.

A three dimensional representation may also facilitate understanding of how a burial pit was filled (for example, at once, or over a period of time) and what the burial conditions were like. From an osteological perspective, a representation such as this aids the rapid matching of disassociated elements or pieces of a bone and thereby facilitates the calculation of the minimum number of individuals and taphonomic analysis, including decomposition processes. For example, this relates to factors such as whether complete or incomplete, fully decomposed or partially decomposed bodies had been deposited. Analysis of trauma, including timing (i.e. antemortem, perimortem, or postmortem), type (for example direct or indirect) and mechanism (for example, sediment pressure, trampling or an assault by another individual with a weapon) may also be greatly assisted. Access to three dimensional representation during the excavation of a deposit is also important. This can inform the excavation strategy and define search parameters to be undertaken during osteological analysis (Tuller 2005). In other-words, it can help to distinguish certain elements as candidates for matching up with skeletons or other elements, based on a rank order of most likely through to least likely.

All of these factors combined may inform about the funerary practices and the events surrounding and following the death of those buried. This may only be achieved in a limited manner through the application of two dimensional representation, and can be a lengthy process. Thus, without the third dimension, the full potential of a mass deposit to yield osteological and cultural information is not realised.

3 Approaches to Excavating and Recording Mass Deposits of Human Remains

Two-dimensional recording was employed during the excavation of mass deposits from the north and south burial chambers at Hazelton North, Somerset, England (Saville 1990). In addition to photography, this involved drawing bones in plan on overlays, assigning each bone a unique number and recording the absolute height of each bone in situ, as a vertical control (Saville 1990:81). This information was used to create a series of plans, in sequence, which were amalgamated to give an overall two dimensional impression of the density of the deposits in plan. Combined with an element matching exercise and creating plots of particular skeletal parts, the distribution of elements, both horizontally and vertically, was analysed to explore patterning. Larger, more recognisable elements were represented naturalistically, while symbols were employed to represent smaller bones.

This approach was time consuming and provided no opportunity for on-site interpretation of the deposit so that excavation strategy could be informed. Some bones were overlain and thus not represented in the overall amalgamated drawing. Further, the drawing, as the authors state, gives a rather false impression of the deposits in that they '....compress the vertical dimension....[and]....record only the bones and not any of the accompanying stones.....' Thus relationships to structures and layers cannot be fully appreciated.

An approach that involved superimposing rectified photographs over surveyed points was employed by Sutherland (2000) to a mass burial of individuals who met their fate at the battle of Towton (1461) in Yorkshire, England. Vertical photographs, copied to scale, were traced, superimposed over the surveyed points of each skeleton and digitally scanned to create a composite of the skeletons superimposed over each other (Sutherland 2000:38). This resulted in '.... a representation of the original appearance of the grave, as if it were in an x-ray.' Sutherland (2000:38). This process allowed stratigraphic relationships within the grave to be explored, elements

of skeletal parts to be matched, and the calculation of the minimum number of individuals to be clarified (the Harris matrix suggested a different number to that calculated during osteological analysis). Further, hypotheses raised during the excavation could be tested. For example, this includes purported evidence for binding based on the posture of one of the skeletons, a hypothesis that was disproved when the rectified images were scrutinised and, combined with osteological analysis, suggested an alternative explanation. Lastly, the images revealed the manner in which the pit had been filled with bodies, in this case by laying (rather than throwing) them down in a way that aimed to fit as many individuals in as possible.

Similar methods that employ digital rectification have been employed elsewhere (for example, see Jacobi et al. (2006) on an Iron Age mass grave from Westerhausen, Germany). These provide a means of representing mass deposits in a faster manner than hand drawing. However, the method is nevertheless still time consuming and relies on good quality photographs taken in a horizontal plane, requirements that may not always be met during some excavations where access is inhibited, time is pressured and the work undertaken in poor weather conditions. Further, the resultant images, which show naturalistic representations of bones superimposed upon one another, are un-necessarily complex for exploring spatial relationships.

A solution to these problems was recently provided by Wright (2003) who produced a three-dimensional program called 'BODROT'. Aimed at mass graves that are encountered in forensic contexts, the program creates three-dimensional stick figures based on survey data taken at certain anatomical landmarks. The figures can be rotated so that they may be viewed from all angles to explore spatial relationships. Primarily designed for a wide audience comprising lawyers, archaeologists, magistrates and courts in general, the program was made freely available and was designed to be very accessible. Unfortunately, the linear representation of bones makes it hard to ascertain bone type or directionality, and the software is not easy to integrate with other data sources.

4 Issues for Commercial Practices

The spatial recording of human skeletal remains presents a number of further issues for commercial archaeological companies, not least in attempting to strike a balance between data accuracy, completeness and cost. Traditionally (and currently, in some cases) skeletons have been recorded by hand drawn plans, related to the local site grid and incorporated into the overall site plan using manual or digital means. Although this is an adequate means of recording, there are several drawbacks inherent in the method. Hand planning takes a great deal of time in the field, minimizing the number of skeletons which can be excavated in any given period of time and increasing the cost of the excavation. More importantly, this method of recording must rely on the skill of the excavator to produce an accurate and objective representation of the skeleton.

Although orthometric height values are always obtained in such circumstances, using them in conjunction with the hand drawn plans is not easy - often leading to the creation of two separate data sets, one containing two-dimensional information, the other formed from purely height information without an x-y element. Marrying this up is possible but it is a time consuming and costly process. With the increased affordability and functionality of total station theodolites (TST) and global positioning systems (GPS) systems, metric survey has become increasingly prevalent in the recording of archaeological sites. Pre-excavation survey is normally carried out using GPS and it is common to have a permanent surveyor on site using a TST to record the location of excavated features. In the recording of human skeletal remains, it is usual to employ TST survey, together with the use of digital photography in order to produce a photogrammetric plan of the skeleton. This is an attractive method for commercial companies as it reduces the time required to record the skeleton from as much as a day to under one hour. The digital photographs produced are incorporated into the survey data by means of software capable of accurate image georectification and manipulation. Providing the photographs are of sufficient quality and the person producing the plan has enough information to identify all parts of the skeleton, a far more objective representation of the skeleton can be produced. This digitization can be completed in around 2.5 hours.



Figure 1: Hand-digitised skeletons

When a TST is available on site, orthometric heights are also recorded but usually in such a way as to produce a stick figure of the skeleton. 'Levels' are taken on main articulations such as the head, top of spine, base of spine and at the proximal and distal ends of the humeri, radii, femora, tibia, hands and feet. Once this data has been downloaded, the position of the skeleton within the context of the site can be seen, even before the digital photographs have been incorporated. Having been recorded in 3D, this data is also available to quickly and easily view in this form. Since modern total stations can incorporate attribute data in the surveyed features (such as context number), this then allows those looking at the position and orientation of the skeletons access to an added layer of information without the need for complex post-processing. Although more easily related, these stick figures remain somewhat separate from the 2D plans produced from the rectified photography.

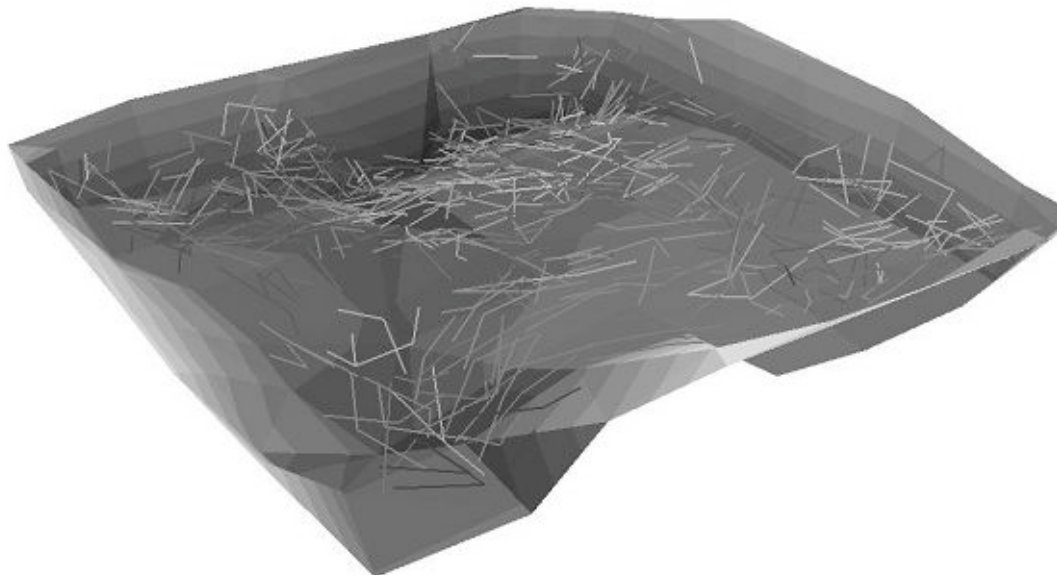


Figure 2: 'Stick figures' in mass burial

Although it is clear that this system has benefits over traditional methods, there are again some drawbacks. Frequently the order in which the points are surveyed is not consistent between skeletons on the same site. Primarily the recording is done to produce the 'levels' thought necessary by the excavator, the production of a 3D representation of the skeleton is something of an afterthought. In addition, the ability to identify particular elements of the skeleton, the arms or legs for example, relies primarily on the relationship of these elements to those forming the rest of the skeleton. Problems therefore arise where skeletons are incomplete or are buried in close proximity to one another.

5 The X-Bones Methodology

The execution of the X-Bones survey methodology differs little from that for standard TST human skeletal remain survey and because there is little change in the actual physical processes involved, there is also little if any addition to the time required on site, and hence the costs involved. The X-Bones system builds on traditional survey methods but, by implementing a set of rules this survey must follow, introduces another layer of inherent metadata. Put very simply, obtaining a skeletal outline becomes the priority, level data is merely gathered as part of this process.

X-Bones requires all human remains survey on any given site to follow a set schema with the ends of each major element of the skeleton assigned a particular point ID. The point IDs assigned do not change with skeletal orientation allowing supine and prone skeletons to be readily identified once data is downloaded. The same rules apply for very incomplete skeletons. If only a tibia and fibula are present these will be numbered in such a way to indicate whether they belong the right or left side of the skeleton. Schemas can vary from project to project, as long as they are fully documented.

An example survey schema has been set out below (and is also listed in Appendix I). It is necessary to have two points at each articulation (e.g. the patella), because these levels do not represent the patella itself, but rather the distal end of the femur and proximal end of the tibia and fibula. The Crossbones software package described below can then be employed to process the data and relies on these end points to create the skeletal representation.

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Site Name	SKELETON SURVEY SHEET	Site Code
Shade the parts of the skeleton which remain, survey them using the appropriate point IDs.	Circle the levels taken	Context Number
Be careful with PRONE skeletons, level numbers relate to side of body		Levels should be taken as SKxxxx.1 etc Two points <u>ARE</u> required for each articulation

Figure 3: X-Bones recording sheet with schema

Because this schema relies only on the point ID given to a particular measured point on the skeleton, it can be applied in any situation where x, y and z coordinate values can be obtained. It is compatible with the latest TST, such as the Leica 1200 series but would also be appropriate for situations where a much simpler machine is used. Even if the x, y, z values are initially written down, as long as they are given an appropriate point ID, they will contain this inherent information about the position and orientation of particular elements of the skeleton. In some circumstances raw data may be archived after only minimal processing and although it is possible to reconstruct the data set and relate measured points to particular parts of the skeleton, this often takes a great deal of time and effort and usually requires reference to paper records. By using the X-Bones method, if the raw data is archived, even without processing significantly more information can be obtained from it in future. Simple reference to the point IDs will illustrate what parts of the skeleton were present and because the data is recorded in a consistent fashion, it can be queried and manipulated with much greater ease.

6 Crossbones

The Crossbones program, which was designed for use with this sort of schema, uses the inherent metadata to create a much more user friendly visualization of the human remains. Because the resulting output can be integrated with GIS software, it is possible to easily link this information to that contained in a relational database. This could be something as simple as a table of age and sex produced by the onsite osteoarchaeologist to the full post-excavation burials database in order to illustrate condition, completeness or pathology.

Crossbones provides a simple process by which a user can convert raw point data from site into a file containing 3D entities which can be represented in a viewer. The internal algorithm for converting individual points into 3D entities is fairly simple. First of all, point pairs are identified. As outlined above, each point has an ID comprising the skeleton number and the location on the skeleton according to a given schema. For example, a point, p , identifying the location of the proximal end of the left humerus for skeleton 123 might be '123.5', whereas its partner point, p' , at the distal end of the left humerus would be '123.6'. The first step identifies and removes any singletons (points without a corresponding partner), or points with duplicate IDs.

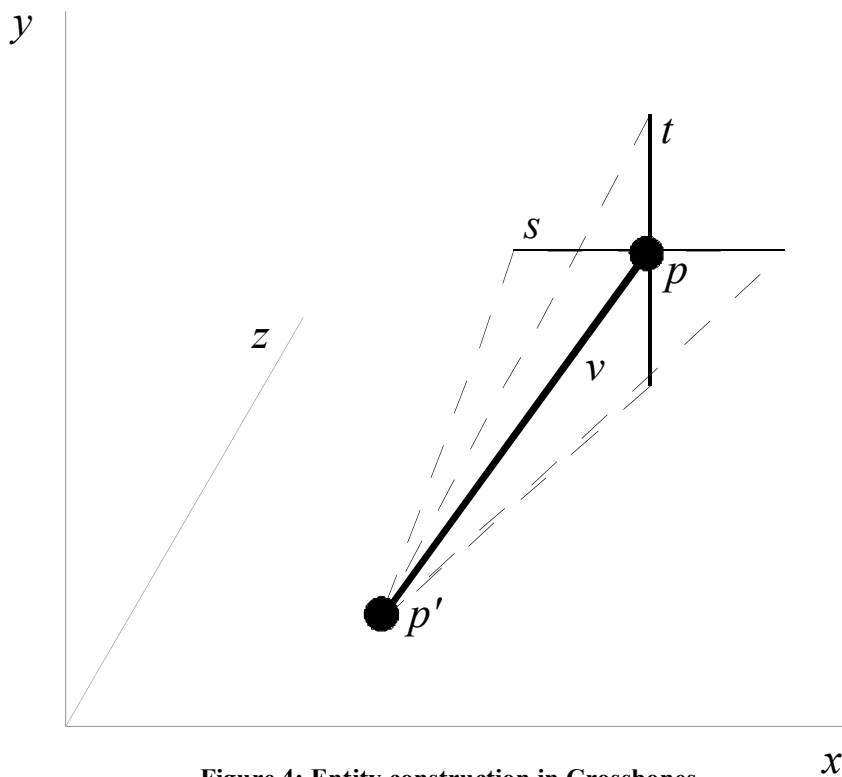


Figure 4: Entity construction in Crossbones

Once a complete set of all pairs has been created, they are converted into the entity of a user's choosing and labelled with the skeleton and bone ID (equal to the p' ID divided by 2), giving a unique value for each skeletal element. Possible outputs are lines, 'horizontal' triangles, 'vertical' triangles, intersecting horizontal and vertical triangles ('darts'), and pyramids.

The simplest possibility is to create a line, which can be done simply by stipulating that a vector, v , be drawn between the two points. This is useful in situations where the exact position of each point, and the relationship between pairs, needs to be seen.

The second option is a 'horizontal' triangle, that is, an isosceles triangle in which the 3rd side, s , is perpendicular to v whilst also parallel to the x / y (horizontal) plane and bisected by p . There is only one solution to these criteria for any v which is not exactly parallel to the y -axis (for which there is an infinite set of solutions, and hence defaults to an s parallel to the x -axis). The advantage of this approach is that, seen from above, all triangles will be seen with a standardized width. Vertically-oriented triangles, take a similar approach only at 90° rotation. These are constructed by making the 3rd side equivalent to a new line, t , perpendicular to both v and s , and are useful for section-style views.

The X-shape constructed by s and t (from which X-Bones and Crossbones take their name) can then also be used either to create 'darts', simple amalgamations of intersecting horizontal and vertical triangles, or

pyramids. Pyramids are generated by forming a square base, the corners of which are coincident with the ends of s and t , from which triangles extend to p' . Pyramids form the most realistic looking entities because they appear to have volume.

For all triangular entities, one of the advantages of knowing what schema is being used is that the length of s and t can be made a ratio of the length of v , depending on the bone type. In this way, a skull or spine can be given greater breadth than arm or leg bones to give a more realistic impression of the original body size. It should be noted however that the system cannot take into account damaged bones, and so shortened bones will also appear to be correspondingly thinner. For this reason, it is important always to do analysis in conjunction with primary data sources such as photographs and sketches.

As the co-ordinates for each entity are generated they are passed to a pluggable rendering interface. This interface is currently implemented to generate Drawing Interchange Format (DXF) files. DXF is a proprietary but plain-text format owned by Autodesk and is complex but fully documented. Its primary advantage is that it can be read by a variety of different software packages, including GRASS/Paraview, ArcGIS, and AutoCAD. The format does not allow much data to be attached to individual entities, but the skeleton and bone ID are given in separate fields. This is important in allowing for database integration as all of these packages give the analyst the ability to thematise skeletons visually (e.g. by colour or line width) based on semantic data within a database. The pluggable nature of the implementation furthermore allows for future extensions that could write to a spatial database or different graphics format.

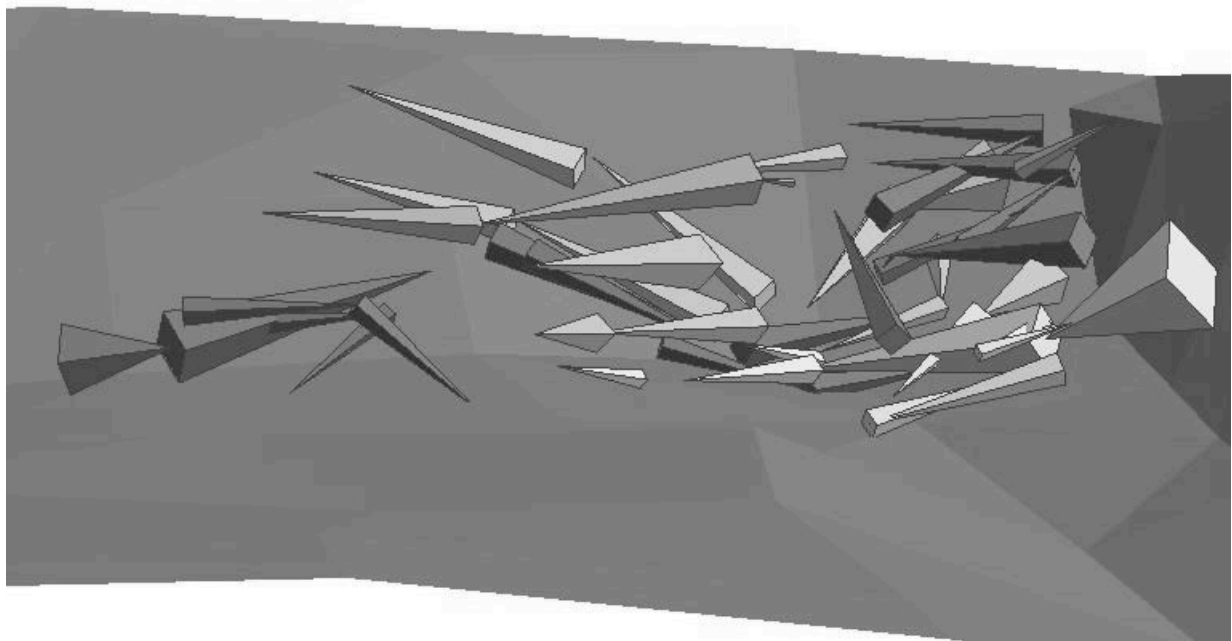


Figure 5: Skeletons represented as 3D solids viewed obliquely

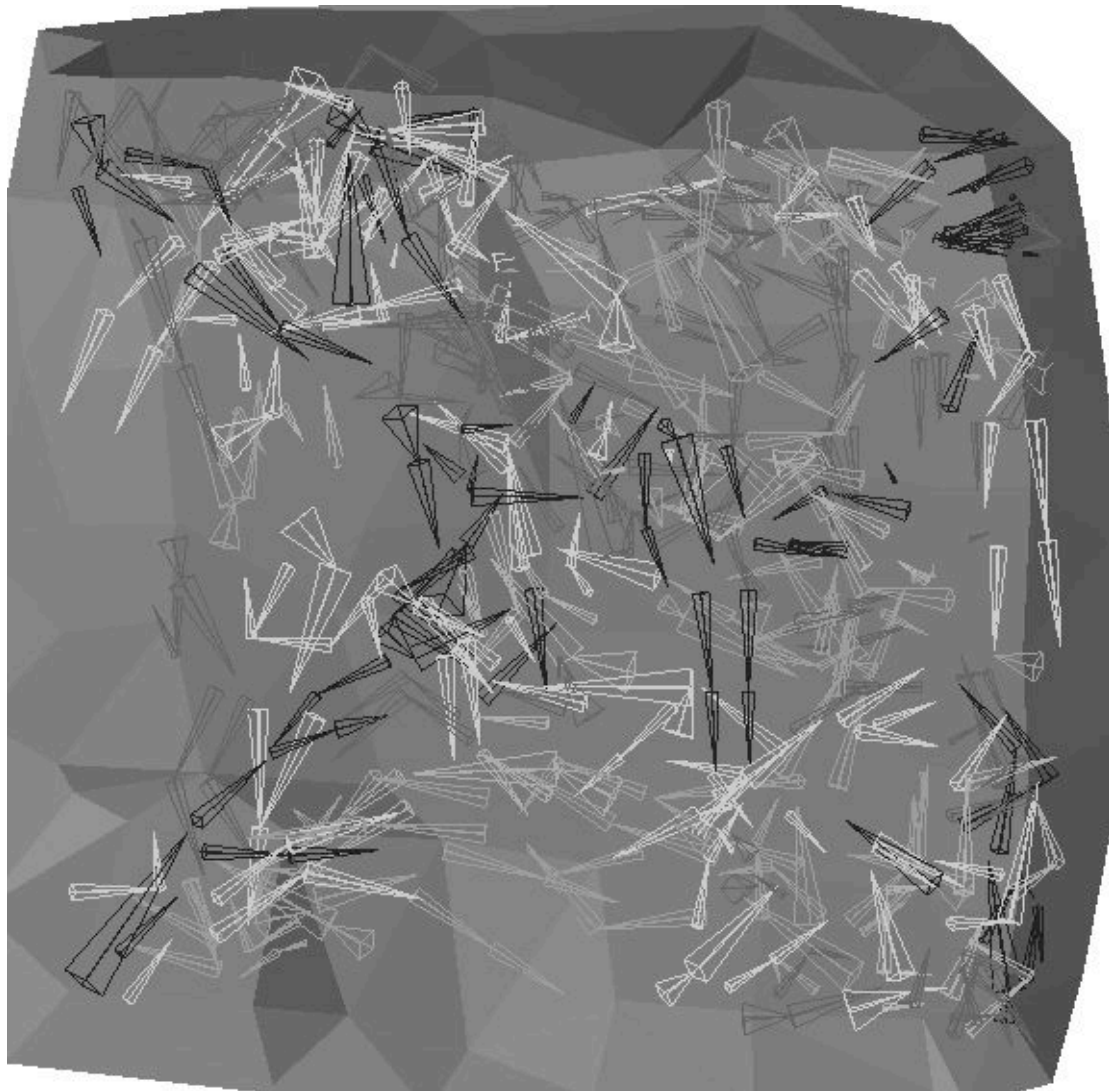


Figure 6: Skeletons themed by sex in wireframe viewed from vertical angle

7 Conclusions

Although clearly very simple, the X-Bones methodology allows for far easier management of raw survey data gathered on site than is usually possible. Of particular importance is its use in cases where data is archived after only limited data processing because the information about the nature and position of the remaining bones is contained in the point IDs. Used in conjunction with the Crossbones program, X-Bones allows a visual representation of skeletons on a site to be produced quickly and easily and it becomes possible to identify particular aspects of a burial even in very complex situations. The capacity of the Crossbones output to be used in conjunction with a GIS permits the integration of this with other layers of data throughout the excavation of a site, greatly increasing the amount of information available to the excavators and helping to influence the way in which excavation proceeds. Different aspects of skeletal data can be visualised rapidly in a broad variety of ways. Of course, this process will never replace the use of orthorectified photography to produce 2D site plans but there is much further potential to usefully integrate the two data sets by the use of software such as 3D Studio Max or a GIS. The software is fully Open Source and available under a GNU Public License (GPL) at <http://sourceforge.net/projects/openarchaeology>.

References Cited

Jacobi F., Bramanti B., Dresely V. and Alt K.W. 2006. Why did they have to die? An Iron Age mass grave from Westerhausen, Germany. Poster presented at the 16th Paleopathology Association European meeting 28th Aug-1st September 2006, Santorini, Greece.

Saville A. 1990. Hazelton North. The Excavation of a Neolithic Long Cairn of the Cotswold-Severn Group. London. English Heritage. Archaeological Report No.13.

Sutherland T. 2000. Recording the grave. In Fiorato V, Boylston A. and Knusel C. *Blood Red Roses. The Archaeology of a Mass Grave from the Battle of Towton AD 1461*. pp36-44.

Tuller H.H. 2005. H51 The importance of body deposition recording in event reconstruction and the re-association and identification of commingled remains. American Academy of Forensic Sciences. 2005.

Wright R. 2003. Aids to the Display of Bodies from Mass Graves Represented in 3D: Program BODROT. richwrig@tig.com

Appendix I: Skeleton Survey Points

Skeleton Point (generally recorded as SKX.Y, where X = skeleton number and Y = survey point number below)	Description
Torso	
1	Top of skull
2	Base of skull /1 st thoracic vertebra
3	Top of spine
4	Base of spine
Left side of body	
5	Proximal end of left humerus
6	Distal end of left humerus
7	Proximal end of left radius and ulna
8	Distal end of left radius and ulna
9	Top of left hand bones
10	Base of left hand bones
11	Top of left hip bone
12	Base of left hip bone
13	Proximal end of left femur
14	Distal end of left femur
15	Proximal end of left tibia and fibula
16	Distal end of left tibia and fibula
17	Top of left foot bones
18	Base of left foot bones
Right side of body	
19	Proximal end of right humerus
20	Distal end of right humerus
21	Proximal end of right radius and ulna
22	Distal end of right radius and ulna
23	Top of right hand bones
24	Base of right hand bones
25	Top of right hip bone
26	Base of left hip bone
27	Proximal end of right femur
28	Distal end of right femur
29	Proximal end of right tibia and fibula
30	Distal end of right tibia and fibula
31	Top of right foot bones
32	Base of right foot bones
Unsided arm	
33	Proximal end of humerus
34	Distal end of humerus

35	Proximal end of radius and ulna
36	Distal end of radius and ulna
37	Top of hand bones
38	Base of hand bones
Unsidled leg	
39	Proximal end of femur
40	Distal end of femur
41	Proximal end of tibia and fibula
42	Distal end of tibia and fibula
43	Top of foot bones
44	Base of foot bones