

**STRATIGRAPHIC VISUALISATION  
FOR ARCHAEOLOGICAL INVESTIGATION**

A thesis submitted for the degree of Doctor of Philosophy

by

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*To the people worldwide  
I have had the good fortune to  
meet during the course of my studies  
and my parents*

*“John Aubrey was interested  
in pigs, stained-glass windows,  
books rocks, sex, history,  
gossip, scandal, metalwork,  
church architecture – Aubrey  
was interested in everything.  
He had the greatest difficulty  
in finishing any sentence on  
paper, because every line he  
wrote reminded him of six  
other things that interested  
him”*



#### **JOHN AUBREY**

John Aubrey (1625-1697),  
Wiltshire gentlemen, scholar,  
gossip and antiquary, scarcely  
managed to finish any work he  
started in his lifetime, so many  
interests competed for his  
attention. His combination of  
sound, educated common sense,  
and rapturous child-like  
enthusiasm for all the works of  
man and nature, still blazes from  
every line he wrote. (Kennedy,  
1998)

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# Abstract

T

HE principal objective of archaeology is to reconstruct in all possible ways the life of a community at a specific physical location throughout a specific time period. Distinctly separate layers of soil provide evidence for a specific time period. Discovered artefacts are most frequently used to date the layer. An artefact taken out of context is virtually worthless; hence the correct registration of the layer in which they were uncovered is of great importance. The most popular way to record temporal relationships between stratigraphic layers is through the use of the 2D Harris Matrix method. Without accurate 3D spatial recording of the layers, it is difficult if not impossible, to form new stratigraphic correspondences or correlations.

New techniques for archaeological recording, reconstruction, visualisation and interpretation in 3D space are described in these works and as a result software has been developed. Within the developed software system, legacy stratigraphy data, reconstructed from archaeological notebooks can be integrated with contemporary photogrammetric models and theodolite point data representations to provide as comprehensive a reconstruction as possible.

The new methods developed from this research have the capability to illustrate the progression of the excavation over time. This is made possible after the entry of only two or more strata. Sophisticated, yet easy-to-use tools allow the navigation of the entire site in 3D. Through the use of an animation-bar it is possible to replay through time both the excavation

period and the occupation period, that is to say the various time periods in antiquity when human beings occupied these locations.

The lack of complete and consistent recording of the soil layers was an issue that proved to be an obstacle for complete reconstruction during the development of these methods. A lack of worldwide archaeological consensus on the methods of stratigraphic recording inhibited development of a universal scientific tool. As a result, new recording methods are suggested to allow more scientific stratigraphic reconstruction.

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# Chapter 1

## Introduction

T

THIS chapter provides a concise background into those working in the field of archaeological stratigraphy and its visualisation. It describes a motive for this research and subsequently outlines the content of each chapter describing why each is a necessary part of this thesis. The final section outlines the contributions of this dissertation and justifies its significance as PhD work.

### 1.1 Background

The earliest record of the application of computers to the manipulation and analysis of stratigraphic sequences is that of Wilcock's STRATA program in 1975. A decade later, two papers presented at the 1985 “Computer Applications and Quantitative methods in Archaeology Conference” in Leiden, the Netherlands, prepared the foundations for several subsequent developments (Wilcock, 1985). By the early 1990s, two tools that were to become widely used made their appearance. Herzog and Scollar introduced a fully automated system for producing stratigraphic diagrams called Harris (Herzog, 1991), whereas Ryan, following Harris' earlier reservations about 'black box' methods (1975), developed an interactive system called 'Gnet' (1988). Gnet is described in more detail in Section 3.3 Gnet

A variety of work has been carried out in visualising stratigraphic relations in two dimensions using the Harris Matrix. In 1990, Herzog and Scollar (Herzog, 1991) outlined existing programs for Harris diagram generation and described a system for manually and automatically removing cyclical relationships between layers and detecting errors, for example, duplication of layers. They indicated the need for extending stratigraphic visualisation applications to combine a finds database so that finds can be visualised in the Harris diagram.

Boast and Chapman (Boast, 1990) presented a Harris matrix generation program that has the ability to be integrated with other forms of information. Fundamentally they described a database schema capable of storing stratigraphic layers (contexts) in relation to one another allowing significant time savings for archaeologists engaged in the analysis of site records.

Desachy and Djindjian (Desachy, 1990) developed an approach for building stratigraphic graphs using a simple interactive method of matrix processing. They aimed to reduce the number of line crossings in matrices to create a new stratigraphic graph with a better formalism than the Harris graph.

In November of 2001, Harris strongly emphasised the need for Geographical Information Systems (GIS) to force the archaeologist to acknowledge the pre-eminent position of surfaces, rather than deposits, in stratigraphic analysis and recording (Harris, 2001). This is not a trivial problem since stratigraphic data is often recorded in such a haphazard and incomplete fashion that it disallows the accurate and convincing representation of the original stratigraphic surfaces (Green, 2001a). Harris claims that with GIS, archaeologists are able to reproduce the topographical development of sites in an efficient manner that was almost impossible to carry out before the invention of GIS and computers. Through the use of GISs, Harris argues that it should be possible for the first time, for archaeologists who excavate to fully complete their work by the production of detailed phase and period plans. It is the view of Harris that most

archaeological records fall far short of the professional standards that are necessary for good stratigraphic interpretation of the data. Without the proper recording of surfaces, GIS methods cannot be used at all for stratigraphic reconstruction, for it is argued, such reconstruction is fundamentally a remaking of the surfaces of a site, not its deposits. The author strongly concurs with these points; using GISs to create plan drawings is a noble goal, fraught with problems due to the nature of recording, as is investigated in these works. Harris goes so far as to say that the glitzy results of computer work should not blind us to the often-inadequate stratigraphic data upon which it is based.

The emphasis of Bibby's latest works in this area is not through the creation of a hermetically sealed complete excavation recording system for stratigraphic excavations, since Bibby claims that such a system cannot suit "all of the people all of the time". Rather, an approach is presented to increase the compatibility and permeability between software systems that are currently tried, tested and in active use. Bibby's approach is looked at in more detail in Section 3.16.

In 2001, Herzog remarked that archaeologically speaking the so called multilinear or floating sequences in a Harris matrix, may lead to a diagram that displays two nearly contemporary layers on widely different levels, although no stratigraphic relationship was omitted from the matrix (Herzog, 2001). The possibility of being able to see the spatial correspondence between strata allows for the more accurate configuration of the strata on a chronological graph (one contribution this work achieves). Herzog has developed a program to layout the Harris matrix automatically taking all the available chronological information into account.

Powlesland and May (Powlesland, 2001) have been undertaking large scale excavations of multi period landscapes in and around West Heslerton, North Yorkshire, England for nearly 25 years. These open area excavations covering more than 25 hectares have been the setting for ongoing experiments in digital field recording since the early 1980s. The applied computing research undertaken as a part of the English Heritage funded

projects in Heselton has followed a number of different yet interrelated strands. Those of which are of interest within the scope of this thesis include 1) The application of hand held computers for data collection in the field. 2) The application of EDM/Total Station devices for 3D location recording of large and complex material culture and environmental data sets. 3) The application of GIS technologies to excavation documentation, management and interpretation. 4) The integration of remote sensing data, database, CAD, matrix and other information within site based GIS. 5) The application of fully integrated and linked GIS based excavation data in both digital and paper publication of archaeological excavations.

In 1999 Koussoulakou and Stylianidis (Koussoulakou, 1999) recognized that working in a 3D environment or a GIS with 3D capabilities would make easier the process of establishing relations between finds in successive layers. They pointed out that due to practical limitations 3-dimensional space that was recorded by the archaeologist was only represented in 2D space. They attempted to combine all the information available from the Toumba hill excavation in Thessaloniki, Greece into a true 3D representation of the excavation site through the use of GIS and visualization tools.

## 1.2 Motivation

During an archaeological dig, a large amount of data relating to stratigraphic positioning (SP) is recorded. This data is recorded in a variety of different ways; excavation notebooks, stratigraphy forms, and in the control computer attached to the theodolite. The widely used archaeological practice of analysis and representation of SP is the Harris Matrix approach (Harris, 1989). This is a valuable technique to analyse and compare 2D SP data. With the advent of cheap and powerful 3D computing, there is a growing capability for the archaeologist on site to test hypotheses and gain immediate results. The 3D representation and analysis of this SP data, with the ability to perform real-time hypotheses without prolonged sifting through hard copies of excavation logbooks presents a real innovation to future



archaeological interpretation. The ability to replay the excavation in a timely order, stratum by stratum after the site has been excavated allows both the casual user and the specialist archaeologist to gain insights previously not possible.

With the advent of Geographical Information Systems (GIS), archaeologists should be able to reproduce the topographical development of a site in a fast and efficient manner. It should be possible for archaeologists who excavate to complete their work by producing detailed phase and period plans. However, most archaeological records fall far short of the professional standards necessary for good stratigraphic interpretation of the data. This work investigates the problems with current recording methods, and overcomes some of these problems through the development and use of a custom-built GIS tool focused solely upon archaeological stratigraphic recording and reconstruction. Using GIS to create plan drawings is a noble goal, fraught with problems due to the nature of recording, as is investigated in these works. This thesis establishes new methods of archaeological stratigraphic visualisation, both serving as an educational tool to new students of archaeology, as well as enabling instant information about a campaign to new archaeologists.

Although the initial purpose of this research was not to change archaeological working-practice, but to create new methods for stratigraphic visualisation, it became necessary to suggest new archaeological working practice to improve recorded data so that GISs such as *Strat* have some value. Chapter 8 suggests some methods.

The creation of tools and methods, which will in effect supersede the slew of existing stratigraphic visualisation tools, as well as provide additional functionality in the way of automatic surface correspondence matching is a task which requires a careful view to interface design, a high level of 3D processing and a pragmatic view on archaeological fieldwork practice in order to maintain data integrity and to mimic actual practice. Such a system is essentially a Geographic Information System, albeit one which needs to be tied very closely to archaeological practices and principles. In his book

“Techniques of Archaeological Excavation” Barker (Barker, 2001) describes a GIS as enabling the relationship between, for example, aerial photographic, geophysical and field-walking data on the one hand, and topography, geology and soils on the other hand, to be systematically analysed, allowing predictive models of the preservation and quality of the archaeology to be developed. The full potential of a GIS database, Barker writes, would lie not in the ‘passive’ marshalling and analysis of existing data, but in the provision of a framework for carefully targeted future fieldwork as part of an active strategy of research into management of archaeological resources.

Excavators as a rule, record only those things that appear to them important at the time. But fresh problems in many disciplines such as archaeology and anthropology as well as computing are arising requiring a greater level of detail in the recording of data pertaining to a site. One of the stumbling blocks that this research has faced is that of the lack of attention to the careful registration of stratigraphic data. Although the stratigraphic reconstruction of the whole of the ancient Greco-Roman city of Sagalassos both physically and temporally is a fine goal, current methods of recording are not comprehensive enough to make this possible.

The problems intended to be solved in this thesis are made all the more challenging since the subject matter spans two disciplines that are more often than not in opposition; archaeology and computing. Archaeologists are usually not familiar or greatly interested in the specifics of computer technology and it is uncommon to find a computer scientist who has a thorough understanding of archaeology. This thesis has in some ways spanned this gulf.

### **1.3 Organisation of Thesis**

The following chapter describes in more detail the role existing software has to play in achieving stratigraphic analysis. It outlines emerging stratigraphic visualisation software as well as some of those in closely related fields indicating their applicability for the field of stratigraphic visualisation.

Chapter 3 serves as an introduction to the ideas and technical material relating to archaeological methods and practices. This chapter is intended for a general audience to acquaint them to what is possibly a foreign field.

Since archaeology is not an exact science, the methods used on the test site of Sagalassos, used for this research are detailed in Chapter 4.

Chapter 5 takes a detailed look at the software that has emerged from this research - that of the *Strat* tool. The ways in which legacy and contemporary stratigraphic data are combined is looked at in the study of the recording GUI elements of the system.

Chapter 6 shows the possible resulting accuracies of stratigraphic reconstructions using today's recording methods. It employs two differing stratigraphic profiles for its reconstruction.

Chapter 7 looks at the errors and quality of reconstructions that can be formed using legacy stratigraphic data. As its input, three forms of stratigraphic data are used to describe the same spatial region, as recorded by the Sagalassos team.

Chapter 8 proposes intermediary disciplined recording steps which can be taken on sites where a theodolite is used, such that spatial data describing stratigraphic layers is not permanently lost.

Finally, the thesis is concluded in Chapter 9, which summarises the important results of this work and giving suggestions for further work.

## 1.4 Contribution of Thesis

The research described in this dissertation has focused on the development of new methods to accurately and scientifically visualise in its entirety an archaeological site allowing for a new method of post-excavation analysis, particularly with a view to stratigraphic analysis.

A computer program has been developed that allows for the entry, visualisation and analysis of stratigraphic information, that is to say, layers of stratigraphy that have been excavated from the earth's surface and measured in a scientific way. It allows for the entry of legacy stratigraphy

data, from archaeological field-books recorded from any site and allows visualisation of strata using up-to-date photogrammetric methods where available or from less detailed records. This tool can be applied to any situation where soil dimensions are recorded as it is removed from the ground. This is described in Chapter 5.

One of the evident problems uncovered during this research was that data recorded by archaeologists is often haphazard, incomplete and sometimes incorrect. The system developed allows for varying levels of detailed information to be visualised alongside related data recorded in a different time frame, thus allowing for new insights to the data, and as a side-effect, the analysis of archaeological practice itself. The ability to solve stratigraphical correspondence relationships automatically in three-dimensional space is also a valid contribution of this work.

Original contributions presented within this thesis that have been presented at conferences include:

1. "Moving Towards the 3D Visualisation and Automatic Correlation of Stratigraphic layering."
2. "A Real Time 3D Stratigraphic Visual Simulation System for Archaeological Analysis and Hypothesis Testing."
3. "Visualisation Legacy Stratigraphic Data from Archaeological Handbooks."
4. "3D MURALE: A Multimedia System for Archaeology."
5. "3D MURALE: Multimedia Database System Architecture."
6. "The Heritage Of Stratigraphy - Visualizing Legacy Data".
7. "An Integrated System For The Spatial Visualisation Of Archaeological Sites."
8. "A Novel Multimedia System for Archaeology".

# Chapter 2

## Archaeological Excavation

T

HIS chapter provides an introduction to the field of archaeology with a view to the principles of stratigraphy for those with little or no knowledge in the area. This chapter is intended for a general audience to acquaint them to what is possibly a foreign field. Archaeology is a broad field and this section is not intended to provide a comprehensive text on the subject. For further reading see (Barker, 2001) and (Harris, 1989b).

### **2.1 Why Excavate?**

The ultimate aim of an excavation is to draw together the very varied strands of evidence into a coherent whole: the sequence of natural and structural events, which have taken place on the site from the earliest occupation (or before) up to the present day. To this structural framework is added all the converging cultural, economic, domestic and environmental evidence which can be detected and assessed.

### **2.2 Profile Drawings and Plan Drawings**

Professors Gudmund Hatt and Axel Steensberg in Denmark and Professor Gerhard Bersu in Britain showed that the only way to elucidate the intricate patterns of the timber buildings found on by far the majority of ancient sites is to combine highly detailed observation of the layers in plan with a study of

their own composition in depth; a fully three-dimensional approach in which they claim that every cubic centimetre of soil is made to yield the maximum information (Barker, 2001). However this result would only be achieved if plan drawings and cross sections were taken at every centimetre, which, of course they are not.

A plan drawing is exemplified in Figure 1 and an example cross-section or profile drawing is illustrated in Figure 2. These drawings were taken from the test site of Sagalassos, Turkey. Aesthetically, these drawings are pleasing with their shading and attention to each stone inclusion, however scientifically they are not very accurate. An attempt was made to stitch together four detailed profile drawings and the plan drawing using 3DS Max in order that a 3D reconstruction be made, but the layers of strata did not match up. An approximation as shown in Figure 3 illustrates the resulting 3D stratum represented if only the heights of the strata are recorded, hence making a cuboid for every stratum. Barker (Barker, 2001) writes that all interpretation is a personal opinion or a consensus of opinions and that one must be careful as far as possible to keep the interpretation separate from the evidence on which it is based. This is particularly evident if plan and profile drawings are made by hand without taking measurements, but with the advent of computerised photogrammetric techniques human bias should be avoidable.

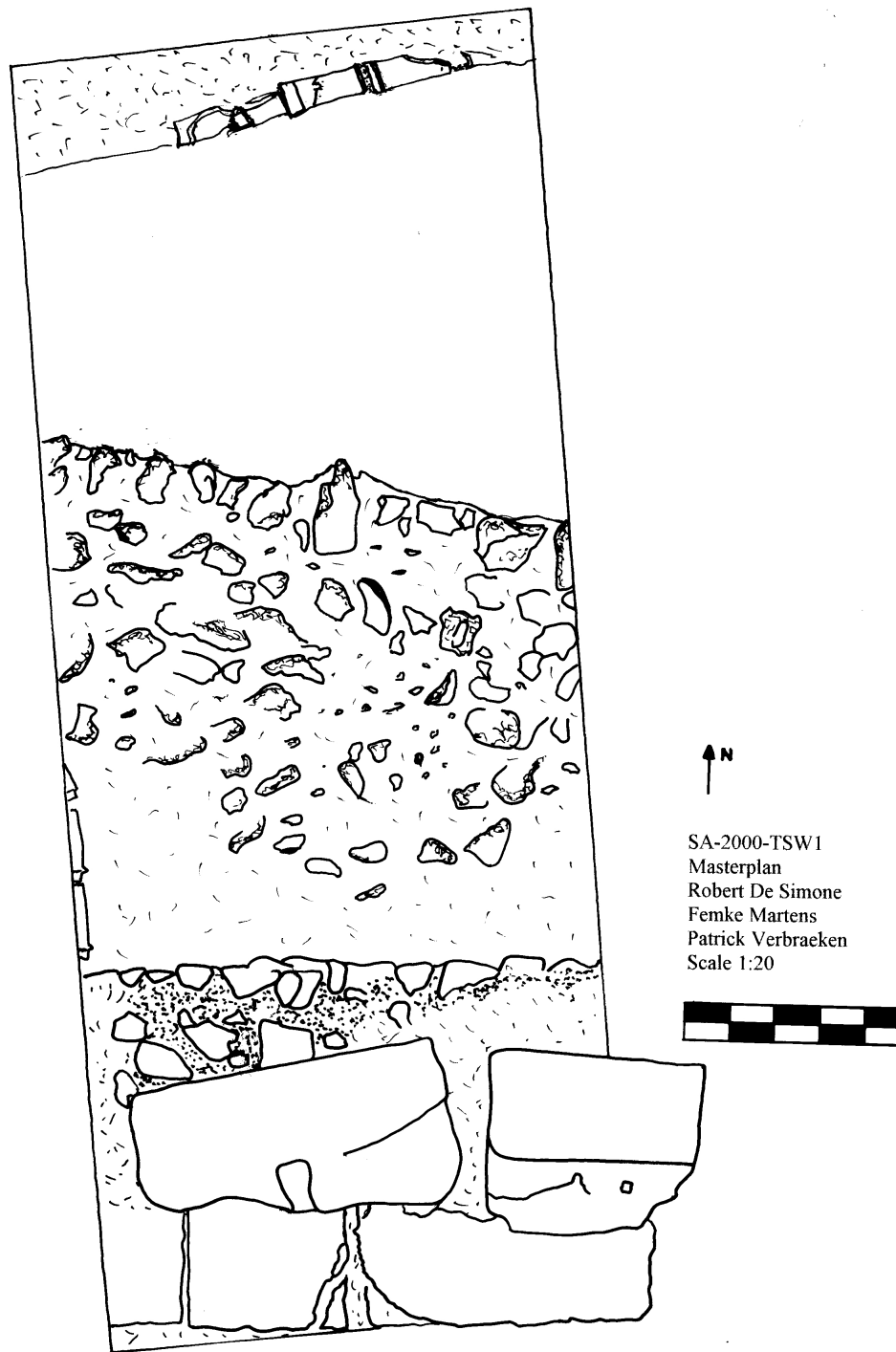


Figure 1. An example plan drawing.

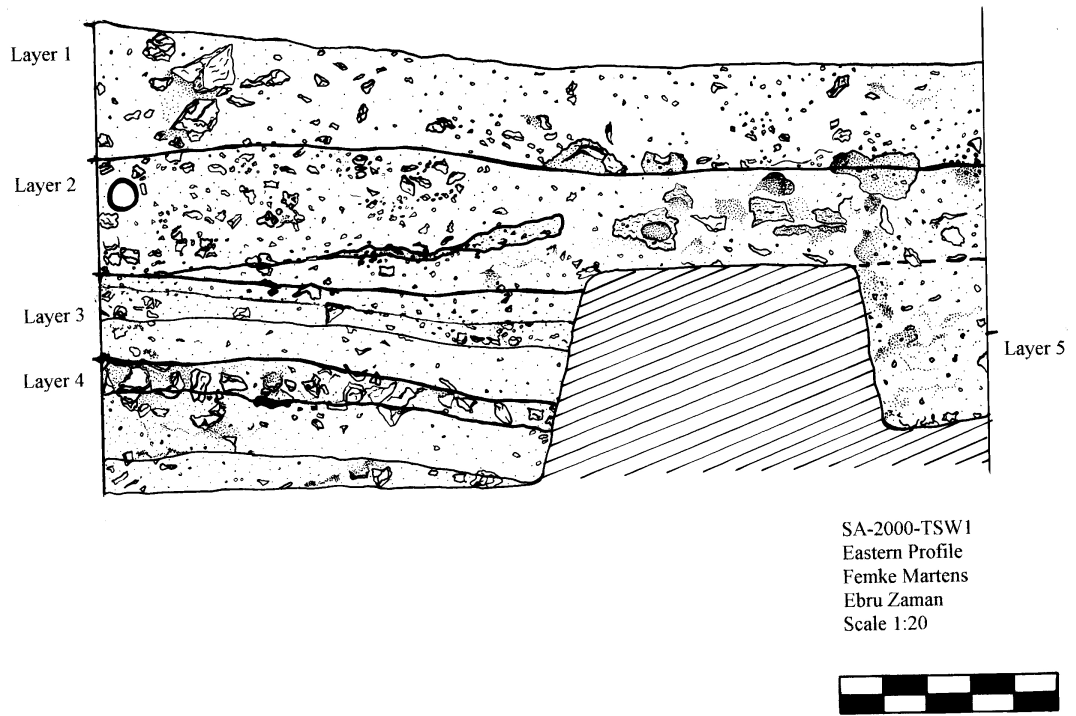


Figure 2. An example section (profile) drawing

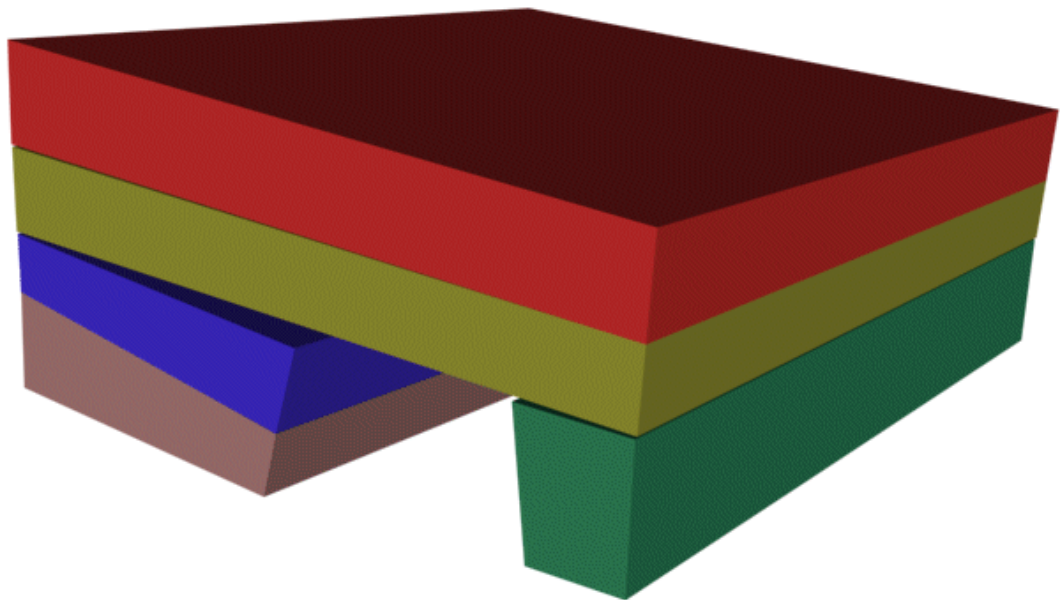


Figure 3. A 3D reconstruction of the TSW1 trench.



### **2.3 Practical Fieldwork**

The methods which archaeologists use when recording are described in this section. This relates mostly to stratigraphic recording and hence methods of sampling wood, sampling for radio-carbon dating, sampling of ceramics for residue analysis and so on are not relevant and so have not been included in this thesis.

### **2.4 Fieldwalking**

The interpretation of artefact scatters from fieldwalking has undergone extensive study within the last ten years, moving a long way from the assumption that a concentration of flints or pottery in the ploughsoil marked the site of a building or settlement, when it might in fact, represent quite the opposite, since as an aboriginal informant told an excavator ‘...them old-timers never put their houses on the garbage dump...they don’t like to live in their garbage any more than you would’. Much pottery is spread on the fields in the course of manuring, and a concentration of flints may be the debris from mining or off-site working. On the other hand, a dense scatter of roof tiles, plaster, tesserae, pottery, coins and other finds is likely to mark the site of a Roman building, though conversely, the site of a timber building in an area where little or no pottery was used is likely to escape detection completely.

### **2.5 Geophysical Site Survey Methods**

Geophysical methods detect underground anomalies such as wells, pits gullies, ditched, walls, floors, hearths, kilns and roads. Resistivity meters measure the differences in electrical resistivity between terminals driven into the ground at intervals – pits, ditches and gullies, which are normally filled with damp humic soil offer less resistance to the electrical current than walls, roads and floors. If the readings are taken on a grid covering the whole site, the varying resistances can be plotted as a series of contours, or simply as anomalies or features.

Similarly, the same anomalies or features tend to carry a detectably different magnetic field from that of the earth. Hearths and kilns (or burnt-down buildings), in particular, have a strong magnetic effect, though pits, ditches and roads can also be detected. The magnetic anomalies can be plotted in a number of ways to reveal their pattern.

While magnetometer surveys can produce detailed plots of silted-up ditches, pits and post-holes, as well as hearths, kilns and the sites of burnt buildings, magnetic susceptibility uses a broader brush, detecting evidence of occupation and defining its limits in the topsoil itself, so that shallow sites which may have only survived in the topsoil can be detected, sometimes in quite fine detail.

Where stratified deposits exist, it is possible, using relative magnetic susceptibilities, to identify phases of clearance and exploitation.

## **2.6 Stratigraphy**

Artefacts are the first thing most people think of when they think of archaeology. This is understandable, since some of the nicest and most evocative objects from the past were archaeologically recovered. However most of a field archaeologist's day is spent digging, deciphering, and recording a site's soils. In fact, artefacts, the undoubted popular superstars of archaeology are only significant in conjunction with the dirt that contained them. A site's soil deposits tell the story of how past peoples used and changed an area over its use life span. Postholes, foundations, and trenches mark where buildings and fences once stood, trash pits and other work related holes point to what activities took place on different parts of the site, and various occupancy layers provide clues to the sequence of these features. When analysed together all of these features bring back to life landscapes long buried and forgotten. Artefacts have an important role to play in this analytical task by revealing what specific tasks people once performed across a site and by providing calendar dates for features and layers. But one should always keep in mind that a feature or layer without artefacts may have lots

to tell about a site, while an artefact separated from its soil context has little to tell.

Archaeology has the distinction of being an endeavour that by necessity destroys its evidence in order to analyse it. For example, in order to place a given posthole in its proper place in a site's sequence it must be dug and digging it means destroying it. Consequently, responsibly and diligently recording the sequence of soils is vital to properly understand and interpret a site. The most widely used and popular method for doing this is known as the Harris Matrix.

## **2.7 The Harris Matrix**

The Harris Matrix (Harris, 1889a) was invented in 1973 by Dr. Edward C. Harris and for the first time provided archaeologists with a means to view stratigraphic sequences in diagrammatical form. Professionals worldwide have since adopted it.

This system entails the creation of a numerical flow chart of the site's sequence of soils. Every layer, feature, and cut (the outline of a historical hole's shape indicating the physical act of its initial digging) receives a unique context number on its discovery that will forever serve as its designation. These numbers are then placed into a flow chart reflecting the order in which they appeared in the ground. Use of this system enables the numerical reconstruction of a site's stratigraphy long after it has been excavated.

In the simplest of terms, but dealing with that most complicated of ideas, namely, time, the Harris Matrix is a new type of calendar, which allows archaeologists for the first time to see the stratigraphic sequences of complex sites. Calendars and clock faces are two of the few ways in which absolute time can be 'seen'. Since it has no physical reality, but is inherent in most things, it must be translated to a diagrammatic form to be understood as a schedule or sequence. The Harris Matrix provides that translator for the relative time inherent in archaeological sites, to its display in a diagram, which represents the stratigraphic sequence, or relative-time calendar, of such sites.

The Harris Matrix shows the stratigraphic sequence of a site in a diagram, which is the only way it is readily comprehensible. The stratigraphic sequence on every site is unique, due to the limited physical boundaries and time-span of strata and features on archaeological sites. The stratigraphic sequence, seen as a 'matrix' (as it is now commonly called), is the unique 'testing pattern' for all later (artefact, ecofact, chronological and topographical) analyses of a site. Since artefacts can travel (but stratification cannot), they can be used to say whatever might be wished, if the archaeologist does not have a stratigraphic sequence against which to test their validity in time and space. The Matrix, or stratigraphic sequence, is the main station into which all recording flows and out of which all analyses will commence and forever be accountable to. It is of universal application because, before analysis of the contained remains, the study of stratification is the same everywhere. A profile diagram is shown in Figure 4 showing layers and a feature with two fills. Each of the layers, feature fills, and the feature cut are marked with their context numbers. The layers, feature fills, and the feature cut sit in untouched subsoil.

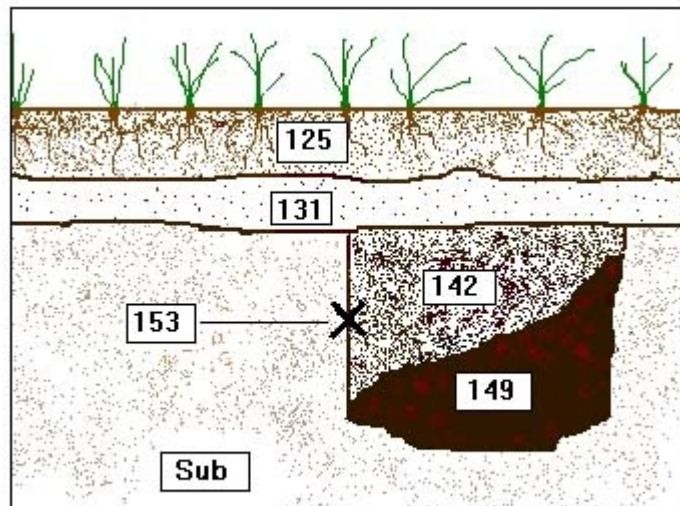


Figure 4. A profile view or cross-section of the soil showing layers and a feature with two fills.

A Harris Matrix of the above-pictured section of a hypothetical site is shown in Figure 5. The hole has been offset indicating that it is a separate but underlying feature. The cut (153) is stratigraphically earlier than its feature's fill.

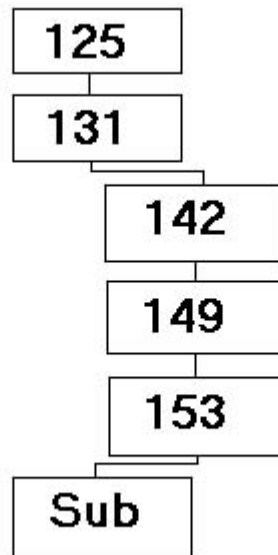


Figure 5. The Harris matrix generated from the soil structure in Figure 4.

## 2.8 The Laws of Archaeological Stratigraphy

These laws of stratigraphy were described by Harris in the unofficial bible of stratigraphy; “Principles of Archaeological Stratigraphy”, (Harris, 1989a).

### 2.8.1 Law of Superposition

In a series of layers and interfacial features, as originally created, the upper units of stratification are younger and the lower are older, for each must have been deposited on, or created by the removal of, a pre-existing mass of archaeological stratification.

### 2.8.2 Law of Original Horizontality

Any archaeological layer deposited in an unconsolidated form will tend towards a horizontal position. Strata that are found with tilted surfaces were

originally deposited that way, or lie in conformity with the contours of a pre-existing basin of deposition.

### **2.8.3 Law of Original Continuity**

Any archaeological deposit, as originally laid down, or any interfacial feature, as originally created, will be bounded by a basin of deposition, or may thin down to a feather-edge. Therefore, if any edge of a deposit or interfacial feature is exposed in a vertical view, a part of its original extent must have been removed by excavation or erosion, and its continuity must be sought, or its absence explained.

### **2.8.4 Law of Stratigraphical Succession.**

A unit of archaeological stratification takes its place in the stratigraphic sequence of a site from its position between the under-most of the units that lie above it and the upper-most of all the units that lie below it and with which the unit has physical contact, all other super-positional relationships being redundant.

Based on these laws of archaeological stratigraphy any stratigraphical sequence can be graphically summarized in a matrix (the so-called Harris matrix). The matrix system admits to only three possible relationships between two given units of stratification:

1. The units have no direct stratigraphic or physical relationship.
2. The units are in superposition.
3. The units are correlated as separate parts of a once whole deposit or feature interface.

The primary objective of the study of archaeological stratification is to place the units of stratification, the layers and the features, into their relative sequential order. The stratigraphic sequence can and should be constructed without reference to the artefactual contents of the strata.

## **2.9 Dating Stratigraphy**

Archaeology was borne of the study of artefacts, taken here to mean things made by people and having a consistency such as to allow for burial and

survival in the ground (Harris, 2001). Evolving out of the geological concept of superposition, namely, that if an object or deposit is found below other such items, the lower entities are earlier, in relative time. This assumes that the deposit and the object it contains have not been turned over, as may happen with solid rock stratification, but seldom with loose rock formations. The latter, in any disturbance of the strength and longevity of motion required for the former, will be destroyed and its unconsolidated material will form the basis of new deposits. The original deposit will no longer exist as a stratigraphic marker, though some its constituents may live on in some manner in new deposits. Herein lies the great strength and utter weakness of the artifact in stratigraphic studies. On the one hand, it provides an inherent date in and of itself in absolute, or calendar, time, and that evidence may help to date the deposit, and indirectly, associated surfaces. On the other hand, the ability of artifacts to survive the destruction of the original burial deposit means that they are all highly suspect as true indicators of the date of the deposits in which they may be found.

Given all this, archaeologists in the nineteenth century used the basic concept of superposition to demonstrate an evolution of artefacts in stratigraphic deposits and thus revolutionized the understanding of human society and history. Artefacts served archaeology well; they were easy to understand, simple to find and carry away, and gave immediate gratification by way of exhibit and display. That the vital stratigraphic record of the site was destroyed without proper record in the quest for artefacts remained the norm for many decades. That the capture of the stratigraphic sequence of a site provided the testing pattern by which the artefact could be of even more valuable took some years to appreciate. Recording methods by which that capture could be made, however, lagged behind for over a century.

The artefact then is a fundamental concept in stratigraphic research, as it may be separated from its burial context without losing its consistency. As an obvious object, the artefact is easy to isolate and may be recorded at discovery and at any time thereafter. The same is not true of deposits and surfaces: museums therefore are full of artefacts but few, if any, preserve

deposits (excepting such "deposits" which are also artefacts, such as a mosaic floor). Artefacts are thus separated at the time of discovery from the articulated body of stratification in which they were found and that data is through necessity destroyed in the process. That articulated body of stratification is comprised of deposits and surfaces.

### **2.10 Theodolite Use**

On reading the latest edition of the popular teaching text of archaeology, Barker's "Techniques of archaeological excavation" (Barker, 2001), no mention is made of accurate techniques for the surveying of archaeological sites. There appears to be no standard defined for using a theodolite or total station in the surveying of the corners of building features or delineating stratigraphic surfaces or deposits. Standards should be defined if reconstructive software is to be used for map creation or stratigraphic reconstruction. Such methods are suggested later in this thesis.

### **2.11 Single Context Recording**

One of the most important developments in the last 20 years has been the introduction of 'single context recording'. That is, the drawing of each site context on a separate sheet of drawing film (thus paralleling the completion of a record card for each context) as distinct from drawing a number of related contexts, or sometimes a whole phase of the site's development on a single sheet. The system evolved in urban archaeology where often the stratification is in discrete islands which cannot be related together on site and where large numbers of workers are employed to dig these islands simultaneously.

It is argued that single context recording is logical and objective and does not confuse the evidence with its interpretation. It also has the advantage that it allows delegation of a simple and routine task to comparatively inexperienced excavators rather than holding up the work while specialist planners draw the site, which has often been the case. Each of the separate plans, together with its record card, are subsequently used to create the site matrix and composite phase plans – a 3D jigsaw.



## 2.12 Global Positioning Systems

This section explains the concept behind Global Positioning Systems (GPS). It is relevant to bring this background to the thesis since the origin (PSD) about which all archaeological sectors are relative is recorded as a GPS position. This section then describes the accuracies and methods used to determine an accurate position on the surface of the earth by the use of satellites.

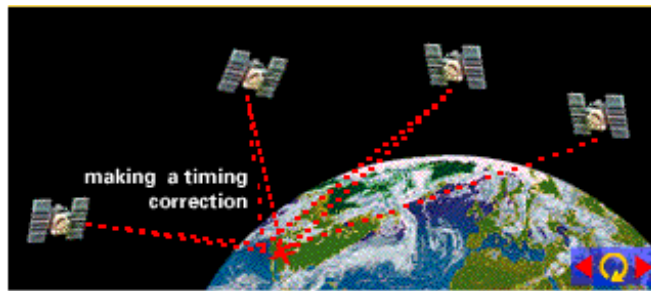


Figure 6. Satellites triangulating a GPS position (Trimble, 2001).

GPS is a satellite navigation system. GPS is funded by and controlled by the U. S. Department of Defence (DoD). While there are many thousands of civil users of GPS worldwide, the system was designed for and is operated by the U.S. military. GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity and time. Four GPS satellite signals are used to compute positions in three dimensions and the time offset in the receiver clock.

GPS is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. In fact, with advanced forms of GPS, measurements can be made more accurate than one centimetre. It is similar to giving every square meter on the planet a unique address. GPS receivers have been miniaturized to just a few integrated circuits and so are becoming very economical - making the technology accessible to a wider audience. At the present time GPS is finding its way into cars, boats, planes, construction equipment, movie making gear, farm machinery, and even laptop computers. GPS works in this manner:

- The basis of GPS is "triangulation" from satellites.
- To "triangulate," a GPS receiver measures distance using the travel time of radio signals.
- To measure travel time, GPS needs very accurate timing, which it achieves with extra satellite range measurements and high accuracy atomic clocks.
- Along with distance, the exact position in space of the satellites in space needs to be known. High orbits and careful monitoring achieve this.
- Finally the delays the signal experiences as it travels through the atmosphere must be corrected.

### **2.12.1 Triangulating from Satellites**

The whole idea behind GPS is to use satellites in space as reference points for locations here on earth. By very accurately measuring our distance from three satellites our position can be triangulated anywhere on earth. Suppose a distance is measured from a satellite and is found to be 11,000 miles. Knowing that we are 11,000 miles from a particular satellite narrows down all the possible locations we could be in the whole universe to the surface of a sphere that is centred on this satellite and has a radius of 11,000 miles. Next, a distance is measured to a second satellite and is found to be 12,000 miles away. This tells us that we are not only on the first sphere but we're also on a sphere that's 12,000 miles from the second satellite. Or in other words, we're somewhere on the circle where these two spheres intersect. If a third measurement is made from a third satellite and we find that we are 13,000 miles from that one, that narrows our position down even further, to the two points where the 13,000 mile sphere cuts through the circle that's the intersection of the first two spheres.

By ranging from three satellites our position can be narrowed to just two points in space. To decide which one is our true location a fourth measurement could be made. But usually one of the two points is an absurd

answer (either too far from Earth or moving at an impossible velocity) and can be rejected without a measurement.

A further, more detailed explanation of GPS systems is beyond the scope of this thesis suffice to say that an idea of the impact of these errors can be realised by studying Figure 7. More information on GPS can be found at the website of Trimble (Trimble, 2001).

| Typical Error in Metres          | (per satellite) |                  |
|----------------------------------|-----------------|------------------|
|                                  | Standard GPS    | Differential GPS |
| Satellite Clocks                 | 1.5             | 0                |
| Orbit Errors                     | 2.5             | 0                |
| Ionosphere                       | 5.0             | 0.4              |
| Troposphere                      | 0.5             | 0.2              |
| Receiver Noise                   | 0.3             | 0.3              |
| Multipath                        | 0.6             | 0.6              |
| SA                               | 30              | 0                |
| <b>Typical Position Accuracy</b> |                 |                  |
| Horizontal                       | 50              | 1.3              |
| Vertical                         | 78              | 2.0              |
| 3-D                              | 93              | 2.8              |

Figure 7. Summary of GPS Error Sources

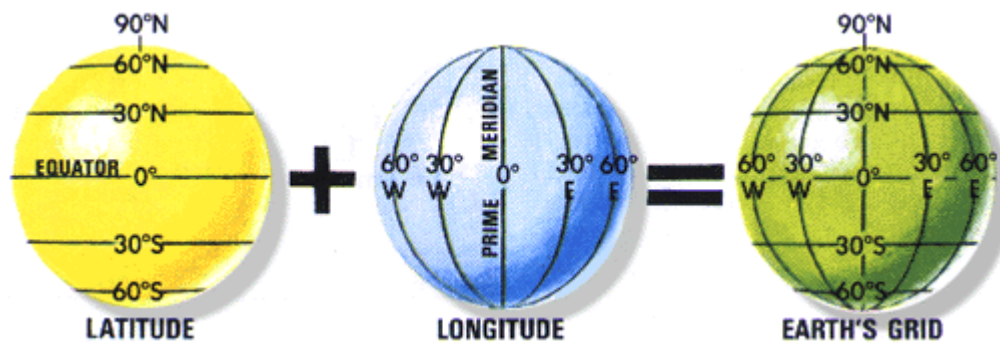


Figure 8. Latitude and Longitude (Trimble, 2001).

### 2.12.2 Degrees, Minutes, and Seconds

Angular measurement must be used in addition to simple plane geometry to specify a location on the earth's surface. This is based on a sexagesimal scale: A circle has 360 degrees, 60 minutes per degree, and 60 seconds per minute.

Therefore, there are 3,600 seconds per degree. For example, 45° 33' 22" (45 degrees, 33 minutes, 22 seconds).

### **2.12.3 GPS in Archaeological Sites**

Only too often there exists no record of the excavation, and the evidence for this has to be found when digging begins, but on other cases there may be a report in a national journal, in the local archaeological society's transactions, the local paper or in the local history collections of the relevant library or record office. Unfortunately, few early excavators, professional or amateur, left plans of the exact positions of their trenches, and their interpretations of their excavations often prove to be wildly inaccurate.

By developing a system, which pinpoints the exact position of each artefact, layer of stratigraphy and building elements in global space, it is possible build up a larger consistent model of all archaeological excavations. Since GPS is a defined standard, about which any point on the earth can be described, it is possible that a multimedia database of archaeological sites could serve as a repository for all archaeological sites worldwide. This would be of great use due to the nature of the problems described above - of archaeological records being found at physically separate locations. A global GPS orientated 3D database of archaeological sites with their finds which could be accessed via the Internet by any researcher would be of great benefit in numerous ways, not least for comparing sites of a typical nature or physical location in order to quickly determine the likelihood of certain effects being present.

# Chapter 3

## Related Work

T

HIS chapter surveys related archaeological software pertaining to stratigraphic visualisation and analysis. This research is carried out to ensure the creation of novel work and to identify possible collaborations. During the course of this research the number of proprietary applications in this area have expanded signifying a growing need for archaeologists to visualise stratigraphy in such a manner.

### 3.1 Harris

In the early 1990s, Herzog and Scollar introduced a fully automated system for producing stratigraphic diagrams, entitled 'Harris' (Herzog, 1991).

The relative chronology of an archaeological site may be obtained by analysing its stratification. The chronological relationships of the site's layers can be visualised with the help of the Harris matrix. The program for Harris Matrix analysis offers the opportunity to enter and change the stratigraphic layers and their time relationships, to check them interactively, to find inconsistent or contradictory relations and to layout the Harris diagram. Any printer supporting the IBM Original equipment manufacturer (OEM) graphic character set may be used for diagram output. Alternatively, the diagram may be plotted with any plotter supporting Hewlett-Packard

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Graphics Language (HPGL) output or the shareware Printglw program can be used to print HPGL data on most printers, see Figure 9.

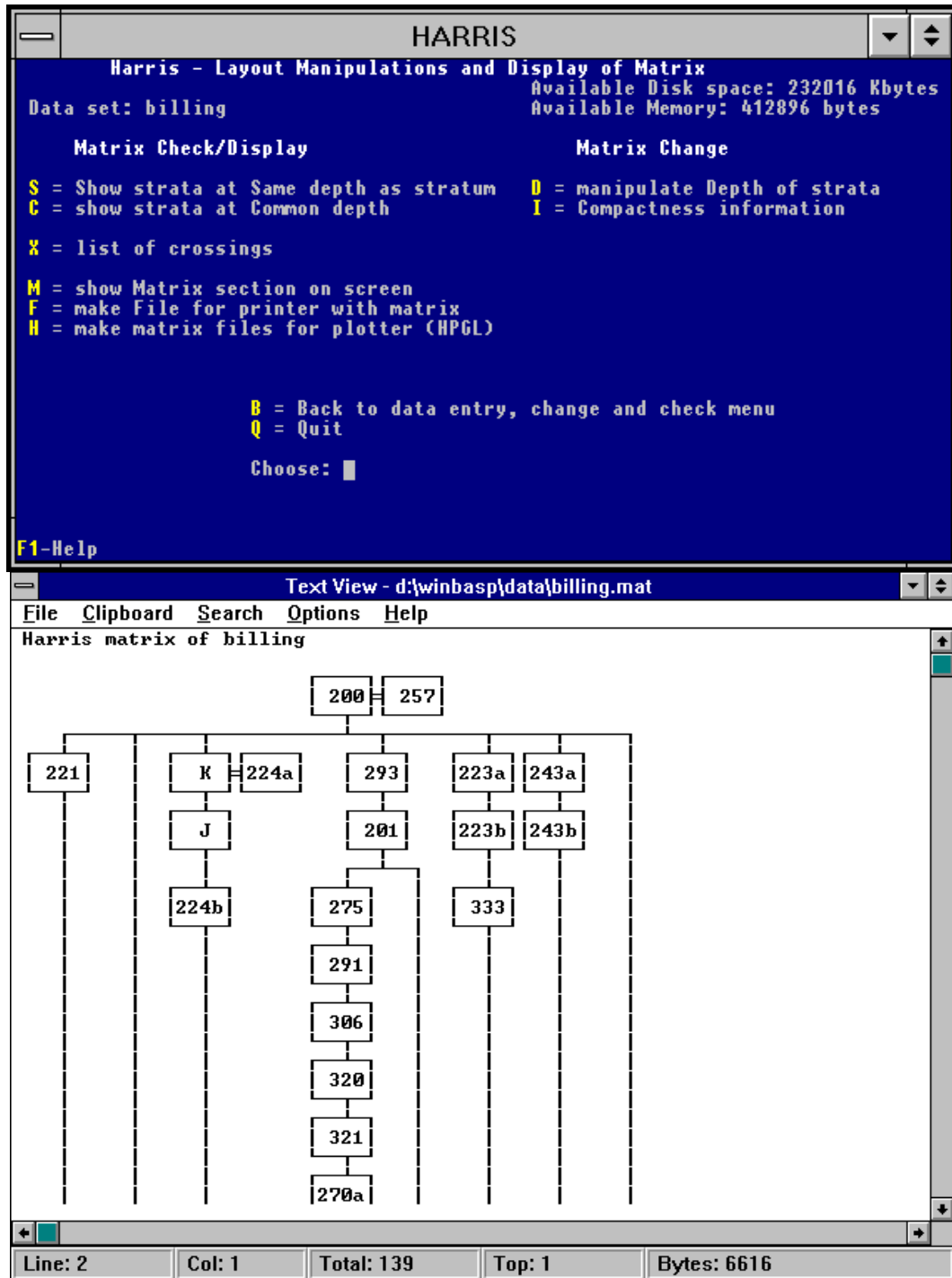


Figure 9. The Harris Matrix program (Herzog ,1991)

### 3.2 ArchEd

The ArchEd program is an interactive tool for visualizing Harris matrices in archaeology (Arched, 1998). Harris matrices can be modelled as hierarchical graphs, where the vertices correspond to the strata and the edges are associated with the "younger than" relations between the corresponding strata.

ArchEd supports different input/output possibilities for Harris matrices. It contains easy-to-use data editing routines (various colour and line styles, data and their relations can be added/deleted interactively), and it is embedded into a comfortable editor, with the ability to perform zooming, undo/redo and printing. The main focus, however, in ArchEd lies on the routines for automatically generating layouts, and on feasibility checking routines.

ArchEd was developed as a student project by Igor Pouchkarev (Pouchkarev, 1999) and Stefan Thome under the supervision of Petra Mutzel, and Christoph Hundack (Hundack, 1997). Since 1998 it has been publicly available on the World Wide Web (Arched, 1998).

Recently, it was decided to revive the development of ArchEd, (Mutzel, 2001) since there has been much feedback from archaeologists using ArchEd for their work.

Procedures for seriation in ArchEd are available. Mutzel *et al.* are currently working on improving the quality of the drawings. The next step is a major redesign of ArchEd in order to get around a serious problem: in windows 95/98, ArchEd users report problems when dealing with big data sets. These problems have their origin in the system library "Microsoft Foundation Classes (MFC)" which is currently used by ArchEd.

The ArchEd program is a tool for drawing Harris matrices that are widely used in archaeology analysis, see Figure 10. Beside its ability to edit such drawings it also contains an automatic drawing feature that redraws the given graph more clearly based on recent graph drawing algorithms. A similar program was developed at the Amt für Bodendenkmalpflege in Bonn in 1990. While this older program runs on DOS systems and uses the

keyboard as input device, ArchEd runs with Win95/98 or WinNT and can also use a mouse as input device.

At the time of writing (2001) the further development of ArchEd was open for discussion with interested archaeologists, and discussions were invited and contacts sought after with regard to the future development of ArchEd.

ArchEd has been commented upon by archaeologists as a very popular tool. This is owing to its well-designed and easy to use user-interface, and its ability to easily create stratigraphic relations and strata and have them redrawn in the best possible manner. The ability to move these relations around and print the resulting diagrams has enabled this software to remain so popular in recent years. The buttons shown on the toolbar are all that is required to create the graphs shown in Figure 10. Relationships are created between strata using a simple dialog-box that allows the user to pick from a list of strata and then pick the relation from a radio button list as shown in Figure 11.



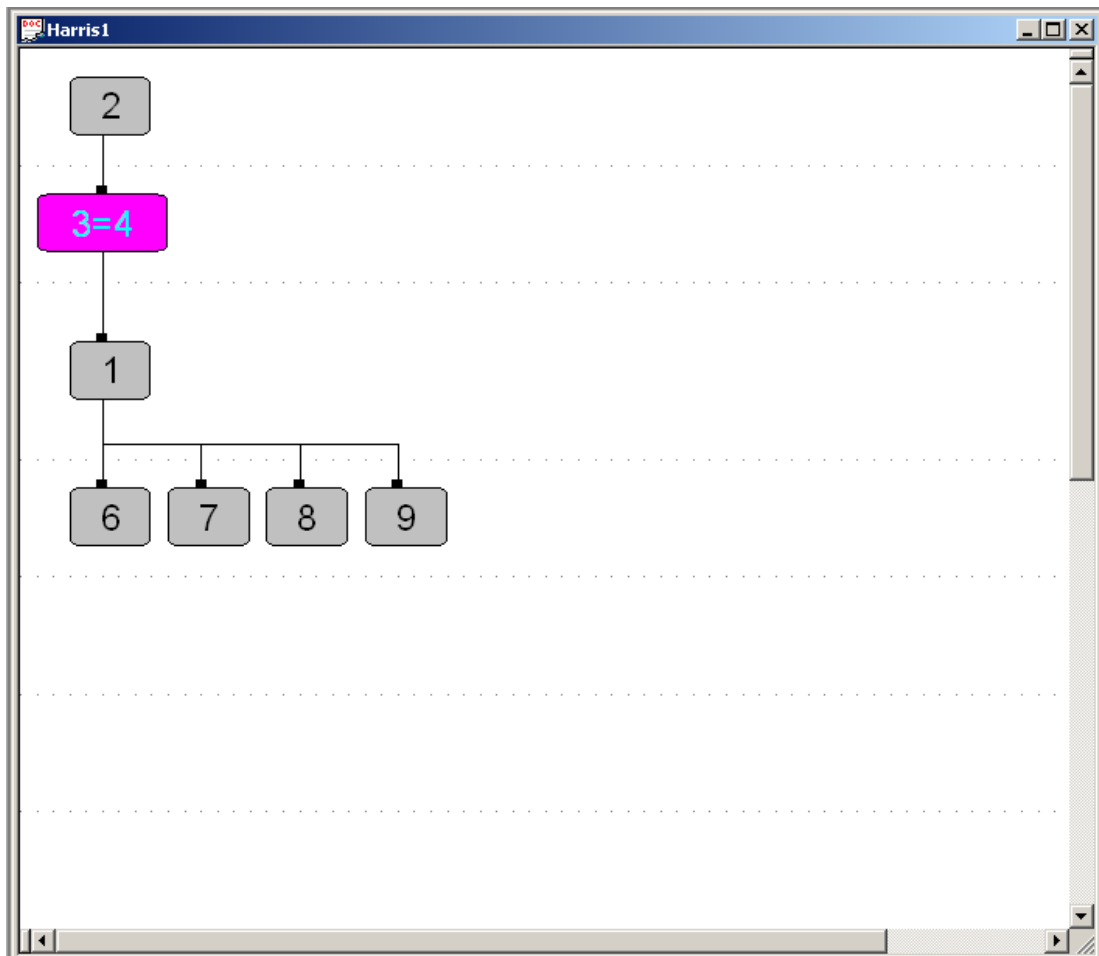


Figure 10. *ArchEd* showing stratigraphic relations.

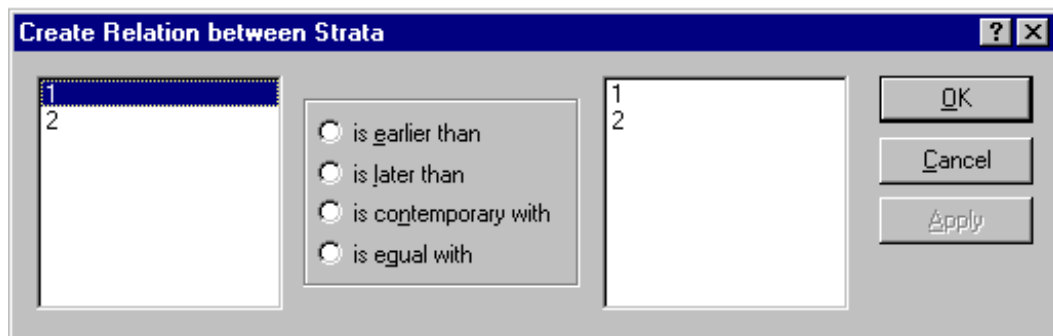


Figure 11. Creating a relationship in the *ArchEd* tool.

Figure 12 shows the output format for an exported “.hm” file (Bonn file) as used by the ArchEd application. This is a text-based format that lists each strata name for each of the four possible relations.

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| Stratigraphic Dataset Harris1 |   |
|-------------------------------|---|
| Name                          |   |
| 2                             | above:<br>contemporary with:<br>equal to:<br>below: 3, 4          |
| 3                             | above: 2<br>contemporary with:<br>equal to: 4<br>below: 1         |
| 4                             | above: 2<br>contemporary with:<br>equal to: 3<br>below: 1         |
| 1                             | above: 3, 4<br>contemporary with:<br>equal to:<br>below: 6, 7, 8, |
| 6                             | above: 1<br>contemporary with:<br>equal to:<br>below:             |
| 7                             | above: 1<br>contemporary with:<br>equal to:<br>below:             |
| 8                             | above: 1<br>contemporary with:<br>equal to:<br>below:             |

Figure 12. Typical output from the ArchEd application,  
a “.hm” file (Bonn file).

### 3.3 Gnet

*Gnet* is a general purpose editor/browser for directed graphs. One of its main uses is as a tool for visualising archaeological stratigraphy, but it is equally suited to a wide range of other applications (Ryan, 2001). Visually the interface (Figure 13) appears similar to Mutzel's *ArchEd* application except for the 2.5D view (Figure 14). *Gnet* was, in fact, a general-purpose network browser/editor, but much of its development was informed by archaeological requirements (Ryan, 2001). Intensive development, in collaboration with excavators in several countries, took place in the first half of the 1990s. Beyond simple error checking and interaction with diagrams, the final system (Ryan, 1995) offered a variety of facilities aimed at post-excavation tasks, including methods for grouping contexts to form phase diagrams and other high-level interpretive abstractions.

*Gnet* was dependent on ODBC to provide connectivity with databases. Pressures of other work and lack of access to suitable development tools meant that Ryan had to abandon development of *gnet* with the introduction of 32 bit versions of Windows and the accompanying changes in ODBC.

After several years of hoping that more recent programs would allow *gnet* to be quietly forgotten, Ryan resurrected the project. *Jnet* was then launched in 2001, intending to offer similar facilities to its predecessor, but with significant improvements in database connectivity, interoperability with other programs, and to enable access from anywhere. Whereas *gnet* was limited to Windows platforms, *jnet* may be used on a variety of desktop and mobile systems as well as through a Web interface.

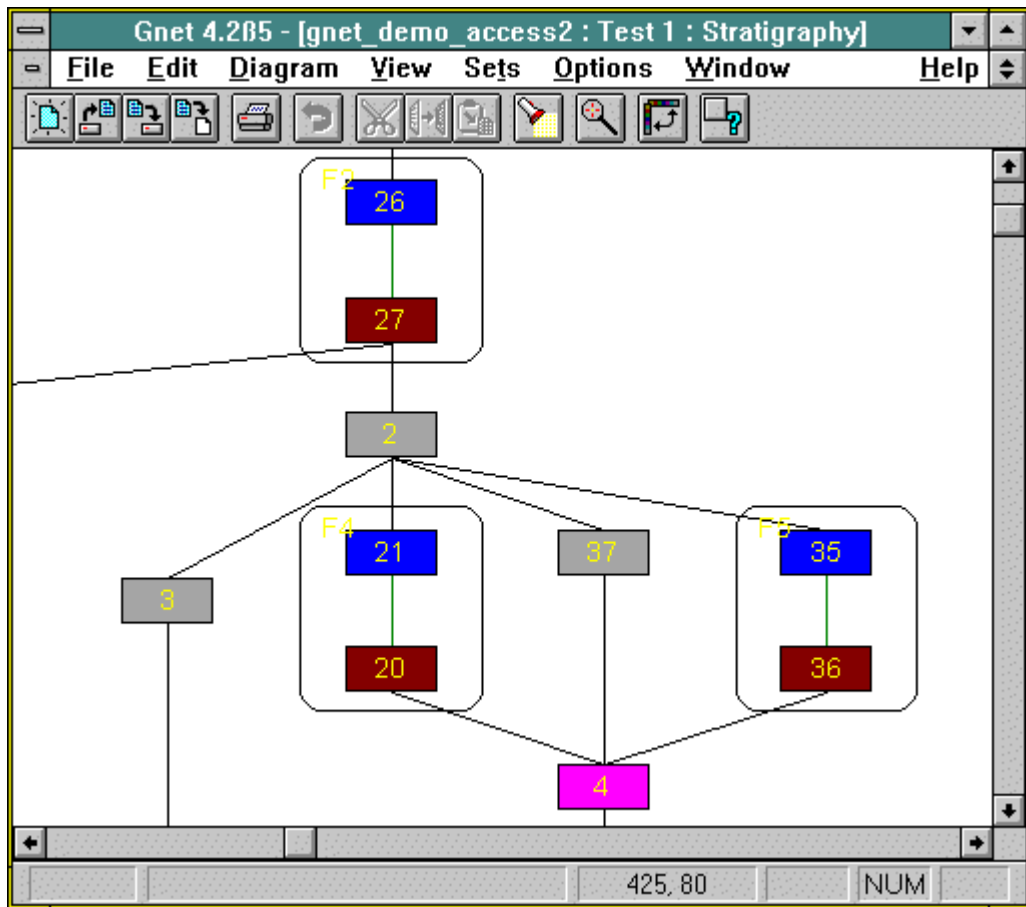


Figure 13. Gnet showing its graph drawing capabilities.

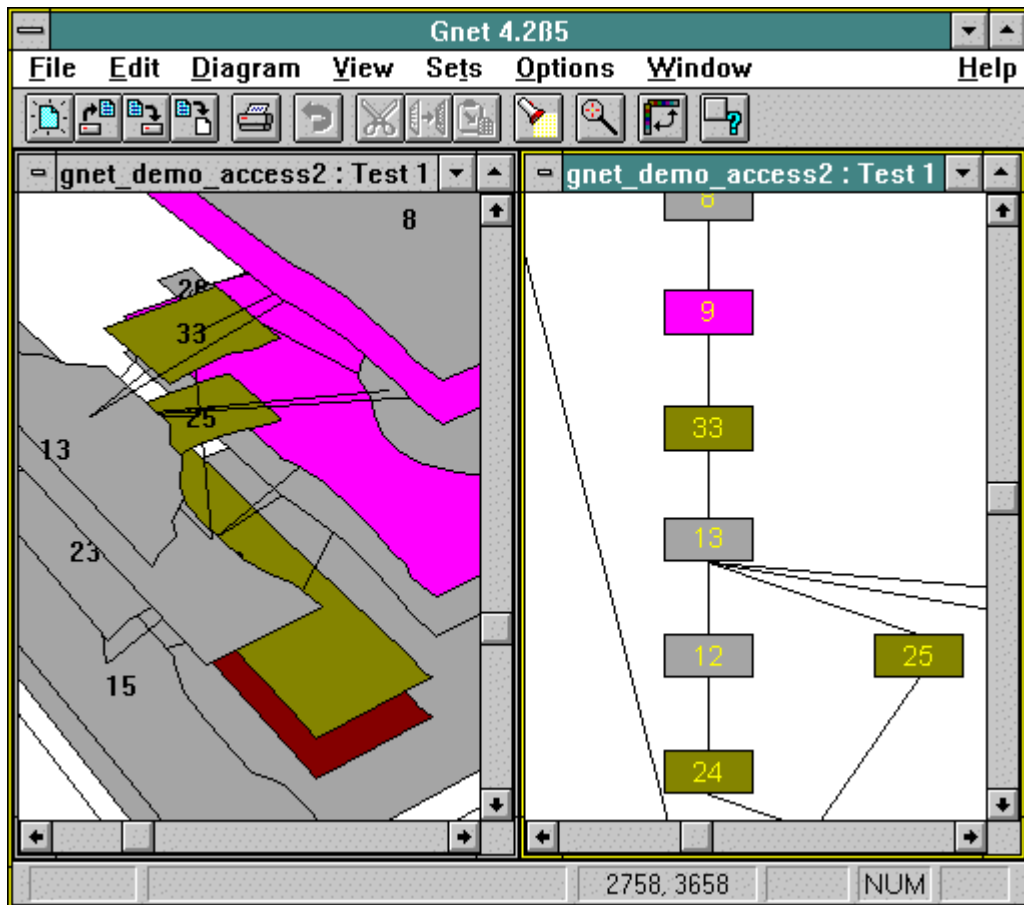


Figure 14. Gnet showing a Harris graph.

### 3.4 ArcheoCAD / AutoCAD

Bibby has developed methods to utilise the softwares ArchaeoCAD and AutoCAD for new ways of stratigraphic visualisations. This is explained in more depth in Section 3.16.

### 3.5 Bonn Archaeological Software Package (BASP)

The Bonn Archaeological Software Package (BASP, 2001) is a non-profit software project for and by archaeologists, which has been developed cooperatively since 1973. It includes more than 70 functions for construction of a relative chronology (seriation), clustering, correspondence analysis, and mapping tools for archaeologists working with IBM compatible PCs under DOS and all versions of Windows. It also includes programs for three dimensional display of data, for finding rectangular structures in scanned

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excavation plans containing thousands of postholes, and for the rectification of extremely oblique aerial photographs and their superimposition on large-scale scanned maps under Windows NT/2000 and Windows 95/98/ME.

The BASP suite of packages includes WinBASP, Airphoto, Displa3D and Posthole. These are described in the following sections.

### 3.5.1 WinBASP

WinBasp (Basp, 2001), (Figure 15) has a consistent user interface using standard Windows menus, dialog boxes, toolbars and toolboxes. Each dialog has its own help that can be called at any time. Learning to use this program is intuitive for all those with any experience with other Windows programs. The programs are all new, with enhanced functions and many additions to those available in the DOS package.

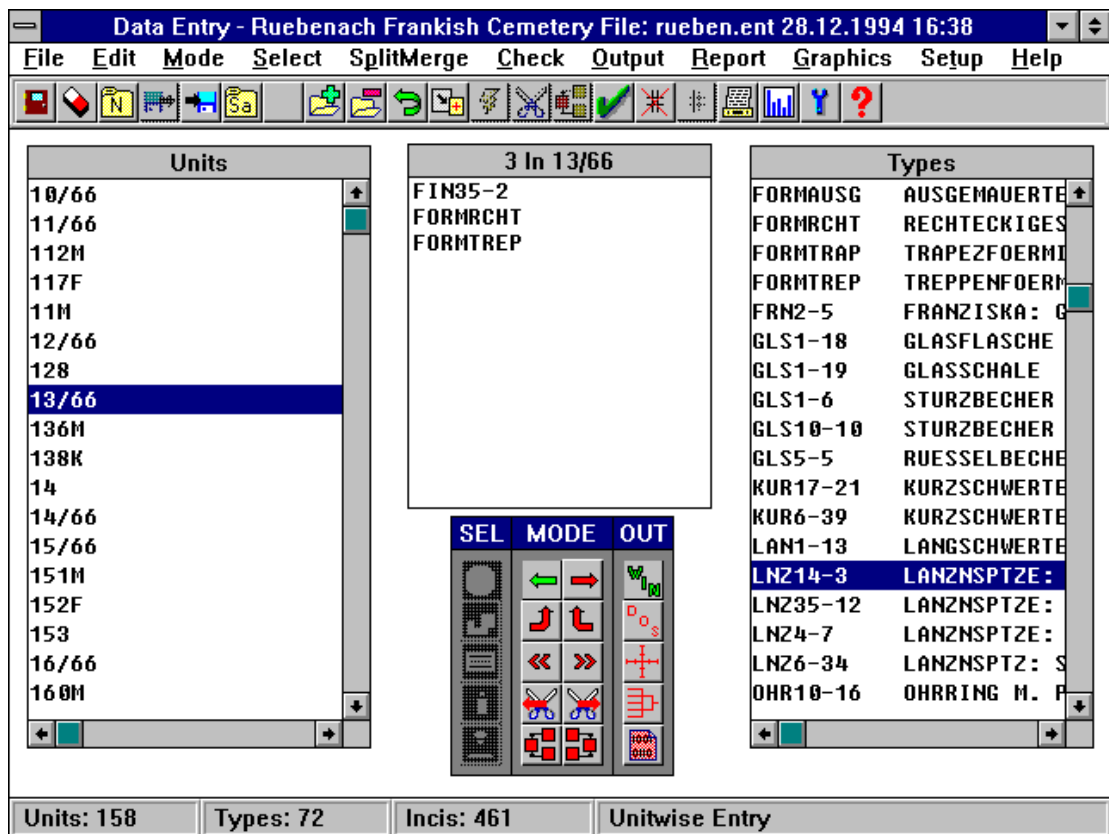


Figure 15. The WinBASP interface

### **3.5.2 AirPhoto**

Irwin Scollar of the Unkelbach Valley Software Works has developed software entitled 'AirPhoto'. AirPhoto provides a tool for archaeologists without large amounts of money to spend on complicated photogrammetric technology that enables them to deal with a reasonable number of the many aerial images that have accumulated over the years. AirPhoto makes orthophotos from scanned extreme obliques and superimposes scanned maps on them in various ways (Figure 16). It is not a photogrammetric plotting program, but a true orthophoto program working from a digital terrain model (DTM) if desired, although the DTM is not required. A DTM may be imported or the program can create one from a collection of manually entered or imported irregular heights. It is designed to give a very fast result with a minimum of handwork apart from the entry of corresponding control points in a picture and a map just by clicking the mouse. Colour or black and white images of various formats may be used or obtained directly from a scanner. Up to four maps may be combined to obtain a result for pictures which show data contained within more than one map. Mosaics may be made from multiple colour or black and white images. The map may be overlaid in black or white with the image(s) or combined with them to give best visibility. If desired, a mosaic may be made with a neutral background for processing elsewhere.

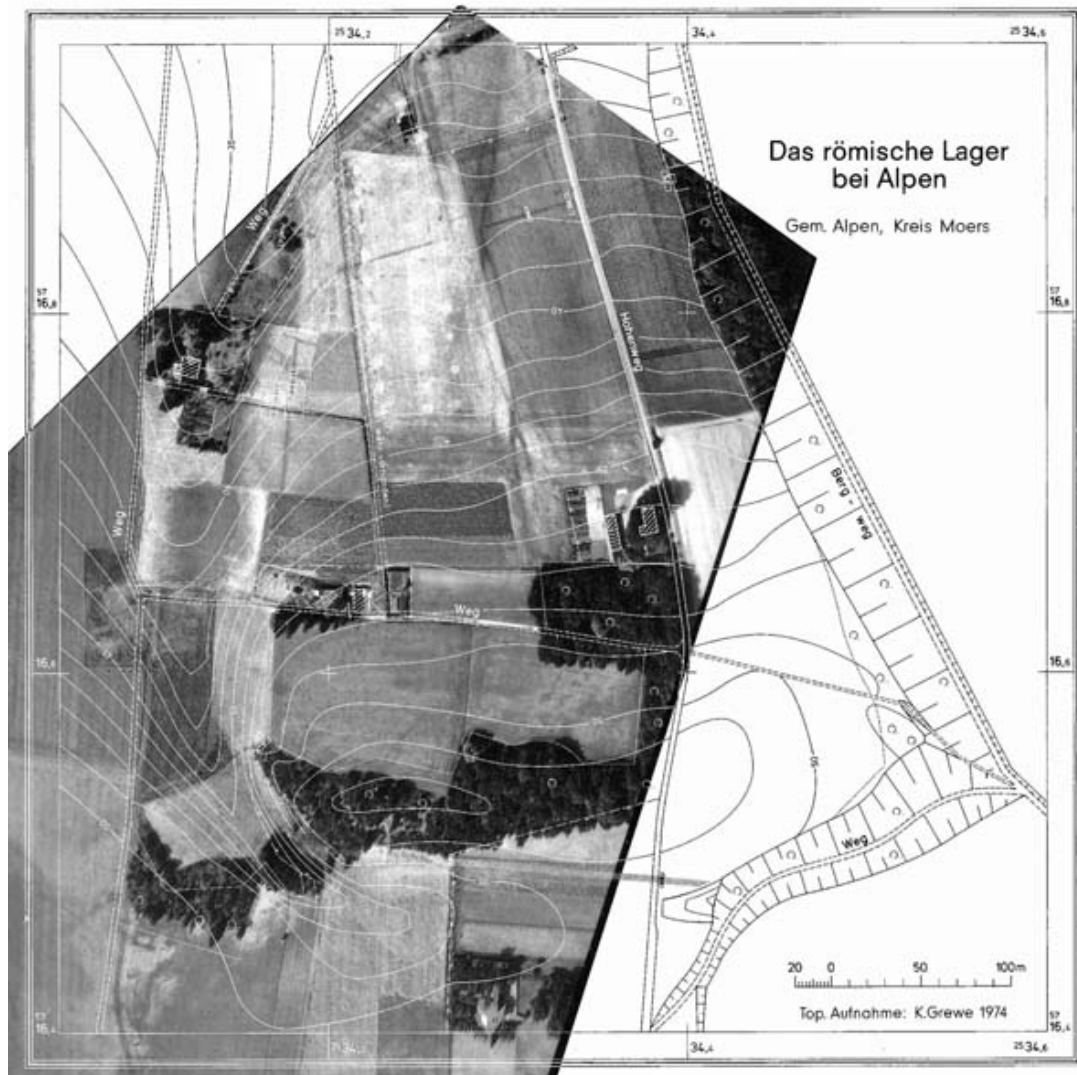


Figure 16. An orthophoto in the Airphoto software.

### 3.5.3 Posthole

Irwin Scollar has also developed *Posthole*, a program for finding and displaying postholes, round or rectangular structures in scanned excavation plans.

With the collaboration of Karel Segeth, director of the Mathematical Institute of the Academy of Sciences of the Czech Republic, Prague, it has been possible to implement a new Windows 95/NT program for detecting rectangular structures in scanned excavation plans or from digitizer output, Figure 17. Karel has devised an especially fast algorithm and a set of data structures that makes very fast searches possible.



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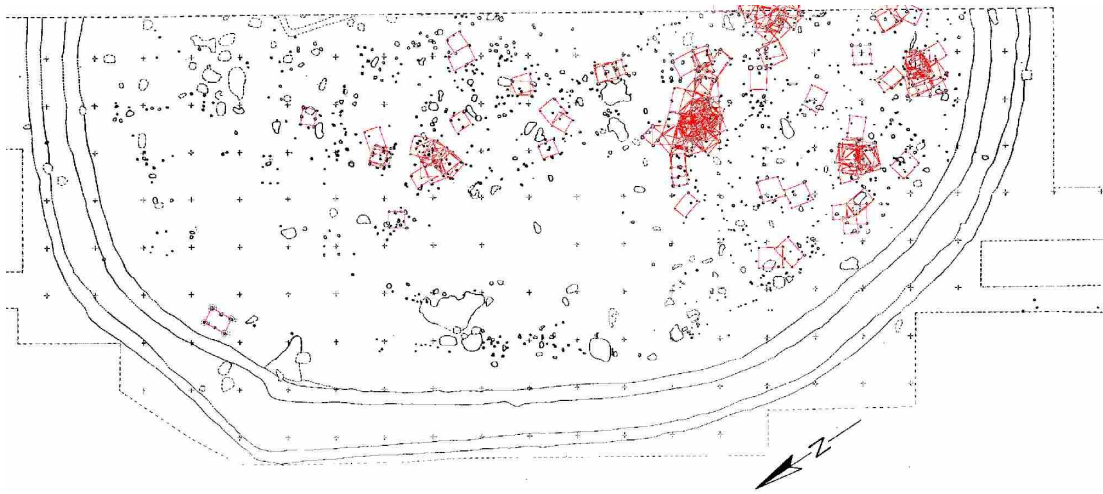


Figure 17. Posthole screenshot.

### 3.5.4 Displa3D

Displa3D is part of the BASP group of software. From a set of irregularly spaced data points with coordinates in the plane, a smooth surface is fitted (see Figure 18). Typical content of a point might be a count of the number of types at that point, representing the local richness of each point, with the surface estimating the distribution of richness over the entire area. If the content is the value of the position in a seriation, then the surface might represent a prediction of chronological distribution over an area. If the content represents presence in a cluster, then the surface might show the scope of each cluster. Any data which can be entered into WinBasp and which contains coordinate information can be displayed as a coloured contour plot, a meshed shaded contoured surface or a number of other variants.

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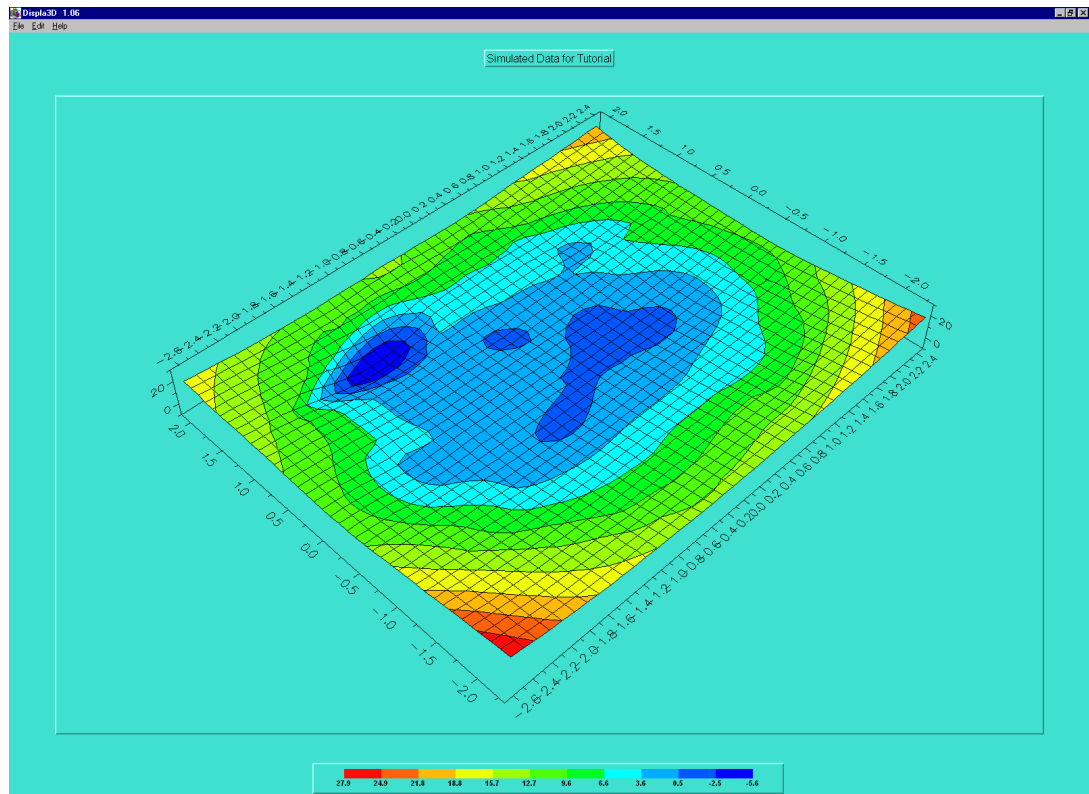


Figure 18. “Displa3D”, part of the BASP suite of applications.

Despite its name, Displa3D is not a truly 3D application. It visualises an isometric view of the data with no way of easily visualising this data from any chosen angle. Figure 19 shows the dialog box for Displa3D. It is small and each tab only contains a small amount of parameters. This makes for an overly complicated interface, which is a deterrent and sharpens the slope of the learning curve.

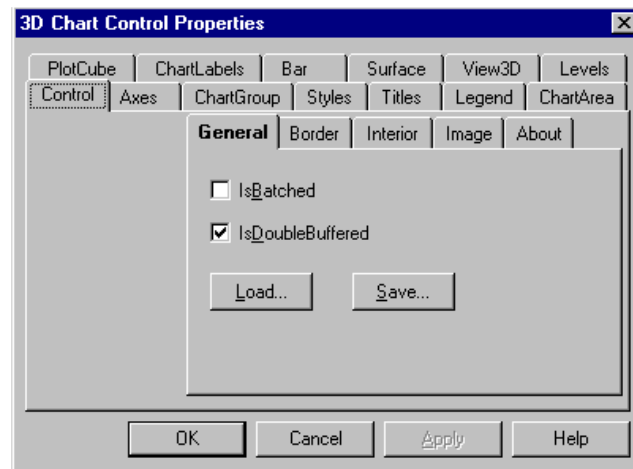


Figure 19. The Displa3D Controls.

### 3.6 StratiGraf

StratiGraf (StratiGraf, 2001) is a recently developed piece of stratigraphic software by Proleg. In the methodology used by StratiGraf, the user works using all the physical relationships of each context. A mathematical model is generated from the physical relationships; see Figure 20 and Figure 21. Once the Harris matrix gets this large it becomes hard to make much sense of the data. This mathematical model can then be used for several functions:

- To calculate and represent the stratigraphic sequence.
- To detect errors.
- To create automatic datings.
- To generate composite site plans.
- To create groupings of contexts.

StratiGraf ensures data consistency by performing real time automatic error detection to spot mistakes such as incorrect relationships among contexts or wrong chronologies. StratiGraf promptly indicates the cause of the error so as to arrive at a proper solution

Interestingly, the creators of this software have organised the hierarchy of their site as follows: site, excavation, trench and SU, whereas this author has named the same units as follows: campaign, site, excavation unit, strata. It becomes apparent that archaeologists need consensus on

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terminology to avoid confusion. Addison addressed this very question at the VAST 2001 conference with the response being that noone wants to sit around a committee table for years on end confirming definitions for every term. This is a fair comment, with the future outcome of terminology possibly being determined by the terminology used by leading software or publications in the subject. The Stratigraf software is probably closest to what archaeologists have been looking for in terms of complete archaeological storage and visualisation.

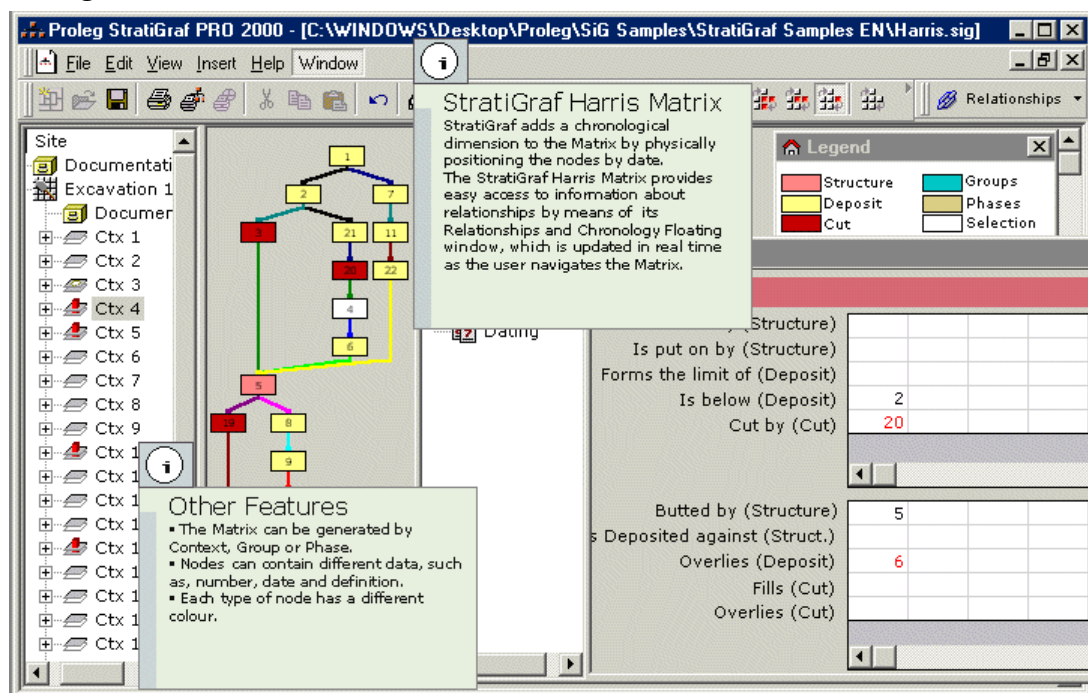


Figure 20. The StratiGraf software showing Harris matrix.

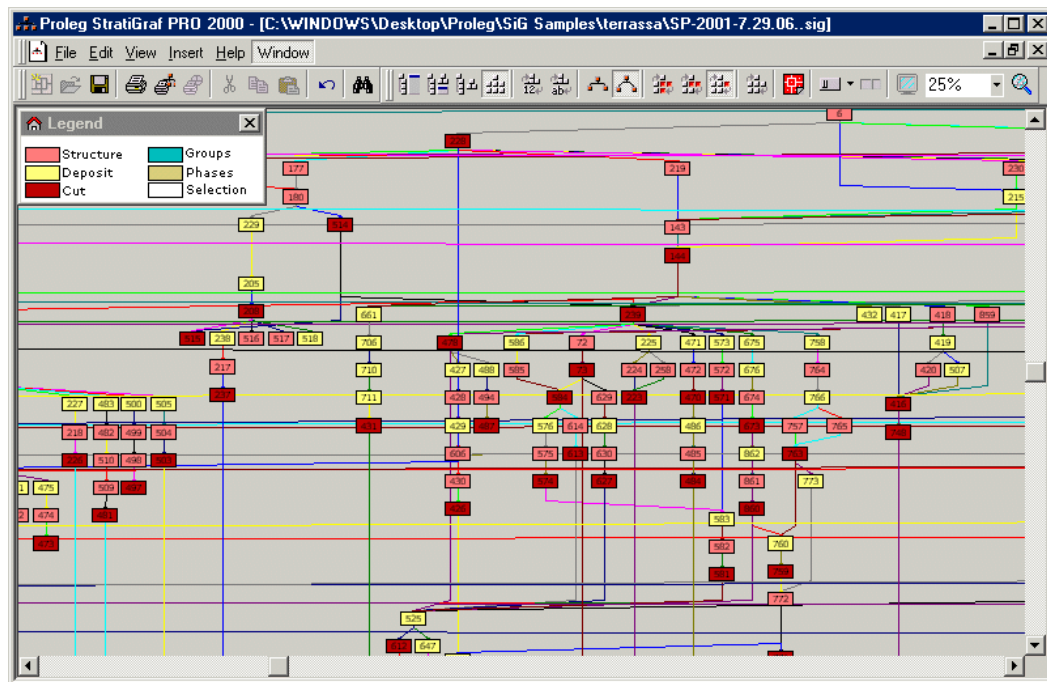


Figure 21. StratiGraf's Harris Matrix capabilities

### 3.7 Virtual Dig

Virtual dig (Dibble, 2000) teaches students the basics of excavation methods in archaeology using computers. The program has been designed to provide a “feel” for doing archaeology without the time and expense of field school. Although it is not a substitute for field experience, it gives students an opportunity to address issues that are not always presented in the typical classroom situation, such as how to set up a research design, deal with the logistics of a field project, and develop a fundable budget. As such, Virtual Dig claims to be more realistic than a standard text and provides opportunities to explore a wide range of situations that are encountered in the field. The interactive nature of the program allows students to experiment using different excavation techniques.

To investigate how far this software goes in visualising stratigraphy, various parameters were set up to perform a dig and various units were selected to be excavated. The units are marked with a blue square on a low-resolution hand drawn plan image of the site (see Figure 22). Once the user has defined units to be excavated, they can then begin excavation by pressing a button. This then opens another dialog box (See Figure 23) that

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shows a plan view of the excavation unit and a profile indicating depths of each stratum.

This software is basic at best. It does not provide the user with real archaeological data and does not allow the detailed recording of any type of archaeological data. Layers are excavated in fixed heights and there is no way of seeing the data from any other dimension other than plan view. The graphics are all synthesised and as such this software provides little in the way of scientific value.

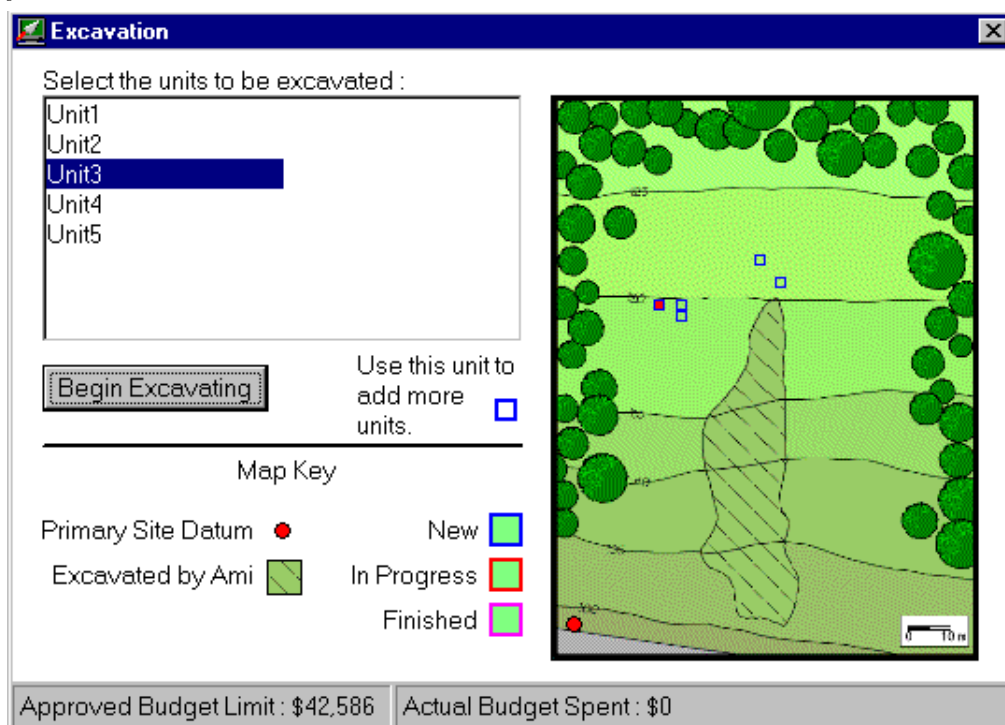


Figure 22. Setting up excavation units in the Virtual Dig application.

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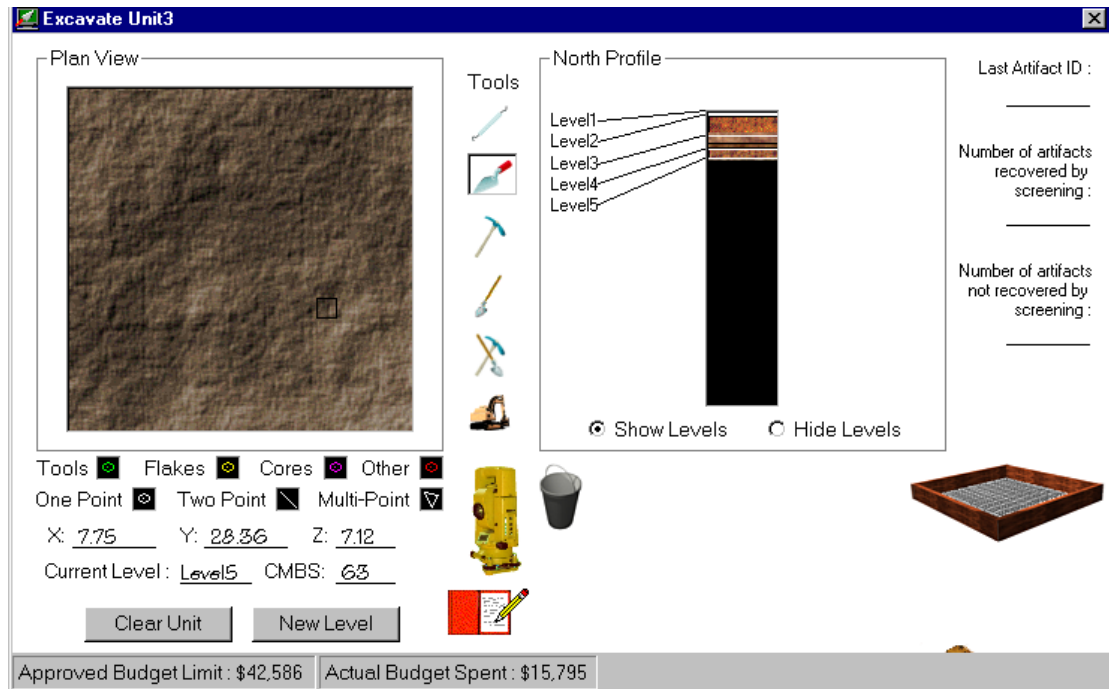


Figure 23. Excavating a unit in the Virtual Dig Application

### 3.8 ArcDig

ArcDig v0.02 is a Windows program designed to present information about an archaeological site in a new way (Warden, 2001). ArcDig is a program that allows you to dig down through a site's layers, discover and examine finds, and go to web pages that give further information.

ArcDig is a simple piece of software, which on the surface appears aesthetically pleasing. The user can toggle between the crop markings or the results of the geophysics survey (Figure 24). The user selects the position of the trench they wish to excavate, by first drawing a line to specify the width, releasing the mouse and then dragging the mouse to specify the width. Releasing the mouse once again and then pressing the mouse button allows the user to define the depth of the trench. The problem with this method is that, if the user wants to dig a trench deeper than a few metres they need to position the cursor off the screen, which then switches to another application. Also, once a trench has been excavated, it is not possible to excavate it further. The window is a fixed size and any user attempts to resize it, result in the window flying to the top-left hand corner of the screen.

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ArcDig also comes with an editor. This has limited capabilities, allowing the user to move around Roman coins, mediaeval pottery, postholes and an Anglo Saxon burial; all of which are represented with low-resolution 2D bitmaps. The user can create their own sites, by specifying a depth in cm, for example, 10 cm and then importing a graphic they have previously scanned or drawn which will then remain fixed at that layer until the user then later excavates it with the main ArcDig application. The user sets the extents of the artefact's depth in a properties window. Navigation is flawed and the user cannot simply see through the layers to visualise finds. There is no way to enter exact global positions of artefacts, or building elements, no way of orienting artefacts or performing analysis and although at face value this looks visually pleasing, it has no scientific value with regard to real stratigraphic layering.

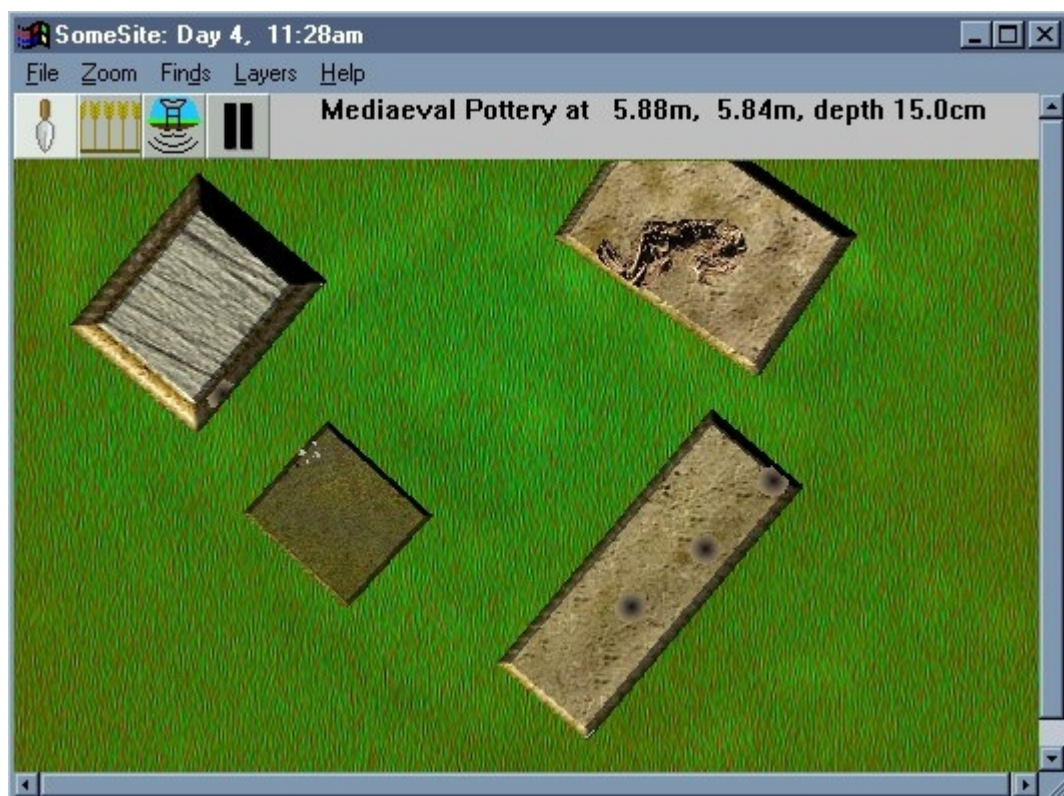


Figure 24. A screenshot of the “ArcDig” application



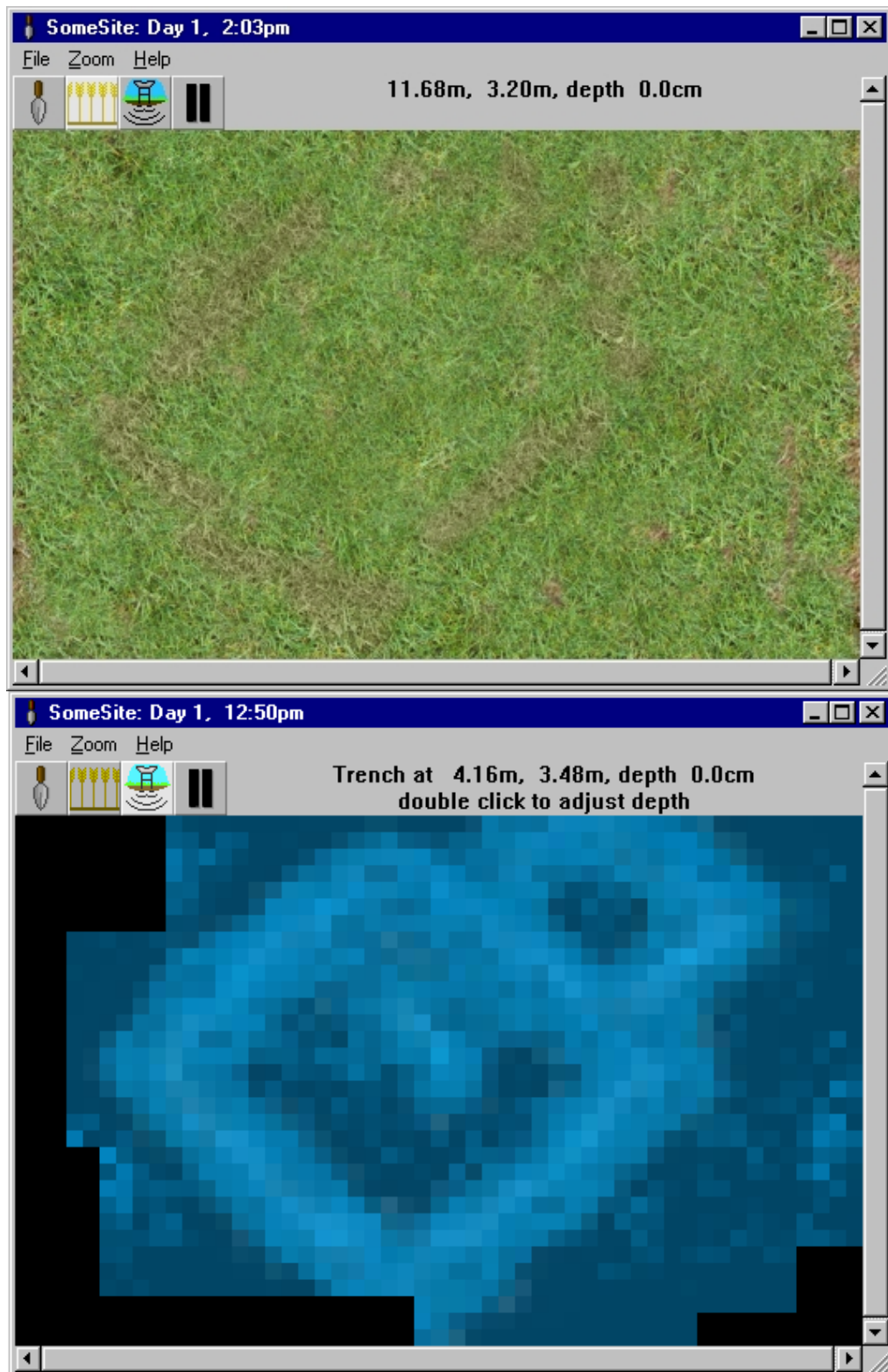


Figure 25. ArcDig showing the crop markings and the results of the geo-physics survey.

### 3.9 ArcView

ArcView (ArcView, 2002) makes it easy to create maps and add data to them. Using ArcView's visualization tools, records can be accessed from existing databases and displayed on maps.

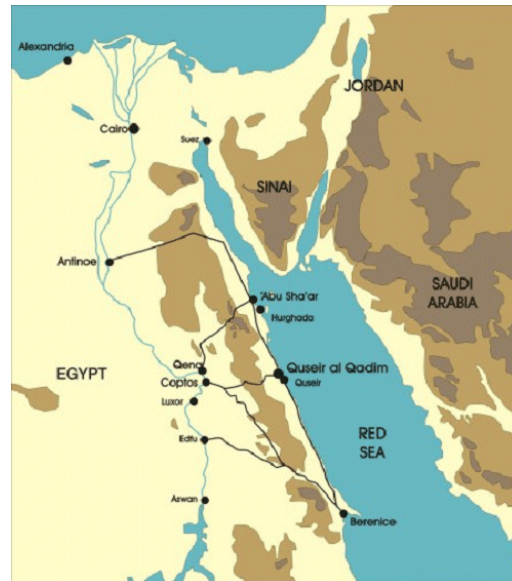


Figure 26. Location of Quesir al-Qadim

It has an easy-to-use interface, integrating charts, maps, tables, graphics, and multimedia. It has powerful visual mapping, and cartographic wizards facilitate high-quality map composition. ArcView includes easy-to-use labelling and text tools, thousands of industry/application-specific symbols, enhanced report writing using Crystal Reports, and a shapefile projection wizard. It has on-the-fly data updating and exceptional analysis capabilities. Analysis wizards facilitate geoprocessing operations such as buffer, dissolve, merge, clip, intersect, and union. High-end address matching and geocoding is included. It has a strong editing environment, geographic hot links to all supported data formats are included and it can integrate images, CAD, map data, tables, and SQL databases. It includes comprehensive database access and seamless client/server access to data warehouses.

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ArcView is used at archaeological sites such as that of Quseir al-Qadim on the southern Egyptian Red Sea coast, (Figure 26, Figure 27) and its surrounding landscape (Quseir, 2001). The project is a collaboration between researchers from a number of institutions worldwide and is particularly focussed on the sharing and representation of archaeological knowledge.

The site of Quseir al-Qadim (old Quseir) is eight kilometres north of the modern town of Quseir, on the Egyptian Red Sea coast. (Figure 27). The site is believed to be the port of Myos Hormos, referred to by Pliny, Strabo and other ancient authors, and thus a very important part of the route between the East and the Mediterranean.

Excavation at Quseir has revealed a wide range of exciting architectural and artefactual information. Since 1999 a large area of the proposed occupation area has been examined, based in part on information from an intensive survey of the area.

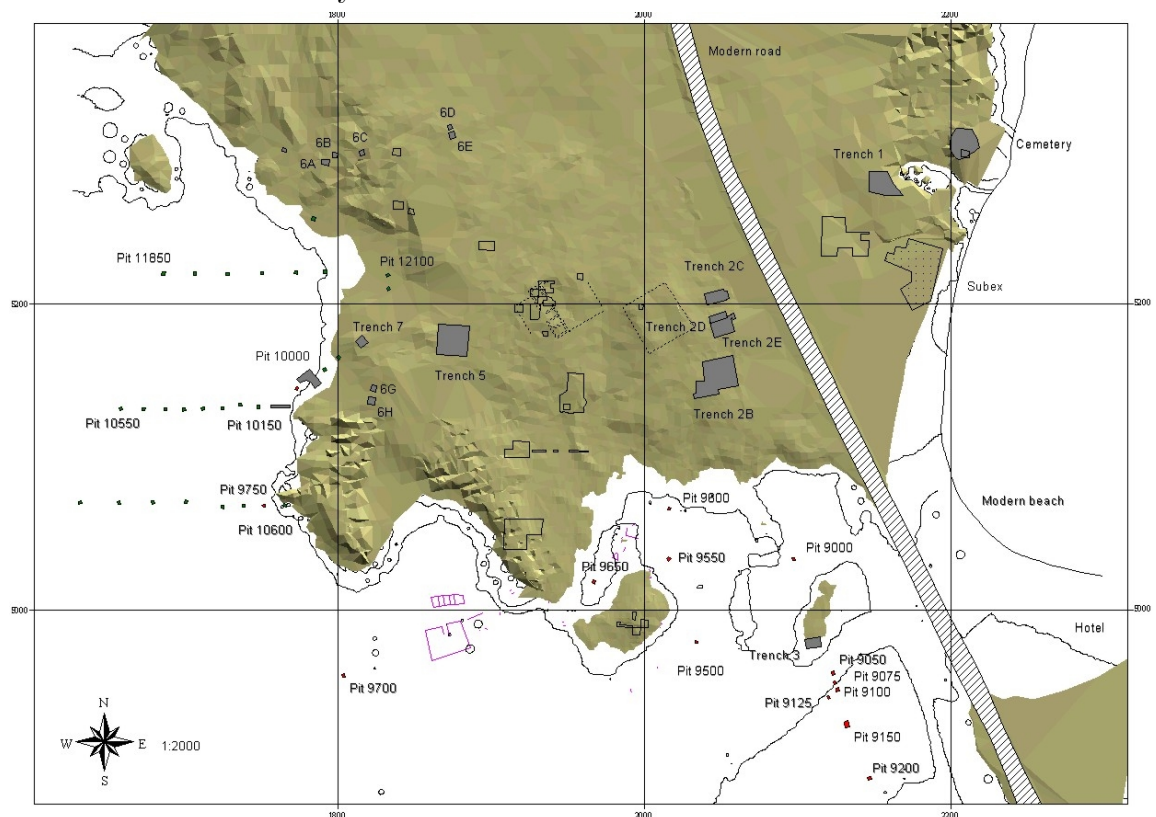


Figure 27. Excavation area plan produced in ArcView GIS for the site at Quseir al-Qadim.

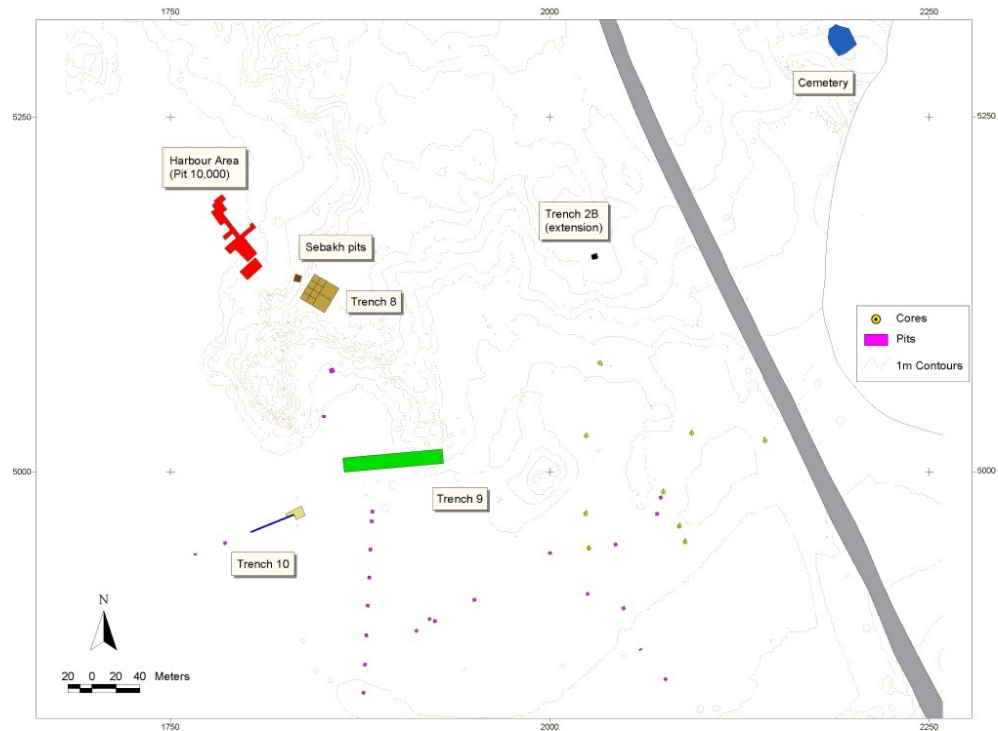


Figure 28. Quseir al-Qadim site plan incorporating 2001 season data.

### 3.10 Visual Groundwater

Visual Groundwater (Scientific Software, 2001) is a 3D visualization software package that groundwater and environmental professionals use to deliver high-quality, three-dimensional presentations of subsurface characterization data and groundwater-modelling results, as illustrated in Figure 29.

Visual Groundwater has pioneered a new frontier in subsurface visualization and animation by combining state-of-the-art graphical tools for 3D visualization and animation with a data management system specifically designed for borehole investigation data. Visual Groundwater also comes with a data conversion utility to create 3D data files using Visual MODFLOW models, random X, Y, Z data, and gridded data sets.

The user can easily create 3D images of complex site characterization data and modelling results in just minutes. The advanced visualization tools provide interactive visualization capabilities for manipulating and rotating multiple three-dimensional data sets such as geological layering.

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With these features, Visual Groundwater is one of the most powerful and versatile 3D visualization and animation software packages available.

Due to the cost of this product, (US\$1695 in October 2001) it was not possible to evaluate this product, but this fact alone makes it inaccessible to many field archaeologists.

Although this software is primarily designed for groundwater applications, it has many features that are of use to an archaeologist visualising stratigraphy.

Planar slices can be used to create cross-sectional views through the site domain along any axis and at any angle or orientation. All slices can be used to show colour shaded and/or line contours for any scalar data. Commonly displayed scalar data includes soil lithology, water levels (heads and drawdown), soil and groundwater chemistry, hydraulic conductivity zones and so on. In addition, arrows and streamlines can be plotted on a slice to represent vector data such as groundwater flow velocities and directions.

It also allows the plotting and comparison of multiple scalar values on the same slice.

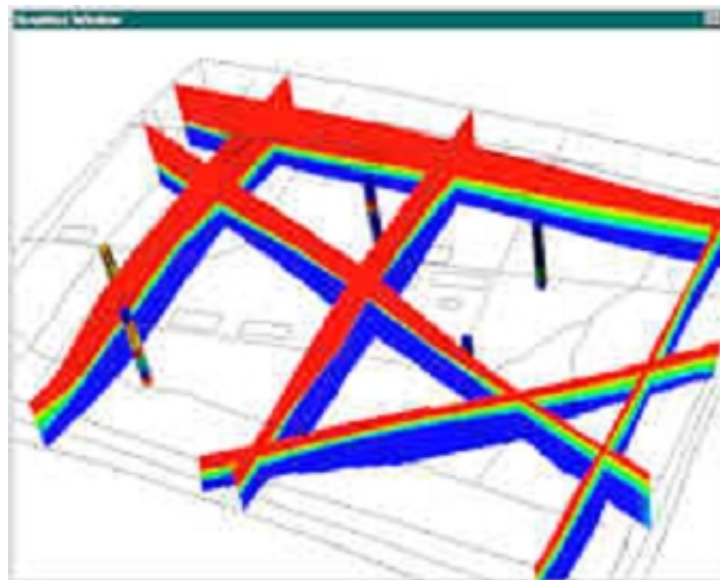


Figure 29. Slices shown in the Visual Groundwater application.

Visual Groundwater allows the display configuration to be saved. This feature stores all of the display settings (including animation and rotation) so

that the configuration file can be reloaded and the Visual Groundwater data files will be automatically re-loaded and the display settings will be automatically re-created. This feature is very important as it saves you time by eliminating the repetitive steps involved in re-creating previously constructed views.

### **3.11 Wellplot**

WellPlot 2.5 is a stratigraphic data analysis and charting application that plots multiple categories (up to 600 columns) against depth or sequence of samples, as illustrated in Figure 30 (Zippi, 2001). It reads data directly from spreadsheets. Sums, percentage and concentration data can be calculated and saved. Plot types include multi-track x-y line plots, butterfly diagrams, bar charts, interval histogram range charts, range-through charts, percent events plots and cumulative data plots with 1st derivative. The Y-axis (depth) can be scaled to depth or sequential samples. The X-axis can be normal (arithmetic) or LOG scale, and absolute or normalized. Exaggeration may be applied to low abundance groups. The charts can be scaled to any horizontal and vertical dimension. Stratigraphic ranges can be looked up. WellPlot can be used to plot many other types of well data such geochemical or petrological.

This software has not received much interest from archaeologists and is more suited to geological purposes than stratigraphic applications.

It provides more statistical functionality than analytical in terms of stratigraphic comparisons or redundancy checking. At the time of printing this software was retailing for \$500 USD for non-profit use, within an archaeologists budget perhaps, but probably not directly suited.



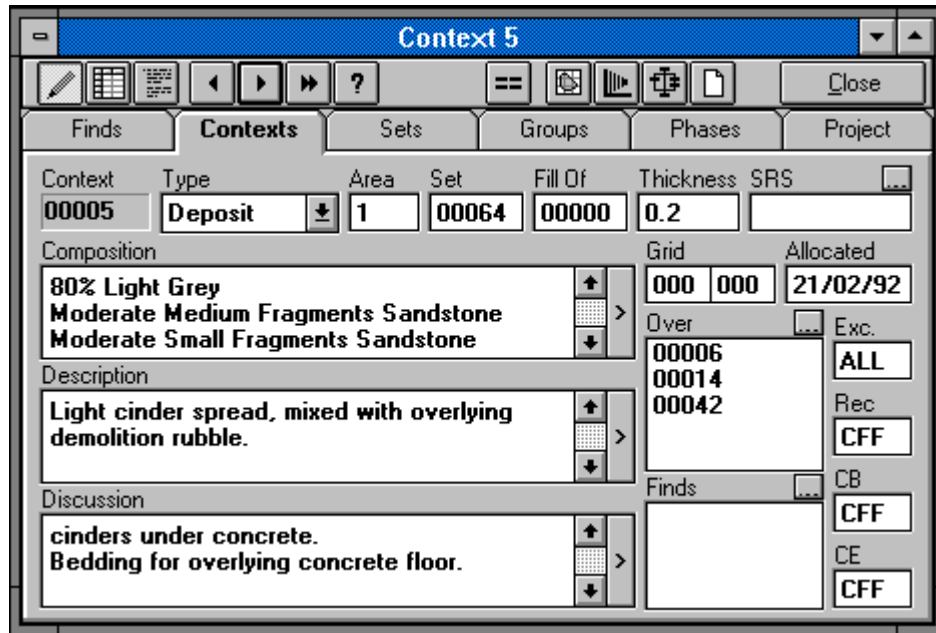


Figure 31. Context data input window in the IADB system.

Each basic Find or Context record only contains data fields that are applicable to all Finds or all Contexts. More specialised data applicable only to a specific class of Finds or Contexts is recorded using Specialised Recording Sheets (SRSs), a term that derives from one aspect of the paper-based site recording system developed by Pete Clark while at SUAT and known as the Toolbox system. Three computerised equivalents of the SRSs are in use at present for Pottery, Skeletons (Figure 32), and Timber. All single context plans are digitised using AEGIS, which is now fully integrated into the IADB system, as shown in Figure 33. It is interesting to note that the level of stratigraphic complexity in this software is low, it only allows for a single depth measurement to be recorded. However, single context plans can be made used allowing two dimensions of detail.



**Skeleton Record: Context 250**

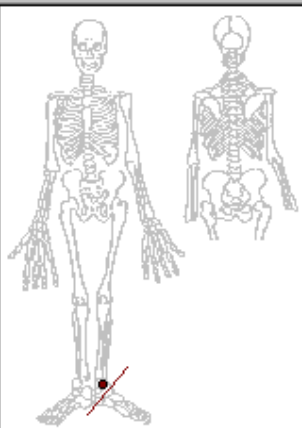
|  |  |   |  |   |  |
|--|--|---|--|---|--|
| Alignment<br><b>N-S</b>  |  | Coffin Type<br><b>Wood</b>  |  |  |  |
| Condition of Bone<br><b>Good</b> <input checked="" type="checkbox"/> Articulated   |  |   |  |   |  |
| Grave<br>Cut: <b>102</b> Fill: <b>103</b>  |  | Levels<br>Skull: <b>12.46</b> Pelvis: <b>12.38</b> Feet: <b>12.31</b> |  |   |  |
| Measurements<br>Humerus: <b>400</b> Ulna: <b>400</b> Radius: <b>380</b> Femur: <b>520</b> Tibia: <b>490</b> Fibula: <b>470</b> |  |   |  |   |  |
| Description<br><b>Example Skeleton record - see SRS.</b>   |  |   |  |   |  |
| Interpretation<br><b>This is a test.</b>   |  |   |  |   |  |

Figure 32. Skeleton SRS recording window in the IADB system.

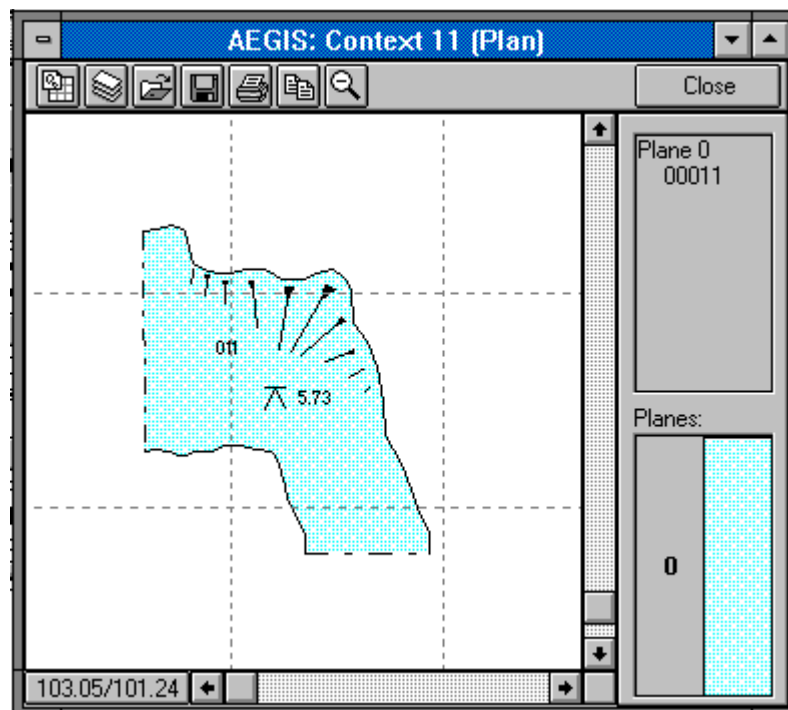


Figure 33. AEGIS plan window in the IADB system.

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The IADB system includes the CONSORT matrix compiler and a matrix editor that can be used together to produce stratigraphic matrices from the underlying Context relationships.

The matrix compiler is used to check all stratigraphic relationships for integrity and then produce a raw matrix in which related contexts are linked by joining lines. The matrix editor can then be used to move individual contexts or groups of contexts to improve the layout and appearance of the matrix while maintaining the stratigraphic links (Figure 34). The completed matrix can then be exported to Corel Draw or another illustration program for finishing. This type of graph drawing is not as highly developed as that used in the ArchEd software. There are noticeable crossing lines, something which the ArchEd software does a good job of removing, see page 27.

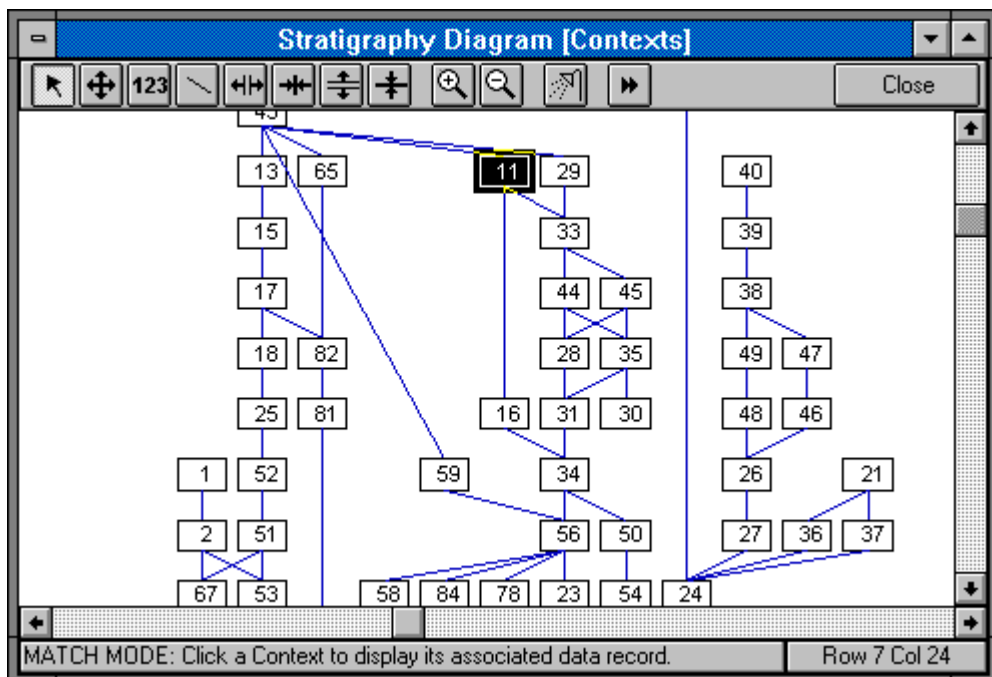


Figure 34. Stratigraphic matrix window in the IADB system.

The photographic record includes both traditional slides and prints that may be digitised using any standard scanner, but can also include purely digital images such as those obtained with a digital camera.

The completed Level II data records form a fully cross-referenced resource for use in post-excavation analysis, during which the higher levels of

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the data hierarchy (Sets, Groups and Phases) are developed. All elements of the Level II data, including text, plans, stratigraphic matrices and photographs, are available in a fully cross-referenced and easily accessible form.

For the development of Level III records, free text notepads, each up to 65,000 characters long, are provided for each Set, Group and Phase. These are the "factory floor" of the IADB system in post-excavation. It is here that textual descriptions of the Level III objects are assembled and it is usually in this window that Contexts are assigned to Sets, Sets to Groups and so on, although Contexts can be assigned to Sets individually Context by Context if required. In assembling Set, Group and Phase descriptions the standard Windows Cut, Copy and Paste commands are used to minimise the amount of retyping required.

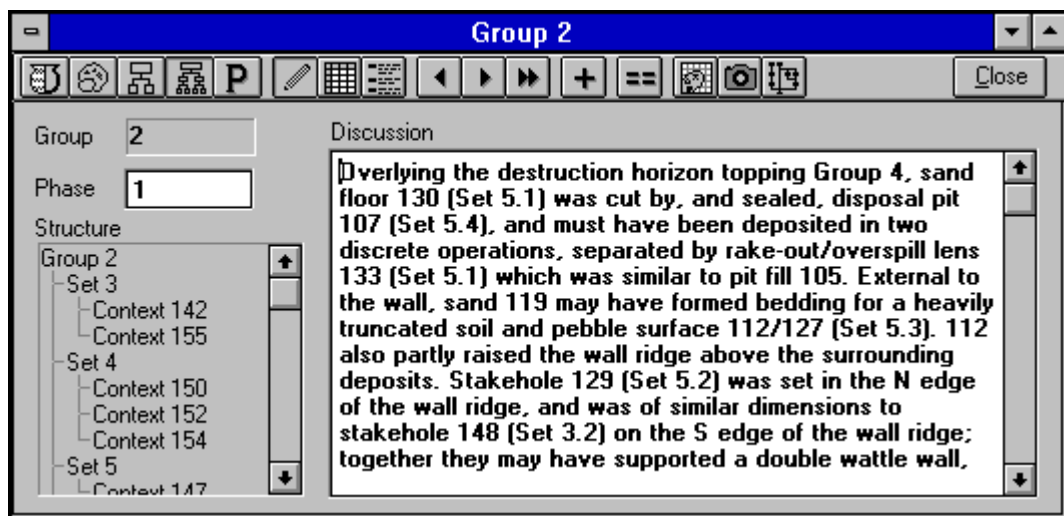


Figure 35. Group data input window

From any Set, Group, or Phase, the user can drill-down to the underlying data objects and examine any aspect of them. Each Set, Group, and Phase window contains a visual display of the underlying structure of the object that will be familiar to all users of the Windows File Manager. These structure lists, and all other places where Find, Context, Set, Group or Phase numbers appear, are "live" in that double-clicking on them will display the data window for the selected item.

The full integration of AEGIS For Windows into the IADB system allows composite plans (Figure 36), such as a Group plan, to be generated automatically, manually, or by using a combination of the two methods. Typically, a Phase plan will be generated automatically and will initially include all Contexts assigned to the phase with their order of superimposition controlled by the stratigraphic relationships of the Contexts. It might then be decided to manually remove one or more Contexts from the plan (but not from the Phase) to improve the overall clarity of the plan. All AEGIS plans can be saved as Windows metafiles, which makes them accessible to WordPerfect and many other Windows applications including, for example, Corel Draw. An AEGIS plan file to AutoCAD DXF file conversion utility is also available.

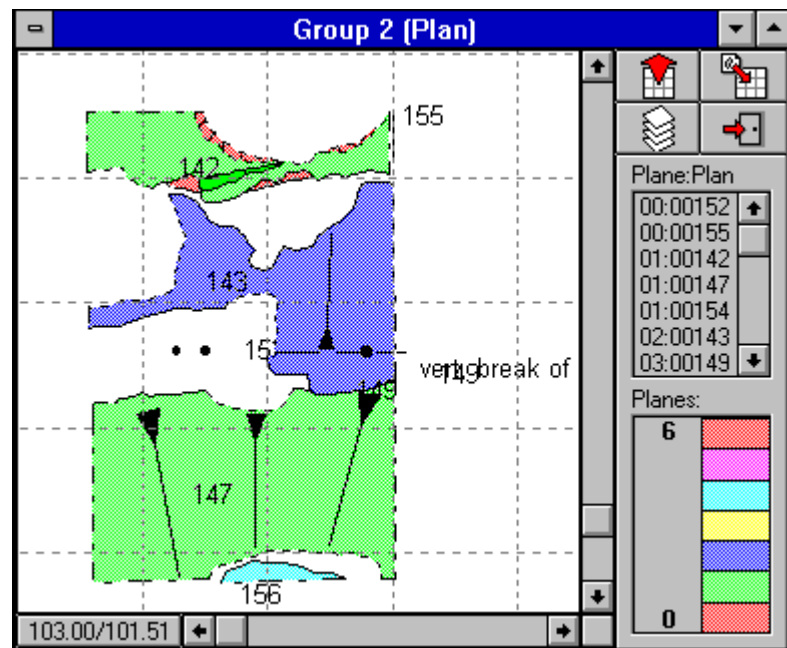


Figure 36. Composite group plan

Because within the SUAT recording system, Sets are always defined stratigraphically, Set matrices can be produced in a similar way. In this case Set relationships are taken to be the sum of the stratigraphic relationships of their constituent contexts. Groups and Phases on the other hand are not generally defined in purely stratigraphic terms and so automatic generation of

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Group and Phase matrices is not possible. However they can be built manually using the matrix editor.

Full access to ANSI standard SQL (Standard Query Language) is provided for simple or complex interrogation of all underlying data tables. Complex SQL query definitions can be saved for later reuse, and replaceable parameters may be used to build generic query definitions. Suitable SQL query result tables may also be graphed in a number of styles (Figure 37).

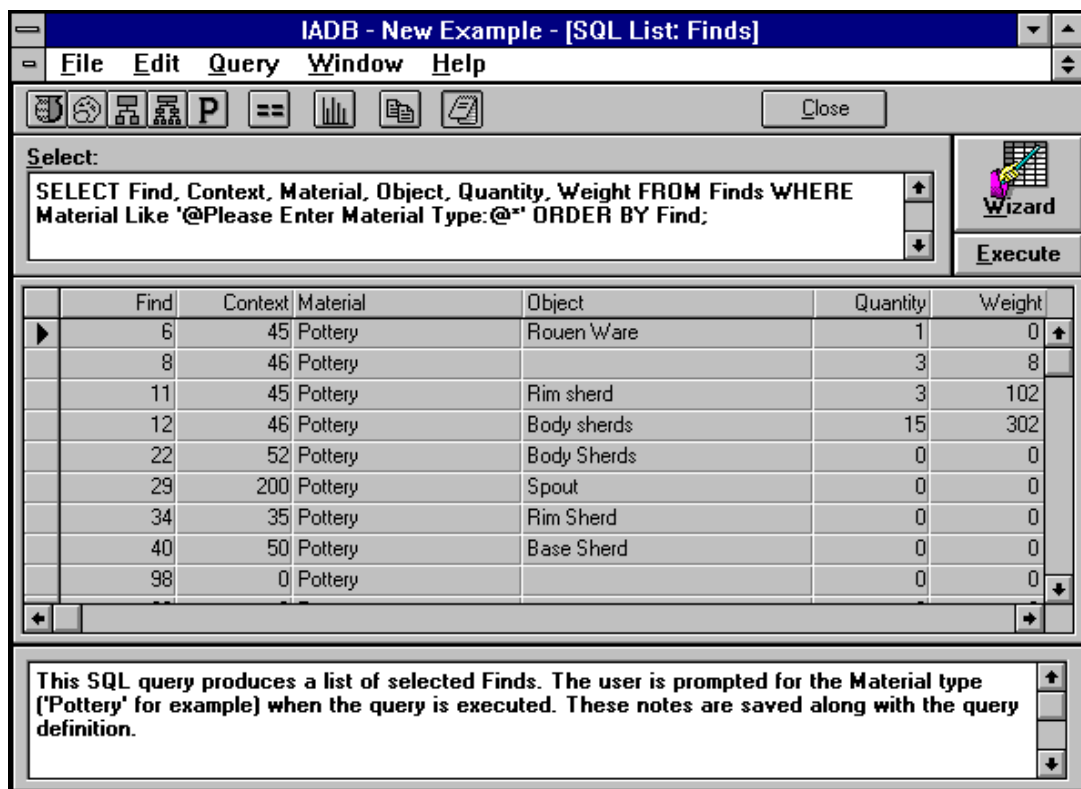


Figure 37. SQL query window of IADB.

As with Data Input windows, wherever Find, Context, Set, Group, or Phase numbers appear in an SQL query result table, an AEGIS plan window, or a stratigraphic Matrix window, they are "live". Double-clicking on one will automatically display the appropriate aspect of the underlying data record in any other open windows. In this way, for example, SQL query result tables or Matrix windows may be used as Plan browsers.

Whilst the Windows clipboard allows most IADB objects including text, SQL Query result tables, AEGIS plans and so on to be transferred

directly to any Windows program capable of receiving them, the IADB system includes several features designed to be used in conjunction with the WordPerfect word-processing program. All SQL query result tables, as well as individual data records, can be saved directly to WordPerfect (version 5.1 and later) document or secondary merge files. Visual objects, such as graphs and plans, may be saved as Windows bitmaps or meta-files.

This software is another example of a hermetic solution to provide archaeologists with a complete digital recording solution. It attempts to take account for any possibility the archaeologists may encounter, and its usefulness in the field has yet to be fully explored. Stratigraphic representation is low with only 2D plan outlines being represented. Although useful, the archaeologist has no real way of determining the depth of the site or being able to form new correlations based on the raw data from the site, as would be provided in a 3D solution.

### **3.13 Mirage Project**

Mirage is a Geographical Information System. The MIRAGE application is shown in Figure 38. Artefacts referenced and defined in 3D allow archaeologists to reconstruct artefacts (a & b), do advanced spatial analysis, link artefacts between sites (c, d & e), for example, tracing lamps between sites in the region allows one to trace trade routes and maintain more comprehensive, accurate and accessible records of artefact geometry and find locations. (Mirage, 1999).

This software is relevant due to the fact that includes a 3D representation of an archaeological site, with concentrations of artefacts displayed by means of their colour and plan drawings can be overlaid. This software, however, does not represent 3D models of finds and has no way of performing stratigraphic correlation. The interface is clean, clear and simple and it is very obvious to the user what it is representing due to its highly visual component. A reconstructed plan drawing is shown overlaid onto the site's surface, the terrain of which appears to be entirely flat. Due to the appearance of the strictly vertical nature of the strata it is quite possible

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that this software could not allow for detailed surface models or excavation units that are not perpendicular, making it of use on only the most simple of archaeological sites, where no building elements are discovered.

On further investigation, with attempts made to contact the author it comes to light that this software has not been developed further for scientific purposes. The URL suggests that it is in fact a proposal for something that *might* be developed. This is unfortunate because its visual simplicity and clarity make it very simple to use for visual-minded archaeologists.

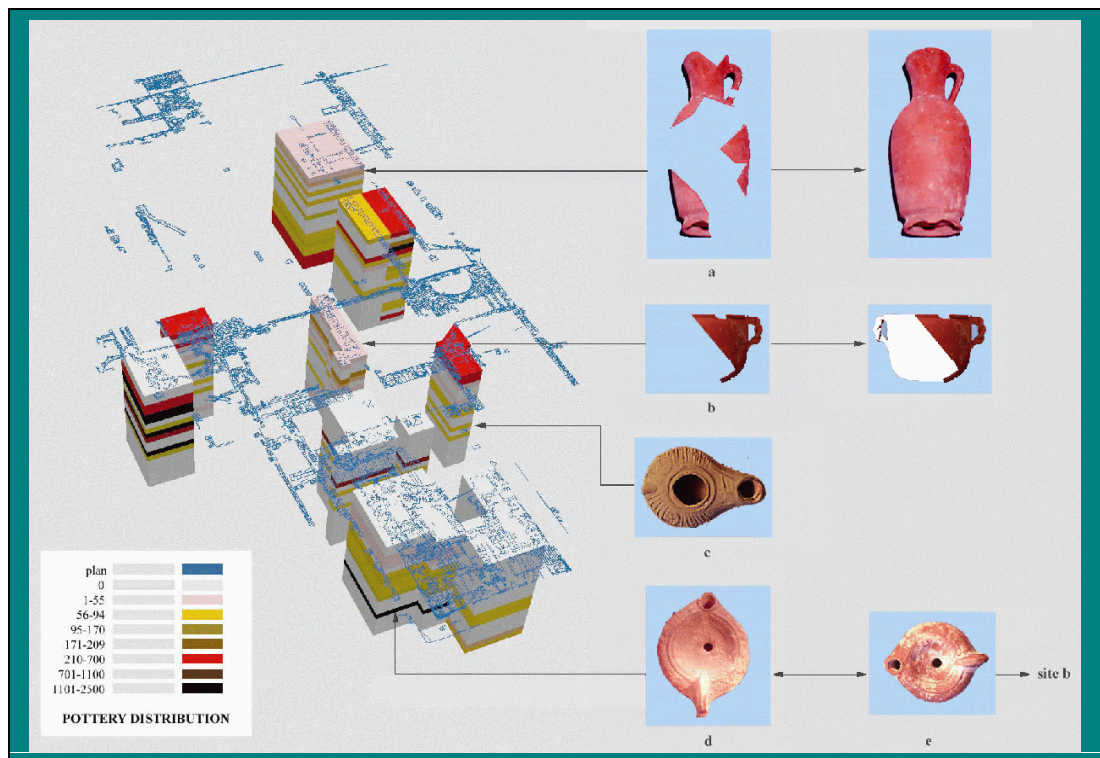


Figure 38. The Mirage project GIS application showing Petra's great temple.

### 3.14 Microstation

Microstation is a draughting tool handed down from the mainframe era. Site plans can be generated quickly when used in conjunction with a digitiser. It includes built in animation functions and multiple viewpoints can be active simultaneously. Microstation deserves mentioning since archaeologists often use it for visualising theodolite points and recreating maps. Figure 39 illustrates the use of Microstation for a sector of the domestic area at

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Sagalassos. Figure 40 shows the Roman Bath at Sagalassos visualised using Microstation from recorded theodolite points. Points are taken and lines are used to join them to delineate building elements. It soon becomes apparent that it is hard to tell from this image what it is being illustrated. No hard and fast rules have yet been established with regard to the recording of theodolite points for reconstruction. Clearly this would be a useful task since theodolites are currently the only widespread tools in place for the recording of 3D data.

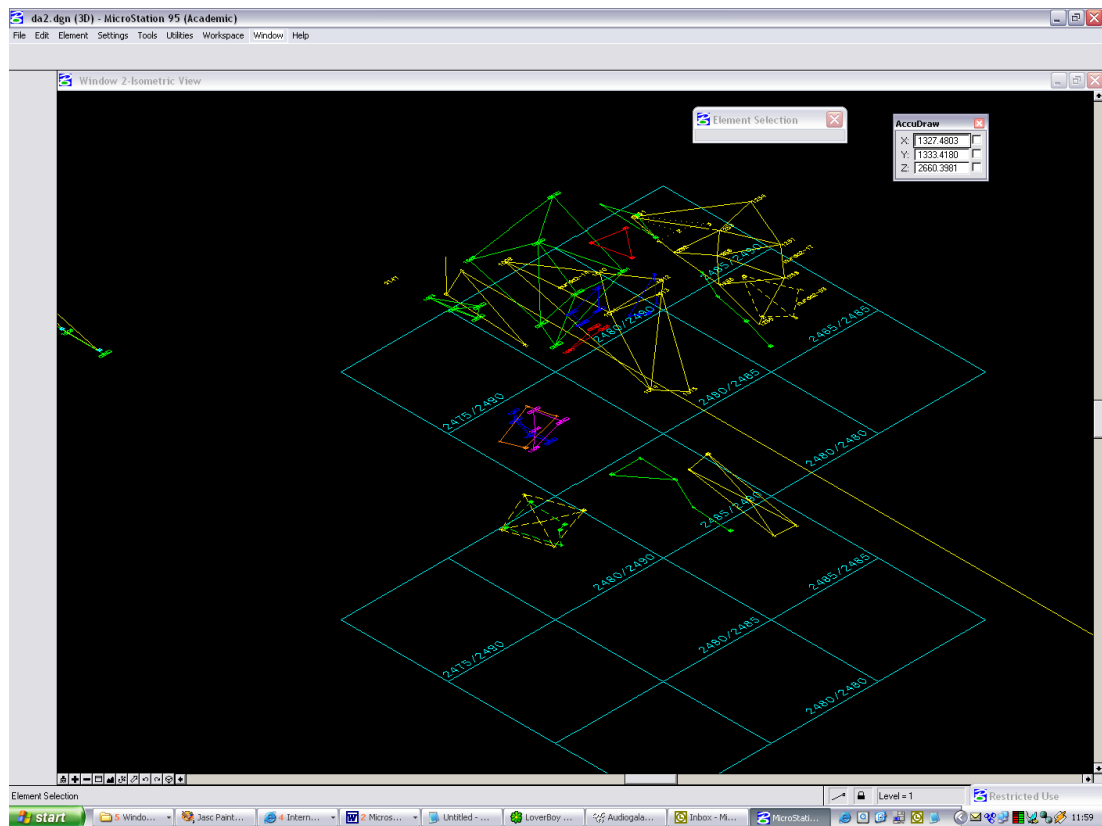


Figure 39. Microstation displaying theodolite points measurements.



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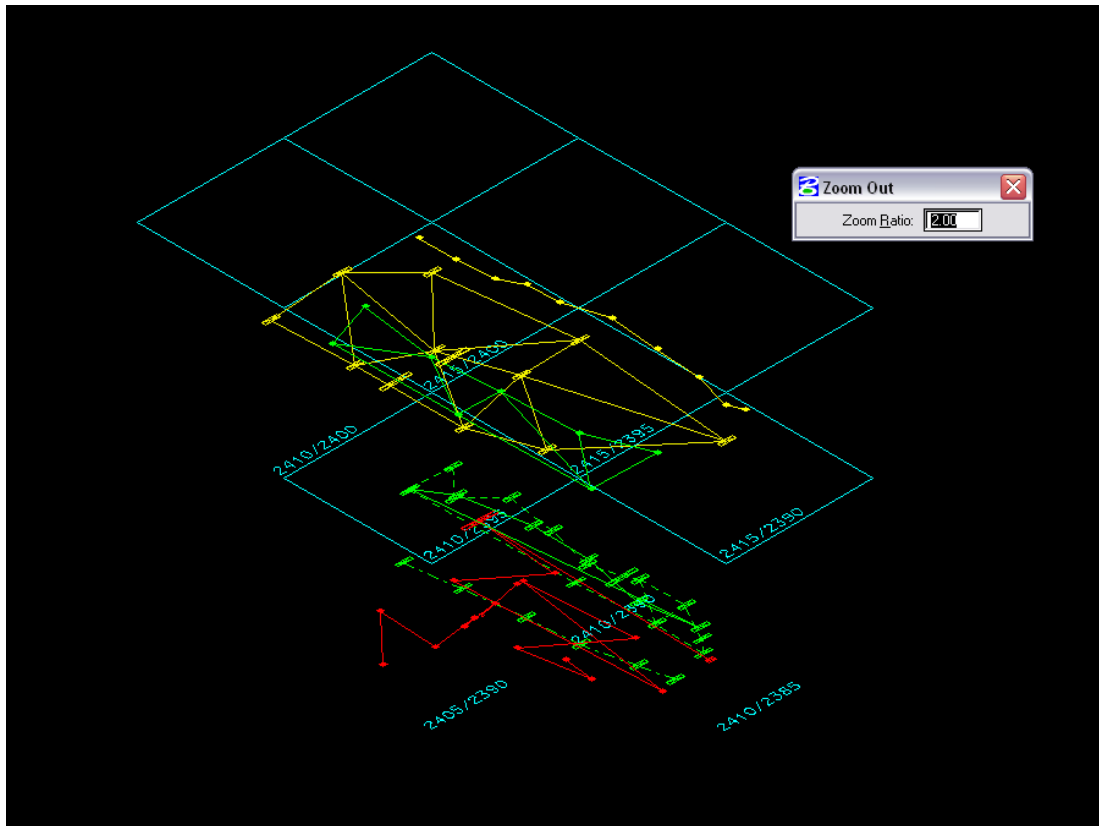


Figure 40. The Roman Bath measurements at Sagalassos visualised with Microstation.

### 3.15 Trenchmaster

Trenchmaster is an archaeological application built using OpenInventor. The main window contains shapes representing artifacts found in an excavation trench. Clicking on a shape brings up additional windows with text and photos. (Data courtesy of William Childs, Dept. of Art and Archaeology; image courtesy of Interactive Computer Graphics Laboratory, Princeton Univ.) This information was found in the book entitled “The Inventor Mentor” (Wernecke, 2000). This software appears to be very relevant to this research. However after attempting to contact the authors no response was received. It is speculated that this software was not developed further due to current erratic archaeological recording methods.

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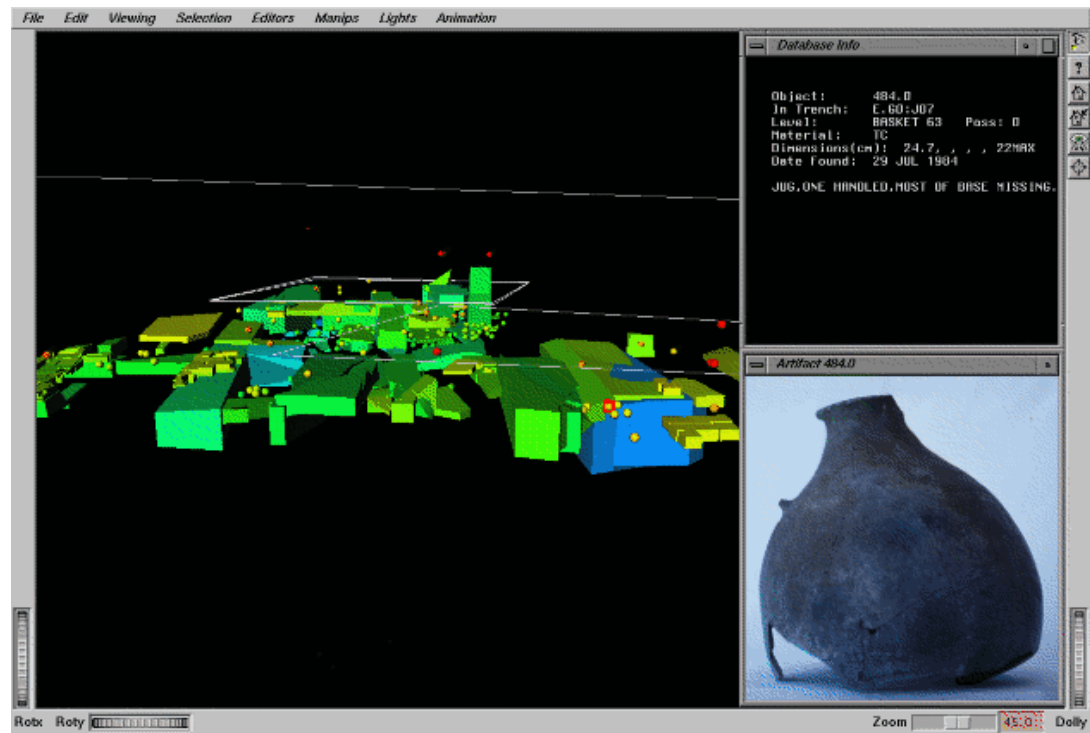


Figure 41. The elusive Trenchmaster.

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### 3.16 Bibby's Software Combination Method

With the aid of digital surveying equipment and modern CAD-supported excavation recording systems, Bibby explains how material from various sources including tachymetric survey data, corrected digital photographs and vectorised maps and plans, can be combined to produce a complete, even photo-realistic visual excavation records. Stratigraphic information

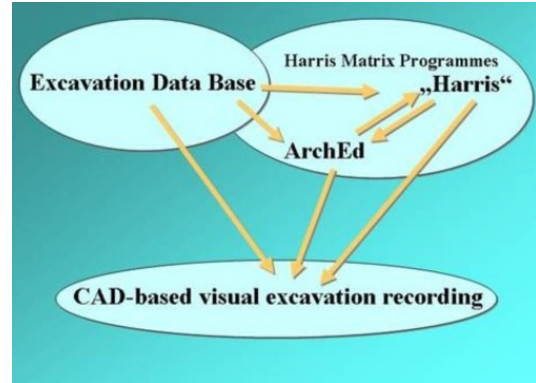


Figure 42. Bibby's proposal for relating stratigraphic software.

can be added by integrating the Harris Matrix into this system. Whatever the origin of the Harris Matrix, whether drawn by hand or computer-generated, it is best used on screen, juxtaposed with the visual record of the features in question. Stratigraphic information on those features or contexts can thereby be endowed with immediacy not otherwise possible. The layer-structure of CAD-programs allows swift correlation of context between the plan and the matrix according to any number of criteria.

Modern operating systems, 'copying and pasting' and the ability of 32-bit programmes to read a wide variety of bitmap file-formats eases some of the problems involved in exchanging stratigraphic data as a Harris Matrix, and a standardised "stratigraphic exchange format" in the form of an ASCII-file which can be generated and understood by the matrix programmes in general use - *Harris*, *ArchEd* already exists. Hand produced matrices might be scanned. Even so, a number of hindrances must be overcome if the Harris Matrix is to be successfully and beneficially integrated into a vector based CAD system.

Using practical examples of digital excavation recording based on Autocad/Archäocad, Bibby introduced possibilities for creating, importing and displaying Harris Matrices in a CAD-system and some uses of the Matrix in that context (Bibby, 2001). Bibby's technique is not through the

introduction of a new computer program or by describing the further development of an existing one. Rather the approach combines individual programs: CAD-based digital excavation recording, excavation databases and Harris Matrix programs. As a practical archaeologist Bibby collaborated on a project with members of the makers of Archaeocad and ArchaeoData.

Digital recording in the field is now fairly commonplace. An electronic tachymeter, EDM or total station is used to collect and store the data on three-dimensional points for transfer to a computer for processing. For automated CAD-drawing Bibby uses Archaeocad, based on Autocad which can interpret the field data from the total station and automatically produce excavation drawings according to the archaeological criteria represented by the codes typed into the tachymeter in the field. The combination of this system with digital photography and another Autodesk product, CAD-Overlay, allows for the production of scaled photo-realistic rectified images of sections, see Figure 43. A small cut through a neolithic beach in Konstanz with wheel tracks is shown in Figure 44.

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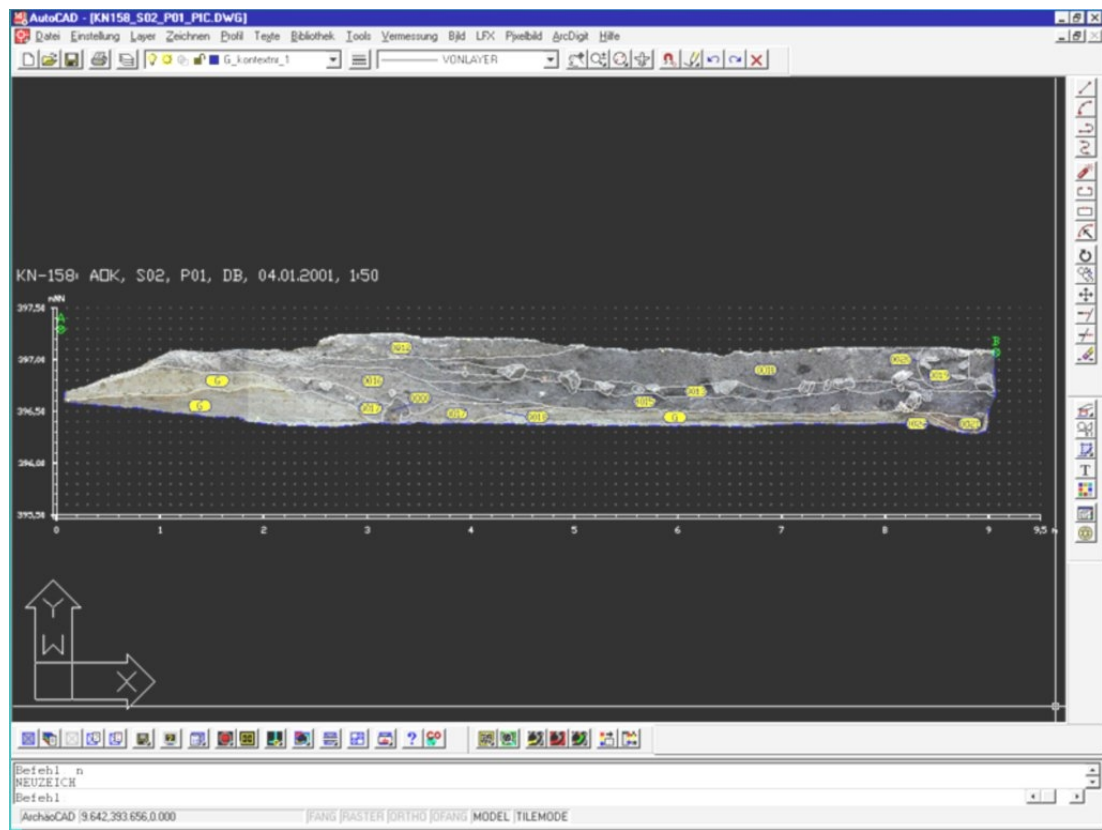


Figure 43. Bibby's AutoCAD + CAD-Overlay approach for photo-realistic rectified images of sections.

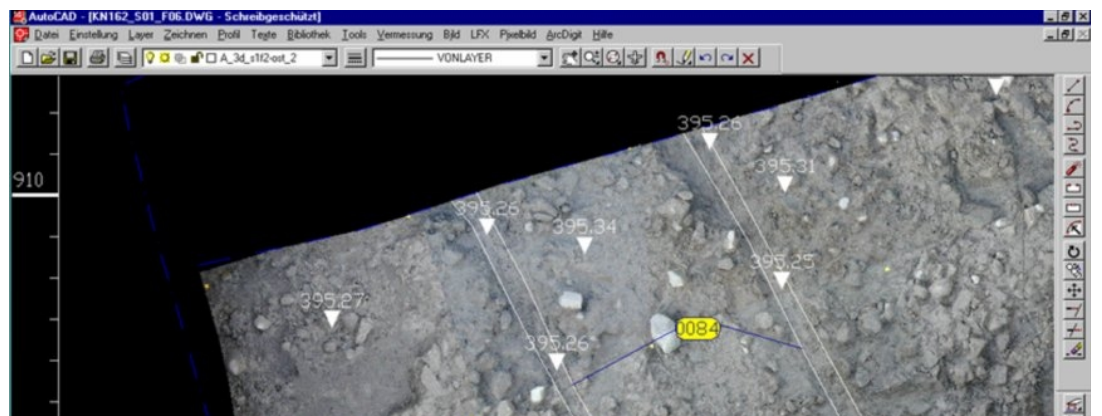


Figure 44. Bibby's approach of using AutoCAD to produce an archaeological excavation record.

The fact that this uses a common system of coordinates and within a common digital environment opens up the possibility of easily grouping differing sources of visual information and, because of that very fact, instantly gaining knowledge on excavated features without reference to finds or other external sources:

Green, D. (2002)

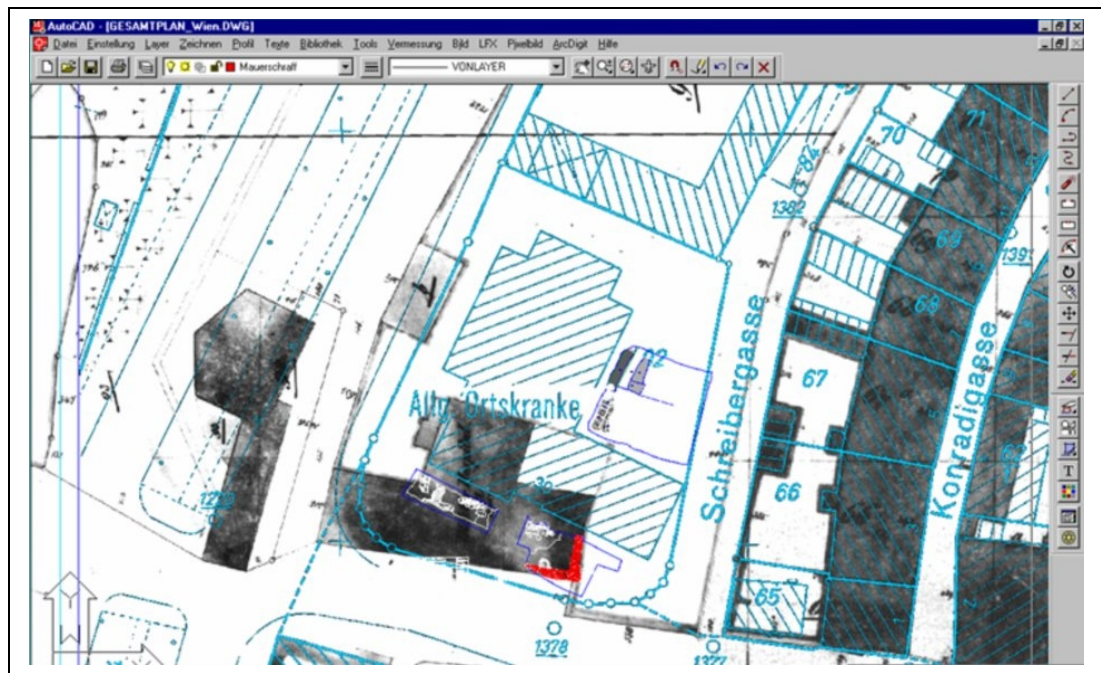


Figure 45. AutoCAD used to juxtapose plan-drawings from different eras.

As an example, a small medieval and Roman excavation in Konstanz is shown in Figure 45., with light grey representing the present large scale official town plan, and black and dark grey representing the first official town plan from around 1870.

In Figure 46, excavated masonry (indicated in red) which could easily be identified as belonging to this house, demolished in the 1960s, noted as a Military Hospital in the 1870 plan, and known to be a medieval house dating to 14th century by following it back through earlier plans. The information on this context is gained simply by overlaying visual material from various sources in a common environment. By adding the excavation database one can write information on the feature.

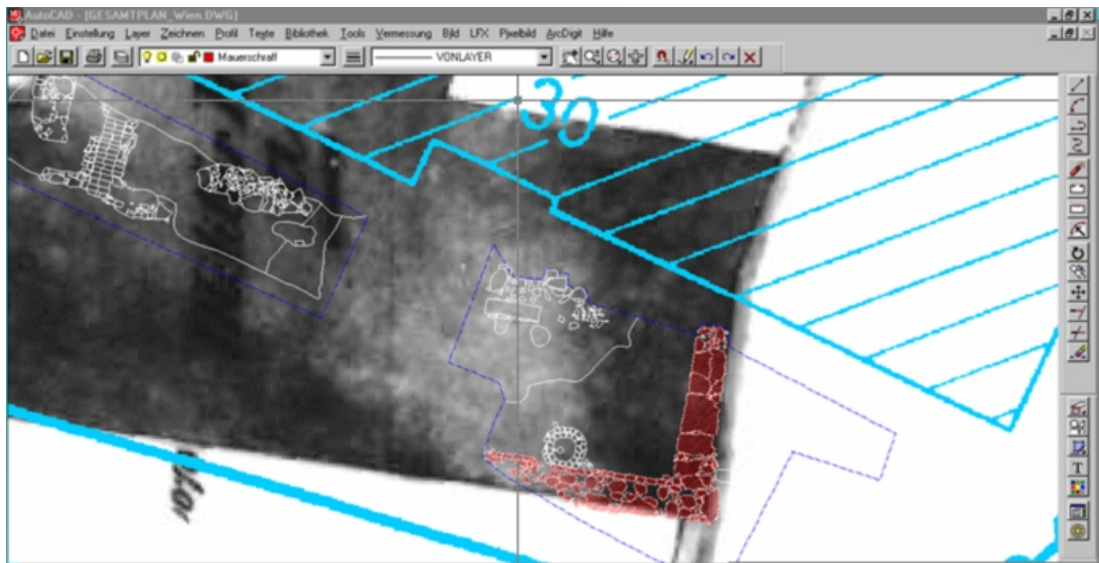


Figure 46. Excavated masonry.

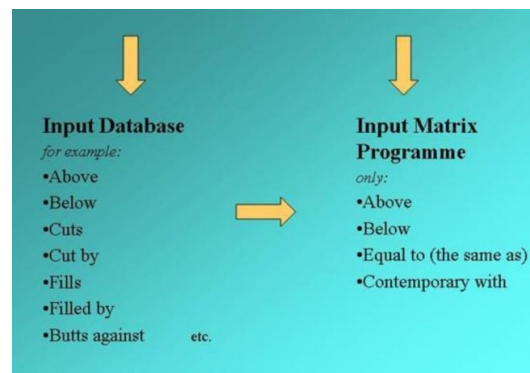


Figure 47. Including cuts as relations.

Part of the visual record is missing - the visualisation of the site stratigraphy in the form of the Harris Matrix. Bibby contends that during the excavation the matrix should always grow with the other elements of recording, and be available on screen juxtaposed with layer plans and sections. At the same time, there should ideally be complete permeability between the three elements of the system: CAD, database and the Harris Matrix. A first step in answering the question of what approach to take, is to examine the relationship between stratigraphic data *per se* and the excavation database.

Excavation databases are (or should be) built to collect and contain as much information as possible about each individual feature. Bibby stresses the point that it is important that the stratigraphic input to the database includes descriptive information about the nature of the stratigraphic relationships, such as *cuts*, *cut by* and *overlies*, which are important for the interpretation of the feature, and that it is not simply reduced to pure stratigraphy, that is to say to the four mathematical axioms of *above*, *below*, *equal to*, *contemporary with* needed for the construction of the Harris Matrix.

By extending the number of stratigraphic relations the visual repertoire available to software tools increases, providing the stratigraphic analyst more insight. Providing additional stratigraphic relations provides more information to computer systems regarding the way stratigraphic layers interface with one another. In Figure 49, layer four cuts through layers seven, eight, nine and ten. Temporally, if layer X is cut by layer Y, layer Y is later than layer X so if a Harris file is exported to versions of stratigraphic software which do not support these new suggested axioms, *cuts* can be simplified to the *above* axiom. Although physically *cut* is a more accurate statement since the layer could be both *above* and *below* the layer in question. The proposed axiom of *cut* itself is not entirely unambiguous since just because a layer is cut, does not mean that the cutting layer passes straight through the layer. In Figure 49, both layers nine and 10 are cut by layer four, although layer four only partially cuts through layer nine, and totally cuts through layer 10. It is not possible using this single new axiom to spatially visualise the relations between the stratigraphic relations. If the repertoire of stratigraphic relations is to be extended perhaps *cuts through* and *cuts into* are more accurate.

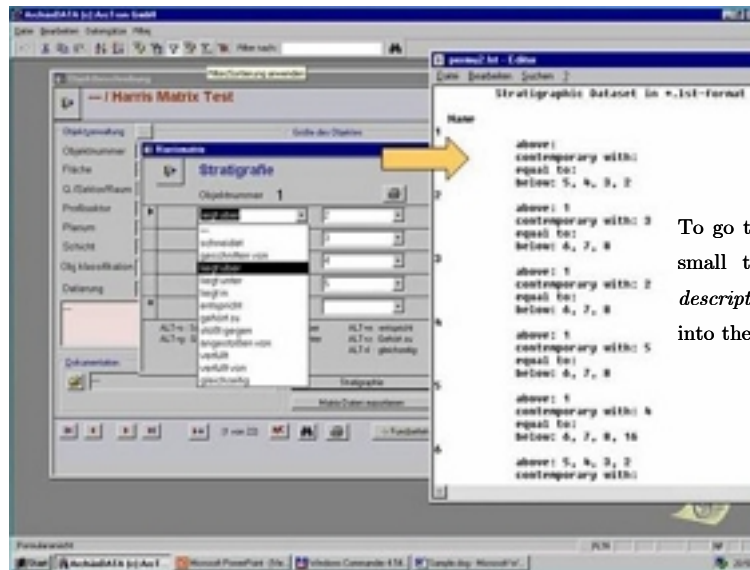
On the other hand, descriptive information is not needed and indeed not understood by the programs presently used to construct Harris matrices. This dichotomy or conflict of interests leads at the very least to the time consuming problem of double stratigraphic input: once into the database and once into the matrix program. The obvious first step, therefore, is to achieve a situation whereby the stratigraphic-descriptive information from the



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excavation database can be understood and processed by the matrix generating programme.

This can be achieved by reading the reduced descriptive-stratigraphic data out of the database into \*.lst format and can be understood and processed by both Harris and ArchEd.



To go through these steps I'd like to use this small theoretical section. Here you see the *descriptive* stratigraphy of context 7 entered into the stratigraphic input of Archaeodata

Figure 48. Exporting .lst files from Archaeodata.

Archeodata can reduce the descriptive stratigraphy and export it in \*.lst-format allowing ArchEd to create the matrix (Figure 48).

The next step is to persuade the Matrix-program to automatically read the \*.lst file and create the matrix. Bibby used ArchEd in his method because it better integrates into a 32-bit operating environment than the Harris program. The final step is to input the complete matrix in a usable form into the AutoCAD environment.

The stratigraphic relations for context number seven of the profile illustrated in Figure 49 are entered into Archaeodata as shown in Figure 50.

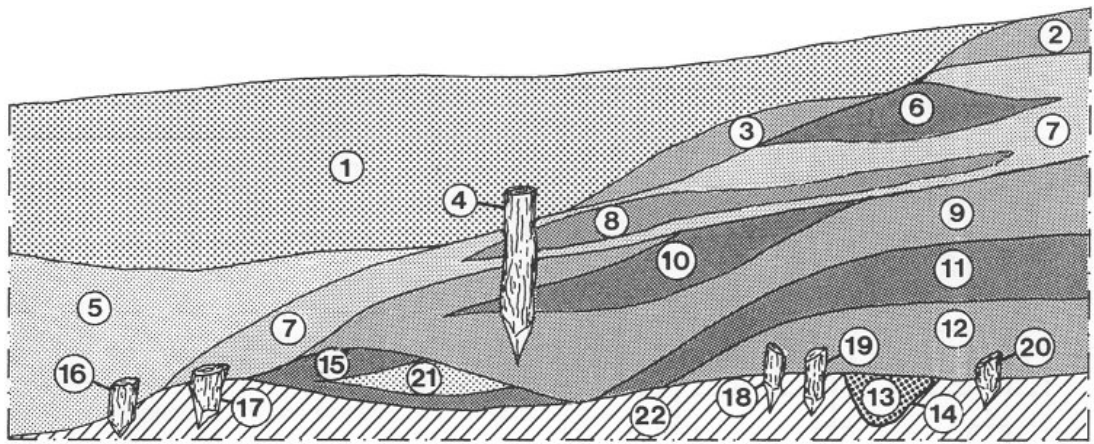


Figure 49. Profile drawing with numbered strata.

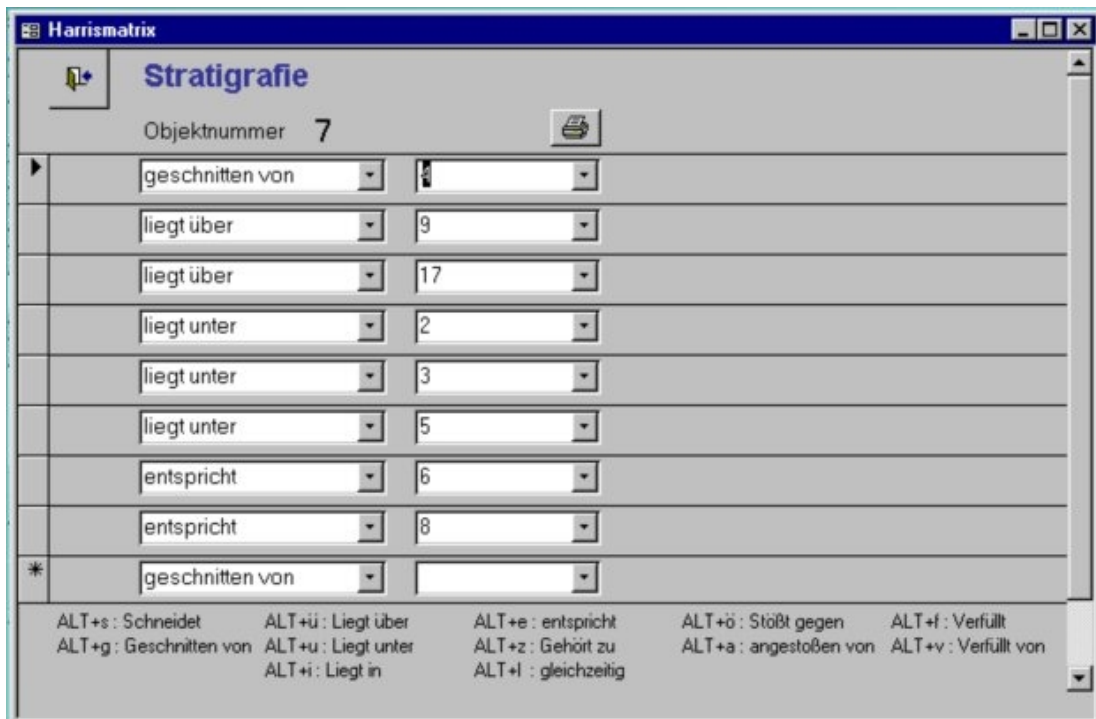


Figure 50. ArcheoCAD representing the stratigraphic relations.

Once the stratigraphy for all the contexts has been entered into the database it can be checked. Figure 51 shows part of the stratigraphy for context 22, which is exported, that is to say reduced to pure stratigraphy. The program runs through the contexts suggesting a file name for the stratigraphic data. At the end of the process the program asks if ArchEd is to draw the matrix.

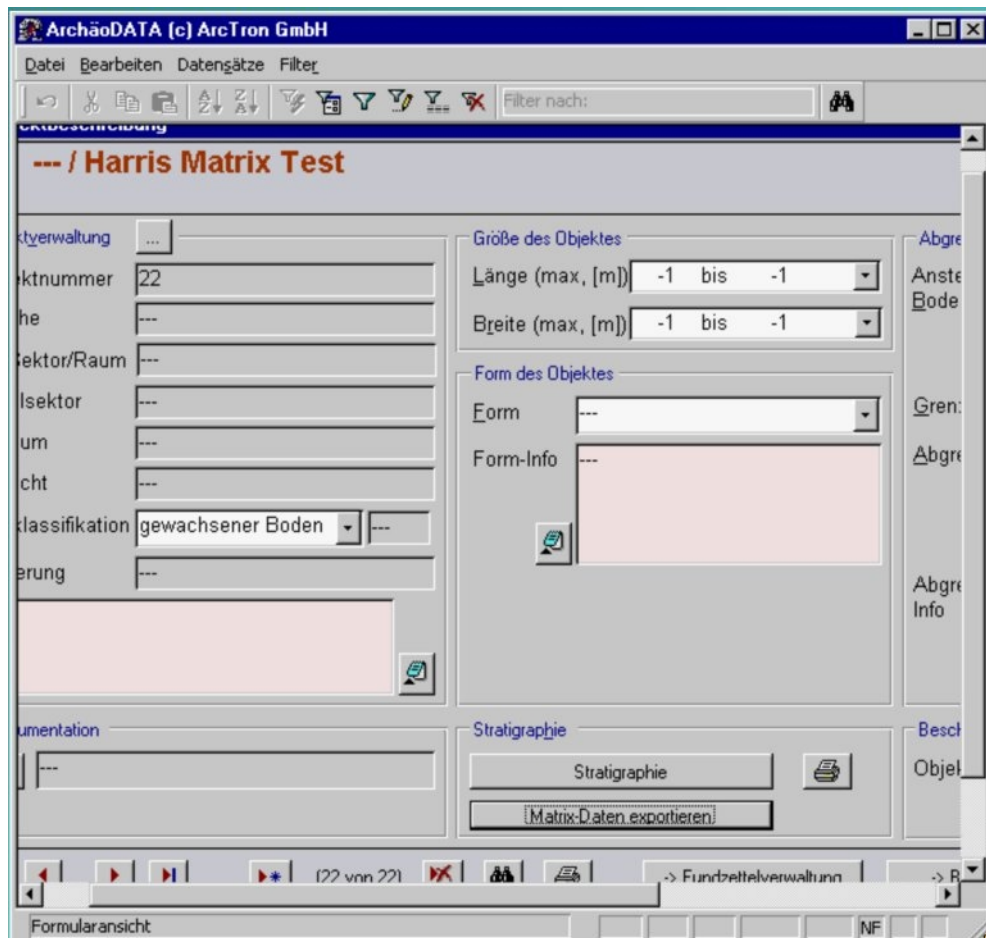


Figure 51. Exporting the matrix data from ArcheoDATA.

If the user chooses *no* to automatic matrix construction the data is stored immediately in the \*.lst format. By continuing with the first alternative, having created the matrix with ArchEd, the next step is to introduce the Matrix into the AutoCAD environment.

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In order for AutoCAD to be used as the basis of all excavation data a file format that can be read by AutoCAD should be used. Bibby suggests using the WMF format but also suggests that the AutoCAD format of DXF be an export possibility used in future releases of ArchEd. It may be more sensible to instead include the functionality to be able to select the Harris matrix and copy it to the computer's clipboard memory thus retaining its vector format properties and enabling it to be pasted into applications such as AutoCAD without producing an intermediate file.

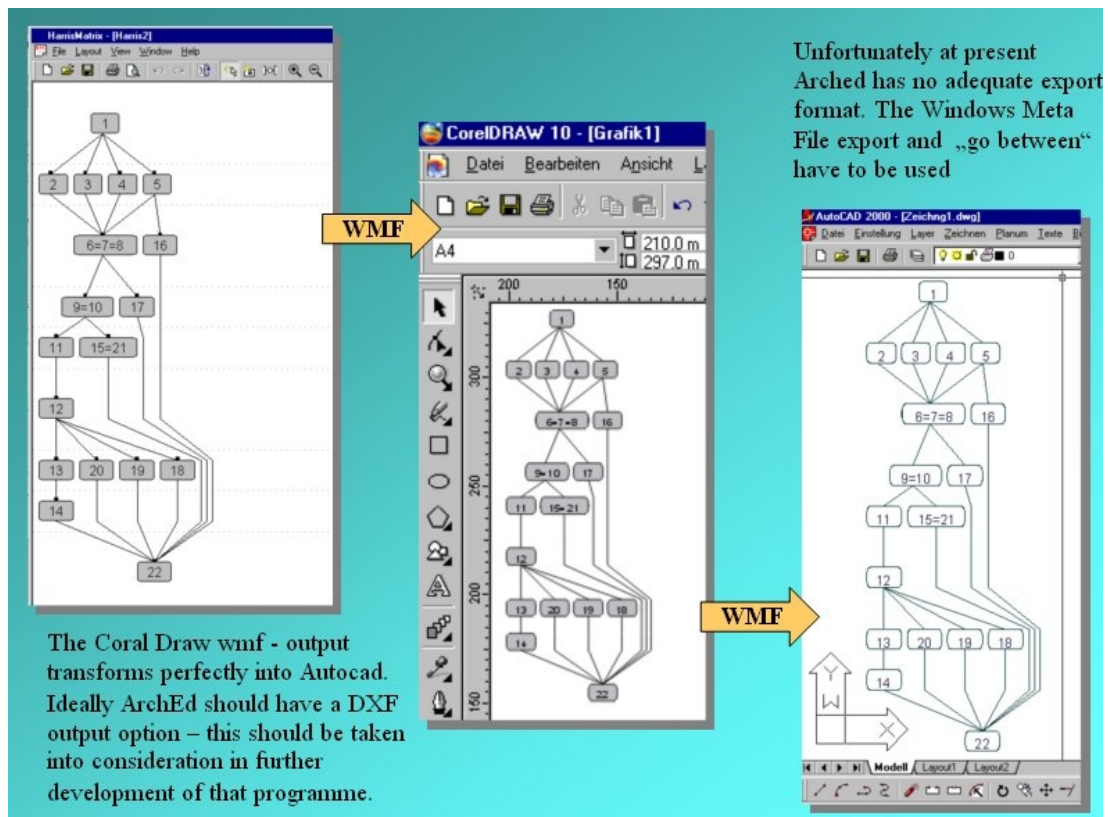


Figure 52. Transmitting files from ArchEd to AutoCAD through the WMF format.

Once the matrix and drawing have been imported into Autocad or Archaeocad (see Figure 53) the Harris Matrix Utility splits the screen, placing the drawing on the left and the matrix on the right. Both windows are freely scalable and context numbers can be searched for in both directions. To find where a context in the drawing appears in the Harris matrix the context number can be typed in the text field, or by clicking on the number in the drawing, in this case context 12, see Figure 54 and Figure 54. The context number is highlighted in the matrix, Figure 55.

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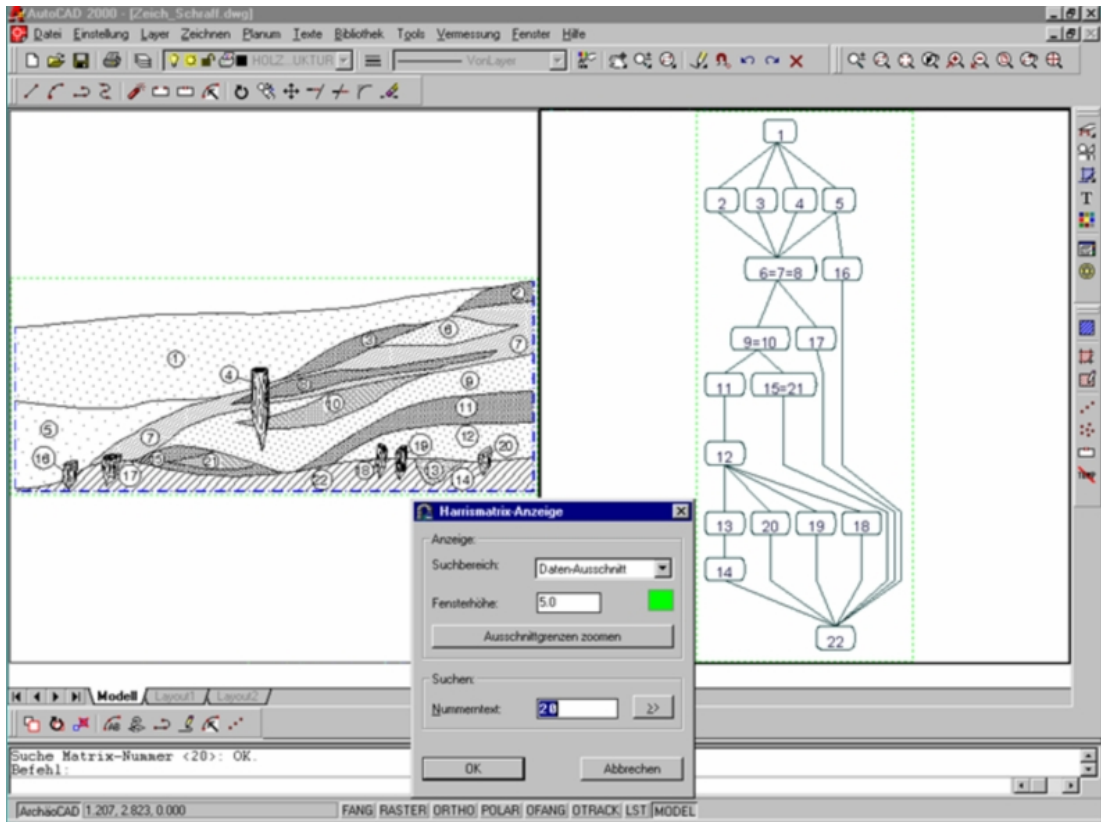


Figure 53. AutoCAD displaying a profile section and the Harris Matrix.

Green, D. (2002)

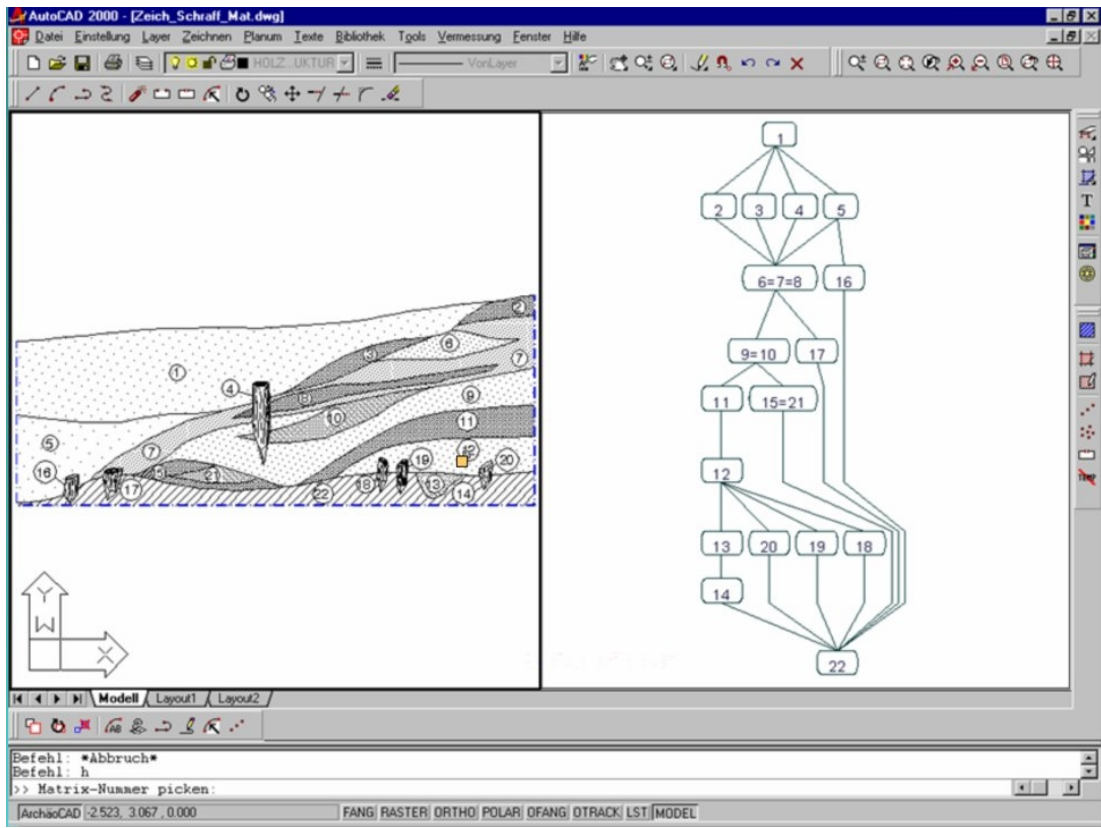


Figure 54. Selecting a context number in the profile.

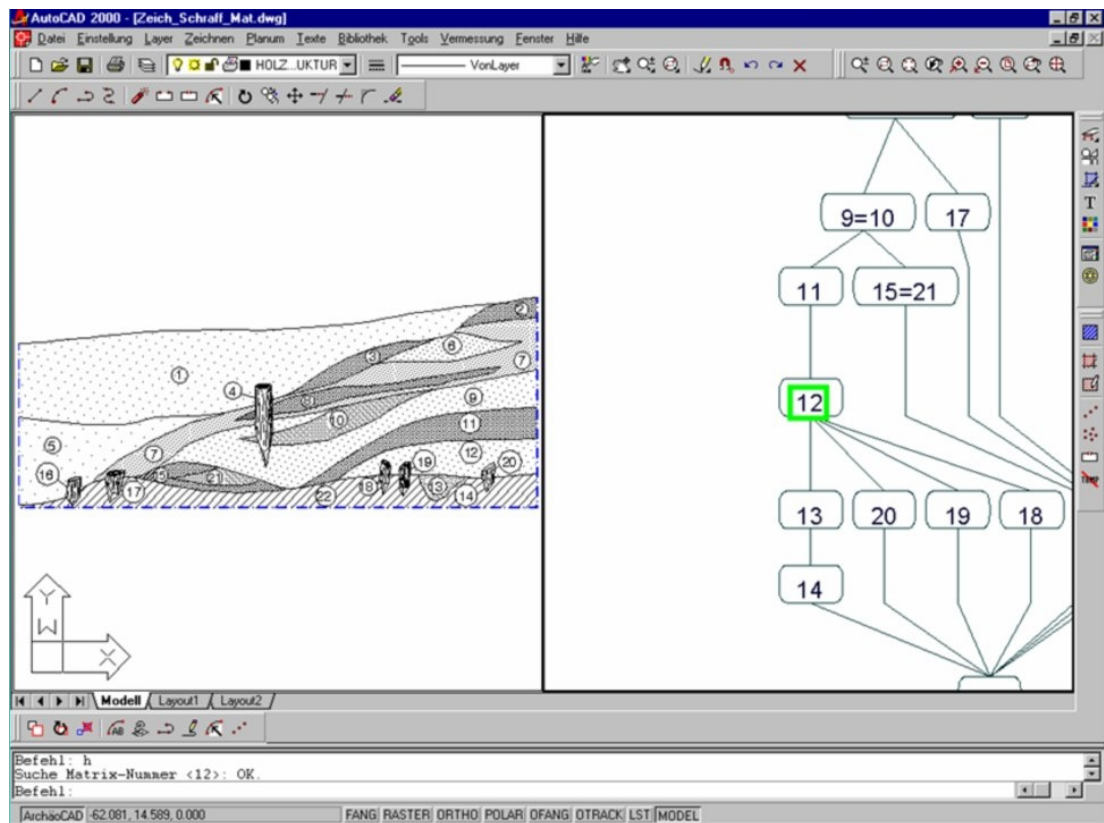


Figure 55. The context number is highlighted in the matrix.

In the opposite direction numbers in the matrix can be found as contexts in the drawing: Equals signs and multiple numbers, in this case,  $6 = 7 = 8$  do not present a problem, **Figure 56**.

Green, D. (2002)

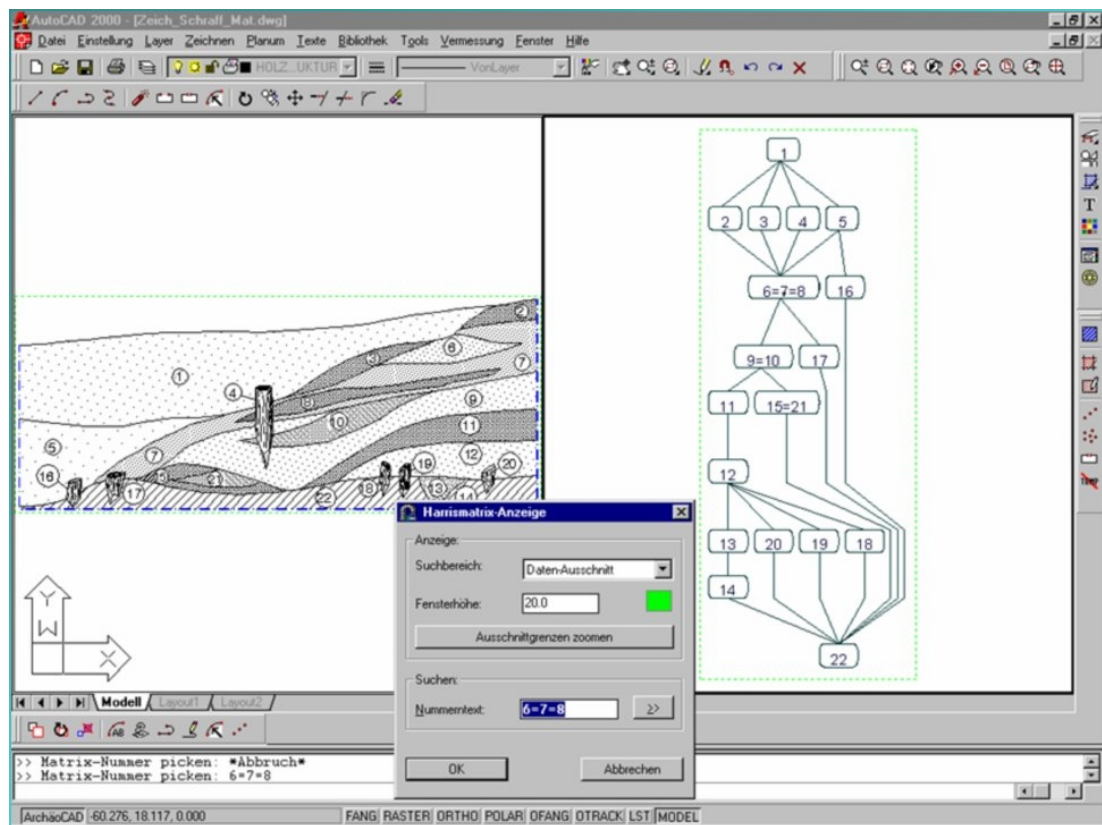


Figure 56. Equivalent strata do not pose a problem with Bibby’s method.

The utility recognises how many times the number appears in the drawing – Figure 57 shows case 6, a lens in 7 is the first of four appearances of 6, 7 or 8. The program then prompts the user to determine if they want to see the rest, Figure 58 shows the next in the series. This technique becomes of use on more complicated matrices as an aid to finding ones way around the stratigraphy. Files from the Harris application can be dealt with in the same manner.



Green, D. (2002)

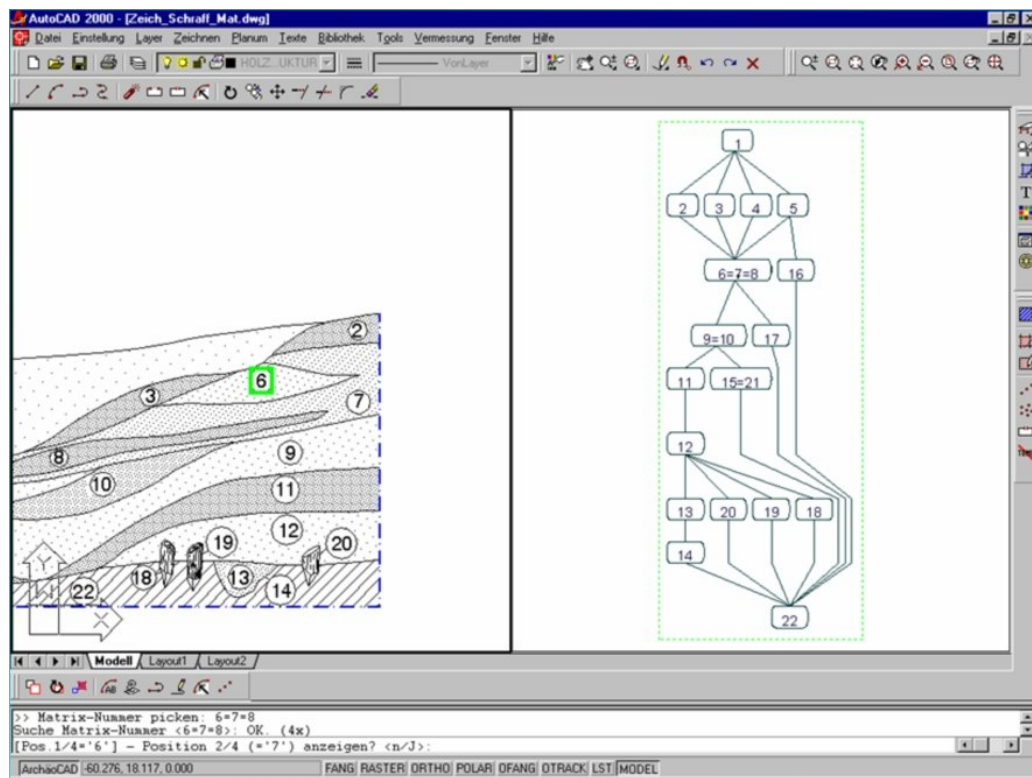


Figure 57. Context six found in the drawing.

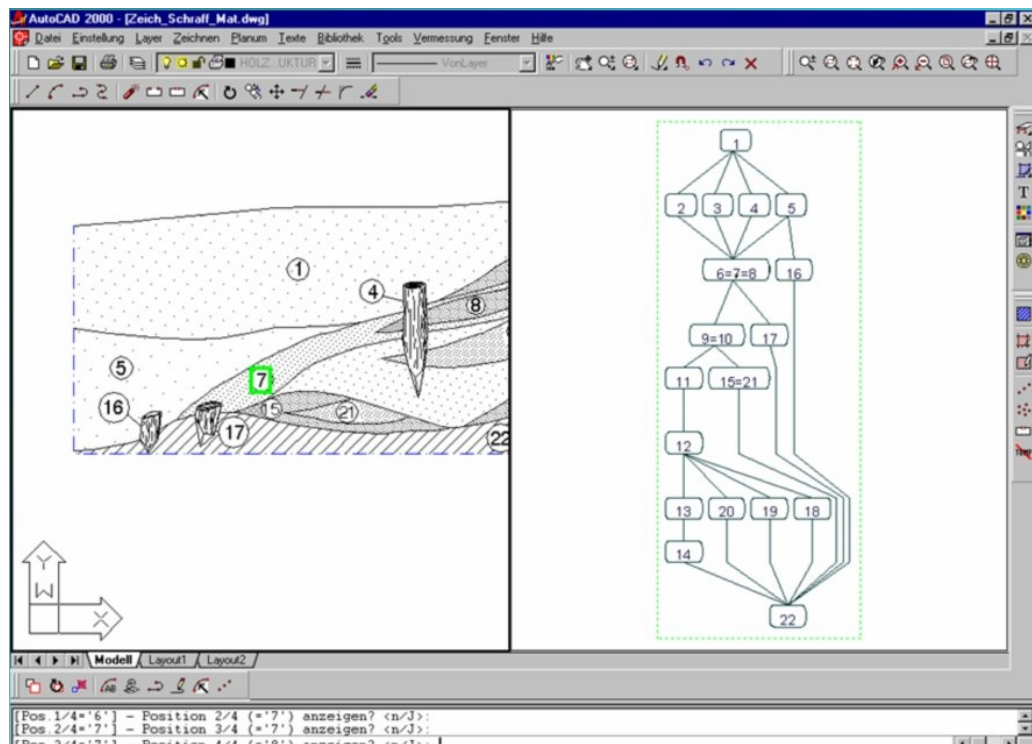


Figure 58. Displaying the next layer.

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Bibby recognises the merit that displaying the matrix alongside the spatial data provides, as shown in Figure 59. In this simple example it is easy to see that equating the six postholes on the top left into one group, for example, a building is easy, whereas the possible viable permutations of the amorphous arrangement below left are more difficult to recognise. This is an extreme example but illustrates how correctly phasing strata from additional information can simplify the matrix creation process.

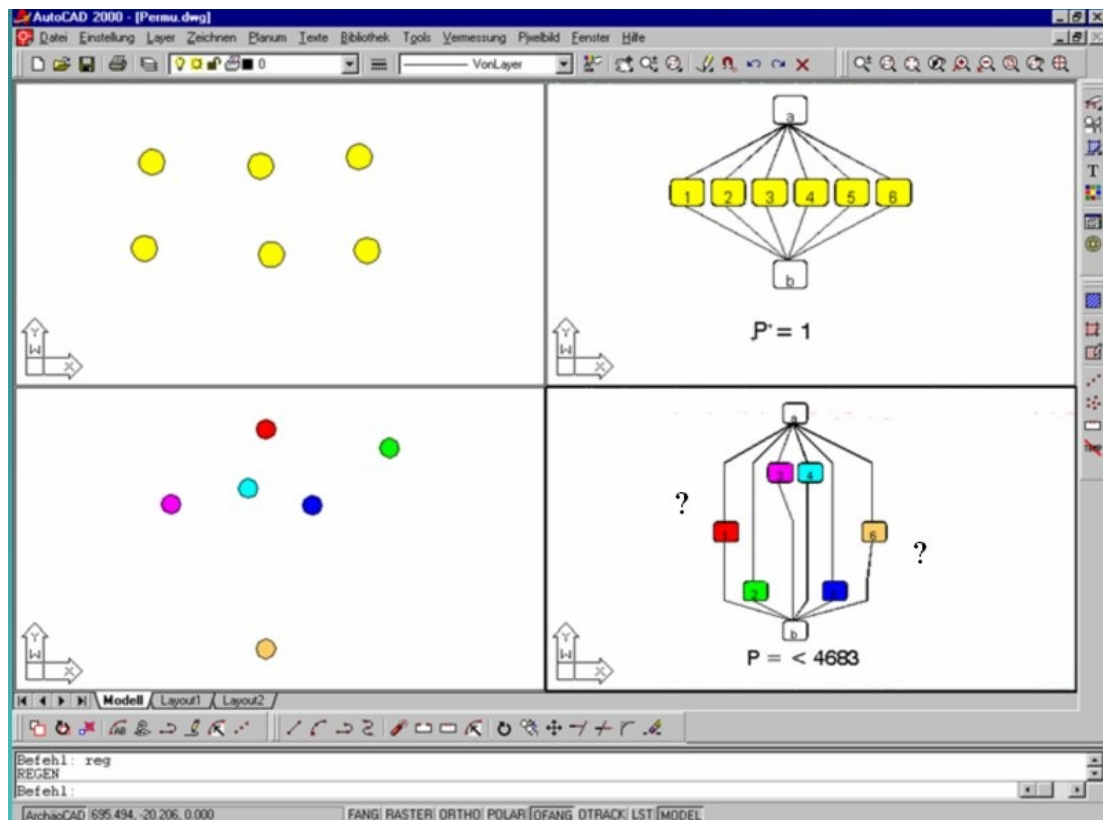


Figure 59. Permutations of Harris matrix configurations increases exponentially.

Having the drawings and the matrix in the same system, new visualisation methods sometimes suggest themselves simply as a function of this fact. It has been clear for some time that a whole different set of phases exists apart from those traditional phases previously mentioned, which are in fact simple phases of deposition or removal.

These phases may be called surface phases , meaning the conglomerate surface that results from the phases of deposition. The question of surface phases cannot easily be dealt with by the Harris Matrix alone, but having all the visual material together on screen suggests ways of addressing the matter.

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The emphasis of Bibby's work so far has not been to create a hermetically sealed complete excavation recording system for stratigraphic excavation, since such a system cannot suit all of the people all of the time. Rather, his aim is to increase the compatibility and permeability between systems that at this time are tried and tested and in active use.

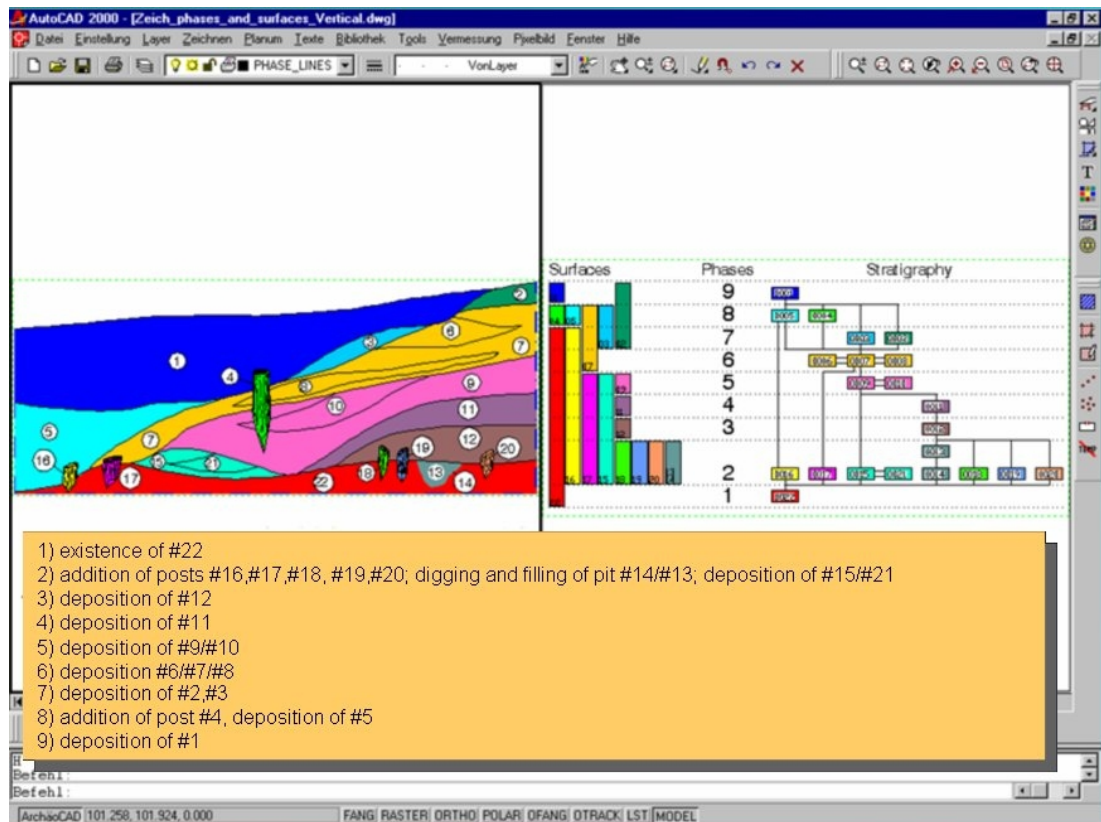


Figure 60. Profiles alongside Harris matrices using AutoCAD.

### 3.17 Conclusion

From the study of prior stratigraphic research work, the underlying thread amongst many is the use of the Harris matrix for visualising stratigraphic relationships. So as not to discard this body of work or line of thinking, ways of including this method are considered. From a 3D standpoint, it is possible to generate the same 2D Harris matrix graph from a 3D graph, providing that the relations are defined in a similar manner. The reverse however, is not as trivial due to the lack of spatial information included within the Harris matrix structure. From the results of the in depth work on graph drawing provided by Mutzel *et al.* in the ArchEd software described here, it would be

imprudent to reinvent the wheel by providing the same functionality in a system for the 3D visualisation of stratigraphy. Instead, it is more sensible to use the powerful graph drawing abilities of ArchEd from within any software developed for 3D stratigraphic visualisation. Gnet performs in a similar manner to ArchEd, with ArchEd's graph drawing abilities performing better and achieving higher aesthetic appeal. A portable text file is exported from the ArchEd software, whereas Gnet depends on a database with an ODBC connection, manually set up by the user. Additionally, ArchEd is a more stable application and thus can be distributed with any application developed. The IADB system includes the Consort matrix compiler and a matrix editor that can be used together to produce stratigraphic matrices from the underlying context relationships. However, the ArchEd graph drawing software is of a better quality in terms of the functionality it provides and of its usability.

Airphoto creates orthophotos from scanned extreme oblique photos. DTMs can be imported and overlaid. Airphoto could be utilised in conjunction with a GIS system to display the overlying surface of the terrain alongside stratigraphic and artefact information in a 3D environment.

Posthole is a program for finding and displaying postholes in scanned excavation plans. It is possible that if the algorithm could be obtained, the functionality could be incorporated into a 3D GIS, such that the plan drawing would be analysed, and 3D postholes created on a user-intervention basis. From a set of irregularly placed points in a plane, Displa3D fits a smooth surface (or curve). This works in two planes. And does not have implication for use in conjunction with a 3D stratigraphic GIS.

Stratigraf is commercial software aimed at archaeological stratigraphy that allows real-time error detection to spot incorrect relationships among contexts or chronologies. It appears to include many of the requirements sought after by archaeologists. The interface is well thought-out. It does not have any means of visualising stratigraphy in 3D or visualising finds or features alongside the stratigraphic relations. However, this appears to be a promising piece of commercial technology for archaeology.

Virtual dig teaches students the basics of excavation methods in archaeology. The software is basic. Real archaeological data cannot be input or visualised. Layers are excavated at fixed heights and plan view is the only possible view. As a toy used educationally it may have limited merit.

ArcDig is similar to Virtual Dig in value and behaviour. It is a windows program used to present archaeological information from a top-down view. It is awkward to use and has very limited functionality. It can be used at a very basic level for teaching archaeological excavation.

Arcview allows the overlaying of maps with data. It can be connected with a variety data sources. It is a 2D application and has proved useful in archaeology in excavations such as Quesir Al Qadim.

Visual Groundwater is not directly relevant to archaeology and has not been developed specifically for this purpose. It does however use 3D for subsoil visualisation. It can be used for visualising stratigraphic layering without connection to other forms of archaeological data. It is perhaps too highly priced for archaeologists although it does include some of the features archaeologists desire.

Wellplot is a stratigraphic data analysis and charting application. It has specific and limited use. It can basically be used for the plotting of categories against depth or sequence of samples.

IADB is archaeological software allowing for the entry of much of the data which is recorded when excavating a site. Finds, contexts, sets, groups, phases and skeletons can be stored. It utilises functionality similar to that of ArchEd and Gnet in that stratigraphic relations are checked for integrity with matrices being produced. In terms of graph editing ArchEd is superior. This program makes bold steps to develop a complete archaeological information recording system. Stratigraphic layers are not visualised in 3D, although context plans can be stacked.

At first sight, Mirage seems to be the ideal software solution for archaeologists. Artefacts defined in 3D allow spatial analysis, sites can be linked between and context plans can be superimposed. Stratigraphic layers are represented in 3D and pottery distributions are visualised by colour

intensity. On closer inspection, this software is only in prototype stage. The layers are all of equal width and attempts to contact the authors have proved unsuccessful.

Microstation is a 3D draughting tool. It is used in the field of archaeology to plot theodolite points delineating building elements. It is commercial software not directly aimed at archaeology, and does not allow stratigraphic correlations or artefact embedding. It can be confusing to correlate the points and lines with building elements without the use of a context plan.

Bibby describes a method of using a combination of commercially available software to visualise survey data, orthophotographs, vectorised maps and plans to produce photo realistic excavation records. It is a well-thought out method to provide an archaeological record without the need to develop new software. Stratigraphic relations can be seen on 2D profile drawings and related to survey data. Common standards are used and this method may provide an alternative in the event of a lack of development of a specific archaeological GIS.

None of the examples looked at above have fully implemented current photogrammetric models of stratigraphy or used them as an aid for stratigraphic seriation. A brief summary of the tools described in this chapter are listed in Table 1.

The following chapter describes in detail the operations of one specific archaeological site to show how theory relates to practise.

Green, D. (2002)

| Software    | Summary  |
|-------------|--|
| Harris      | An automated system for producing stratigraphic diagrams. Allows the opportunity to enter and change stratigraphic layers and their temporal relations. The program is fairly old now. Output is provided in ASCII format. Superseded by newer applications such as ArchEd / Gnet.   |
| ArchEd      | An interactive tool for visualising Harris matrices as hierarchical graphs making use of a very well designed automatic layout generator algorithm. The interface is very clear and easy to use. The output is a portable text file.   |
| Gnet        | A general-purpose editor for directed graphs – used for visualising archaeological stratigraphy. Similar to ArchEd with the addition of a 2.5D view. Visually and ergonomically ArchEd is superior.  |
| AirPhoto    | Creates orthophotos from scanned extreme oblique photos. DTMs can be imported and overlaid.  |
| Posthole    | A program for finding and displaying postholes in scanned excavation plans.  |
| Displa3D    | From a set of irregularly placed points in a plane, a smooth surface (or curve) is fitted. The GUI is not well-thought out. It may have limited use in archaeology.  |
| StratiGraf  | Commercial software aimed at archaeological stratigraphy that allows real-time error detection to spot incorrect relationships among contexts or chronologies. Appears to include many of the requirements sought after by archaeologists.   |
| Virtual Dig | Virtual dig teaches students the basics of excavation methods in archaeology. The software is basic. Real archaeological data cannot be input. Layers are excavated at fixed heights and plan view is the only possible view. As a toy used educationally it may have limited merit. |
| ArcDig      | ArcDig is a windows program used to present archaeological information, from a top-down view. It is awkward to use and has very limited functionality. Can be used at a very basic level for teaching archaeological excavation.   |

Green, D. (2002)

|                                   |   |
|-----------------------------------|---|
| <p>ArcView</p>                    | <p>Arcview allows the overlaying of maps with data. It can be connected with data sources. It is a 2D application and has proved useful in archaeology in excavations such as Quesir Al Qadim.</p>  |
| <p>Visual Groundwater</p>         | <p>Visual Groundwater is not directly relevant to archaeology It is useful for 3D for subsoil visualisation. It can be used for visualising stratigraphic layering but cannot connect to other forms of archaeological data.</p>  |
| <p>WellPlot</p>                   | <p>Wellplot is a stratigraphic data analysis and charting application. It has specific and limited use. It can basically be used for the plotting of categories against depth or sequence of samples.</p>   |
| <p>IADB</p>                       | <p>IADB is archaeological software allowing for the entry of much of the data which is recorded when excavating a site. Finds, contexts, sets, groups, phases and skeletons can be stored. It utilises functionality similar to that of ArchEd and Gnet in that stratigraphic relations are checked for integrity with matrices being produced. In terms of graph editing ArchEd is superior. This program makes bold steps to develop a complete archaeological information recording system. Although this software no longer seems to be developed or supported.</p> |
| <p>Mirage Project</p>             | <p>Mirage seems to be the ideal software solution for archaeologists. This software is still at a prototype stage.</p>  |
| <p>Microstation</p>               | <p>Microstation is a 3D draughting tool. It can be used in the field of archaeology to plot theodolite points delineating building elements. It is commercial software not directly aimed at archaeology, and does not allow stratigraphic</p>  |
| <p>Trenchmaster</p>               | <p>Table 1. Summary of archaeological software available for use in archaeology. Trenchmaster is a 3D software which allows the visualisation of archaeological data in 3D with artefacts represented with</p>  |
| <p>Bibby's combination method</p> | <p>markers, which can be clicked on to view 2D photographs of said objects. This software however still remains in an early prototype stage. It is not known if it will be developed further. Bibby describes a method of using a combination of commercially available software to visualise survey data, orthophotographs, vectorised maps and plans to produce photo realistic excavation records. ArchaeoCAD and AutoCAD are utilised to provide insight into stratigraphic relations. A useful idea requiring the purchase of several proprietary softwares.</p>   |



# Chapter 4

## Test Case: Sagalassos

P

rocesses inevitably vary from excavation to excavation. To ensure that methods and techniques developed for stratigraphic visualisation are useful in practical situations, the methods from one site have been studied in detail, and a field visit was made by this author to see the manner in which stratigraphy is actually recorded.

### 4.1 Introduction

The archaeological site at Sagalassos is one of the largest archaeological projects in the Mediterranean dealing with a Greco-Roman site over a period of more than a thousand years (4th century BC-7th century AD). One of the three greatest cities of ancient Pisidia, Sagalassos lies 7 km north of the village Ağlasun in the province of Burdur, Turkey, Figure 61. The ruins of the city lie on the southern flank of the Ağlasun mountain ridge (a part of the Taurus-mountains) at a height of between 1400 and 1650 metres, Figure 62. A team from the Katholieke Universiteit Leuven under the direction of Professor Marc Waelkens have been excavating the whole area since 1990 and have dug up some wonderful finds, such as the bust of the god of fertility and wine, Dionyssos.

A consortium of universities and companies, led by Brunel University in West London, are collaborating in the European Union supported 3D-

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MURALE project to develop 3D measurement, reconstruction and visualisation tools for use by the archaeological team.



Figure 61. The site of Sagalassos in Turkey

These new multimedia technologies aim to produce rich new ways of recording, cataloguing, conserving, restoring and presenting archaeological artefacts, monuments and sites. These technologies are used to model the Sagalassos site and show how they can be used for preserving and presenting the cultural heritage of Europe in two important ways. Firstly, by putting such new technologies in the hands of the archaeologists themselves rather than creating multimedia content after the excavations. As an important consequence, a more complete record of the finds can be created and presented to the public.



Figure 62. Sagalassos on the Aĝlasun mountain ridge.

Secondly, by presenting the site not as a static entity from a long-gone past, but as a vibrant place that underwent a lot of changes throughout its existence. This includes the visualisation of the situation in different eras and of the excavation as they proceeded through different time layers. Both these aspects of the project help to produce records and visualisations that are more complete and scientifically precise. One of these tools is that of the stratigraphic visualisation component, described in detail later in these works.

## 4.2 Primary Site Datum at Sagalassos.

Primary Site Datums (PSD) are used one at a time at Sagalassos. In the past the PSD has changed at least twice. British surveyors who participated in the early years of the project created the first PSD. The second was a grid system origin set out by the cartography department of KUL, but essentially based on the primary control point network of the predecessors. This was in use until around the mid nineties. The actual system uses as origin a calculated position. The physical origin, that is to say the one from which all

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other positions are derived is at point 2500m, 2500m. The reason for choosing this as the physical origin is its easy accessibility (it lies on a flat rock outcrop behind the house of the site guardian). This point was surveyed with GPS (as were all the others of the basic topographical net) by a sponsoring surveying firm SPC.

### 4.3 Grid Systems at Sagalassos

The origin of the local grid is situated in a point to the southwest of the site of Sagalassos. Each grid square, measuring 5m by 5m is characterised uniquely by the coordinates of the southwest (lower left) point of the square. These coordinates consist of a combination of two four-digit numbers, that is to say the x and y co-ordinates of this point in the grid system, in an xxxx/yyyy configuration. The first four digits denote the value along the X-axis and the last four along the Y-axis, Figure 63. These numbers cannot be shortened and should be separated by a slash (e.g. 5385/4800). Since these numbers stand for distances in metres, the exact locations of archaeological features can be measured easily starting from the grid points and grid lines.

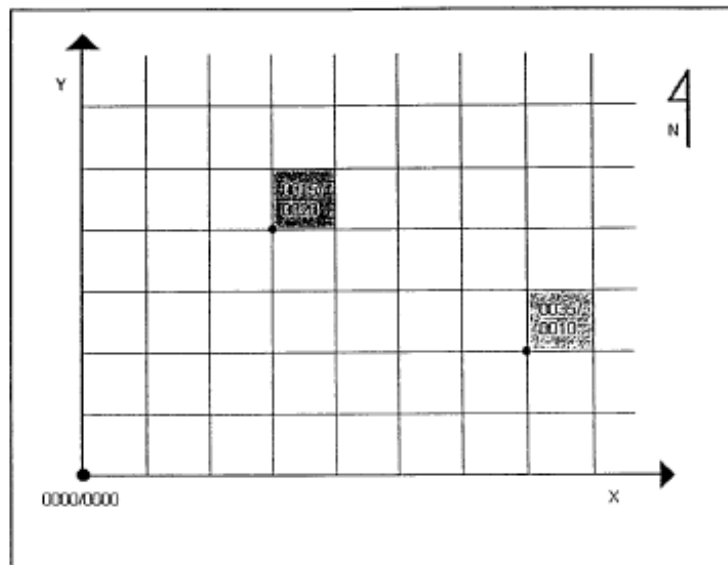


Figure 63. A plan view of the dig site indicating sectors to be excavated.

At the start of the season a relevant number of grid squares are visualised for all sites. Grid points can consist of either a painted marker on rock or a metal nail or a tube in a soft surface. Guidelines must never be attached to these markings, as the movement of the wheelbarrows and persons over these lines put strain on them that results in the dislocation of the grid markers. It is nearly always impossible to put them back in their correct position, which leads to erroneous find positions.

At least two base points of which the exact position has been determined on the same gridline should be preserved at every site during the campaign. Thus the other grid points can easily be measured from this baseline using Pythagoras ( $a^2+b^2=c^2$ ; when using squares of 5 by 5 metres, the diagonal equals 7.07 metres). If this baseline can no longer be preserved because of the continuation of the excavations, new points defining a new baseline must be set out. For this operation the qualified team members should be referred to in advance to visit and set out new points. The archaeologist is asked to keep in mind how and in which direction the excavation is to proceed.

For sites where a complex of small rooms is excavated (for example the Upper Agora North and Domestic Area One), the finds of those layers that are fills in the rooms themselves and not originating from outside the rooms (e.g. erosion fills, destruction fills), should not only be located in their respective sectors, but also in the rooms themselves. To locate the rooms in the plan of the site, four points with their absolute co-ordinates defining the room should be measured.

### **4.3.1 Absolute and Relative Heights**

In the immediate neighbourhood of each site one point of which the absolute height is known is to be set out. From this point it should be possible to measure the heights of the different archaeological features. These heights may be given as a relative value referring to a particular point only if the absolute height of this last point is clearly indicated in the notebook and on plans and sections each time heights are indicated. The measurement of

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heights is recommended for features such as layers, constructional elements (walls, floors, water pipes, drainage channels, and so on) and burials. There are at all times at least two levelling-instruments available, giving every excavation the opportunity to measure the necessary heights. The heights should be measured regularly and noted down in a separate list at the back of the notebook. The positions of the measured points should be indicated on sketches included in this list. All points and heights measured on the site, by archaeologists as well as by any other disciplines (topographers, architects, etc.) must be noted in the notebook.

#### 4.4 Recording Finds at Sagalassos

All archaeological finds must be recorded in such a way that all relevant information is preserved for later study. This information corresponds with the different fields of the labels and includes the location of the finds within the stratigraphy and within the plan of the excavation, the inventory number of the find and the type of material. For every first find of a certain category in a new layer and in a new sector, one yellow label is completed in two different booklets. The yellow labels of one booklet stay with the finds, the other booklet is kept complete for reference. The fields that must be completed include:

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**date** dd/mm/yyyy

**site** LA, RB, DA1, UA, AN, B, H, ...

**sector** x-coordinate/y-coordinate

**feature** only integers (no letters, dashes or combinations of integers and letters)

**inv.nr.** SA year site number (e.g. SA98 RB 54)

**material** see below

**object** see below

**remark** room (if necessary), etc.

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All inventory numbers are unique. This means that the same numbers can never be used more than once during one campaign. When a new layer or

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sector is started numbers follow up and are not repeated. Thus SA98 RB 1 is followed by SA98 RB 2, is followed by SA98 RB 3, is followed by SA98 RB 4, and so on. 1, 2, 3, 4, ... are never used again during that campaign. Figure 64 shows a table of example inventory numbers.

|   |
|---|
| Site RB, sector 5385/4800, layer 1, ceramics: SA98 RB 1 |
| Site RB, sector 5385/4800, layer 1, glass: SA98 RB 2    |
| Site RB, sector 5385/4800, layer 1, bone: SA98 RB 3     |
| Site RB, sector 5385/4800, layer 2, ceramics: SA98 RB 4 |
| Site RB, sector 5385/4800, layer 2, metal: SA98 RB 5    |
| Site RB, sector 5380/4800, layer 1, ceramics: SA98 RB 6 |
| Site RB, sector 5380/4800, layer 1, crustae: SA98 RB 7  |

Figure 64. Example inventory numbers

The categories of finds that can be recorded are simplified to the material of the object. Only two exceptions can be made, namely a small piece of marble, glass, earthenware, or the like, having a square, or nearly square, face, used by the ancients for mosaic, as for making pavements, for ornamenting walls, and like purposes (tesserae), and for coins. The latter all receive one unique yellow label.

Only the materials listed below can be filled in under “material”

|   |
|---|
| finds with (yellow) label includes (object)                 |
| ceramic (pottery, figurines, stamped tiles, oil lamps, ...) |
| glass (vessels, window glass, beads, slag, ...)             |
| metal (nails, hooks, metal jewellery, figurines, ...)       |
| bone (animal bone, bone hairpins, spoons, ...)              |
| human bone (one yellow label for each skeleton)             |
| stone artefact (mill stone, statuary, figurine, ...)        |
| crustae   |
| tesserae  |
| stucco/plaster  |
| coin (exception)  |

If the archaeologist is uncertain whether or not to give a find a yellow label, it can be given another label, not coming from the booklets, including all relevant information. Yellow labels can always be given to these finds at the excavation house after consulting the depot manager. Since only one yellow label is given per category, all other finds of this category that are found in the same sector, same layer, but for instance on another day, will have to be sent down with another label not coming from the booklets. On this last label all information mentioned on the yellow labels has to be repeated.

#### **4.4 Forms**

During the excavations several forms have to be completed. These forms offer a way to collect first hand relevant information in a systematic way and should be treated as such. This means they must be completed on site. Under no circumstances should information be copied from the notebook onto the forms. The only exception to this rule is the stratigraphy form, as shown in Appendix A.1, which can only be entirely completed after a complete layer has been excavated. The notebook should be referred to regarding the forms that are completed. All the forms that are completed during the week have to be handed in on the evening before the weekend. They are collected on a site-by-site basis and are available for reference.

##### **4.4.1 Sagalassos Stratigraphy Form**

At Sagalassos, stratigraphy forms are filled out as shown in Appendix A.1. These forms must be completed for every new layer under excavation. The various sections on this form are described as follows:

The *Stratigraphic relations* field is of utmost importance. The central field contains the inventory number of the ceramic finds of that layer and sector. In the surrounding fields the ceramic numbers of the surrounding layers and sectors are completed. The fields are connected by symbols indicating their stratigraphical relations. These symbols are based on the Harris Stratigraphic Matrix. Together with the stratigraphic forms a complete matrix of the entire site is updated on a regular basis. As such, it is easier to understand the stratigraphy of the site and wrong interpretations



can be identified and corrected immediately. On the back of the stratigraphy form the inventory numbers and type of material of the other categories of finds from that layer in that sector are completed, and a plan and section of the situation of the layer within the stratigraphic context is sketched. North and the scale must be marked.

Descriptions of masonry, skeleton and surface recording forms have been left out for purposes of brevity, as it does not fall within the bounds of this work.

#### **4.5 Notebook**

The site notebook contains a personal account of the excavation, day by day. All relevant information must be written in the notebook. This includes:

- A short description of the layers excavated during the day (as well as on the stratigraphy forms)
- All finds, not only the new ones, made during the day, with inventory number and indication of the material. These finds must be grouped by sector and by layer.
- References to the different forms that are completed during the day, as well as to plans and sections that are drawn during the day.
- An account of the activities of the day, mentioning particular finds and circumstances.
- Polaroids taken during the day.
- Descriptions, measurements and sketches of archaeological features and finds.
- Hypotheses, questions and remarks about the site being excavated

The site notebook should contain all references to the different categories of labels, forms, plans and sections that have been completed during the day. As such the notebook forms the central part of the excavation report and should be kept as up to date as possible. The notebook is handed in, in the evening before the weekend starts and is handed back before the start of the next working week.

Notebooks feature:

- A new page for every new excavation day.
- A list of finds for every layer in every sector excavated on that day.
- A description of the layers.
- The left page for Polaroids, sketches and remarks.
- A comprehensible compiled list of daily plans and forms.

#### **4.6 Stones and Masterplans**

At Sagalassos, all excavations take place in the ancient city, most of them even in its monumental centre. As a consequence, stones turn up at all the sites and have to be dealt with. Blocks that turn up during the excavations and have to be removed in order to be able to proceed are added to the stone list and drawn into the stone situation plans. After they are transferred to the platform, a sketch of the position of all blocks on the platform must be drawn. Blocks that are part of the monument currently being excavated, which are *in situ*, must be drawn on the masterplan.

# Chapter 5

## The *Strat* Tool

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HE *Strat* tool is a stratigraphic visualisation, hypothesis and query tool. One of the main contributions of this work derives from the analytical and educational ability provided by the development of this scientific tool.

This chapter is organised as follows, first the requirements of the system are considered in Section 5.1. A prototype system is looked at in Section 5.2. The applicability and availability of reusable libraries and free APIs are considered for the full development of the *Strat* Tool in Section 5.3. A close look at the relation between archaeological contexts and the resulting data model is provided in Section 5.4. Section 5.5 looks at possible platforms for the storage of multimedia elements in an archaeological database. Section 5.6 explores the best methods for the archaeologist to interact with the GIS. Section 5.7 broadly describes the navigation of *Strat*, whilst Section 5.8 describes the information entry aspect of the system. The design of the legacy data input format is described in more detail in Section 5.9. Section 5.10 looks at how the system deals with the querying of artefacts. Section 5.11 looks at the importation of 3D objects through the use of OpenInventor. Section 5.12 shows the input method for regular grids for the *Strat* tool. Section 5.13 discusses in detail how an animation bar, or time-slider can be used to display different forms of temporal data. Section 5.14 shows how layers can be peeled off in a timely order illustrating the progress of an excavation. Section 5.15 discusses system performance through the use of a

carefully designed questionnaire and shows the results of these user trials. The final section, Section 5.16, concludes this chapter.

## 5.1 Archaeological User Requirements

An initial set of user-requirements for the *Strat* tool was arrived at after discussions with members of the Sagalassos project team. What follows is this list of requirements, with prototype images displayed for clarification. Sometimes these images are taken from programmed prototypes of the *Strat* tool, which at the time of writing had progressed through three iterations. On other occasions, 3DS Max is utilised to provide a 3D impression. This section does not provide solutions to the requirements; this is examined in further sections of this chapter.

### 5.1.1 General Interface

The screen will mostly be taken with a 3D representation of the stratigraphy, possibly with each layer being made semi-transparent. Artifacts will be visible through the stratigraphy at the precise position at which they were found, perhaps in a simplified or symbolic manner. The position of most small finds on digs (for example pottery) is only recorded per sector (i.e. an error margin of 5m); hence accurate artefact positioning is not the standard. Most artifacts discovered are heavily broken, that is to say one pot is likely to be in 100 pieces. Objects should be able to be selected by the layer in which they were found.

The stratigraphic sequence can and should be constructed without reference to the artefactual contents of the strata. Sometimes there are odd sized shapes of stratigraphy, for example circles. Quite often on a dig, two layers of stratigraphy that are recorded by one archaeologist on one sector will be recorded as only one layer in the adjacent part of the stratigraphy. This distinction needs to be represented in some manner.

It is to be expected that full 3D images of individual finds will not be immediately available in all cases. A 3D wire-frame model is considered a valuable enough representation. A hypothesis is shown in Figure 65.

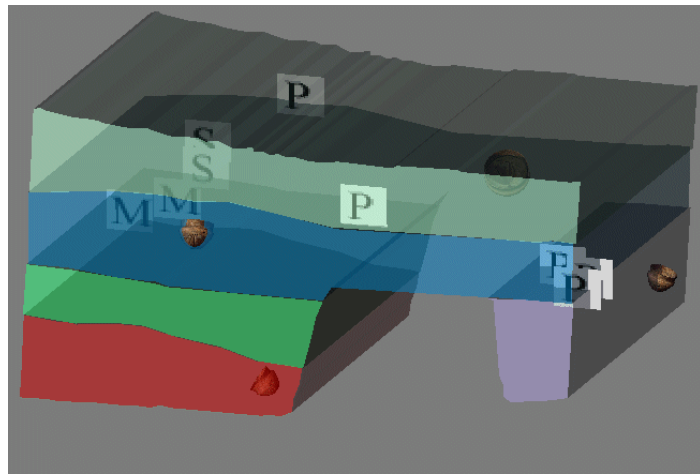


Figure 65. Artefacts embedded in strata.

An exploded view where each layer is taken apart from each other vertically would be very useful, see Figure 66. The layers could be abstracted with hatching as shown in Figure 67.

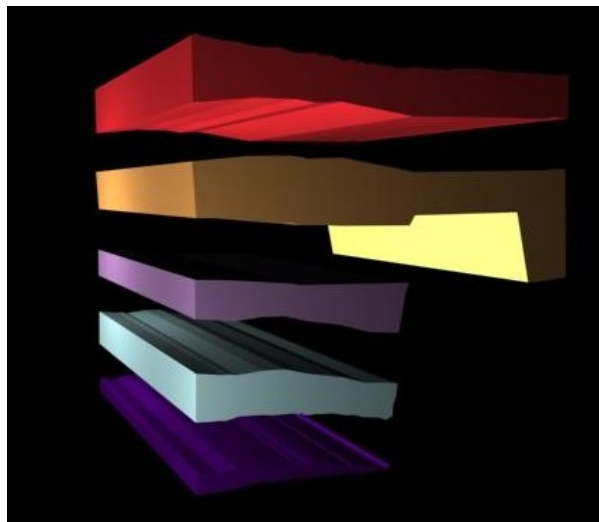


Figure 66. Exploded strata.

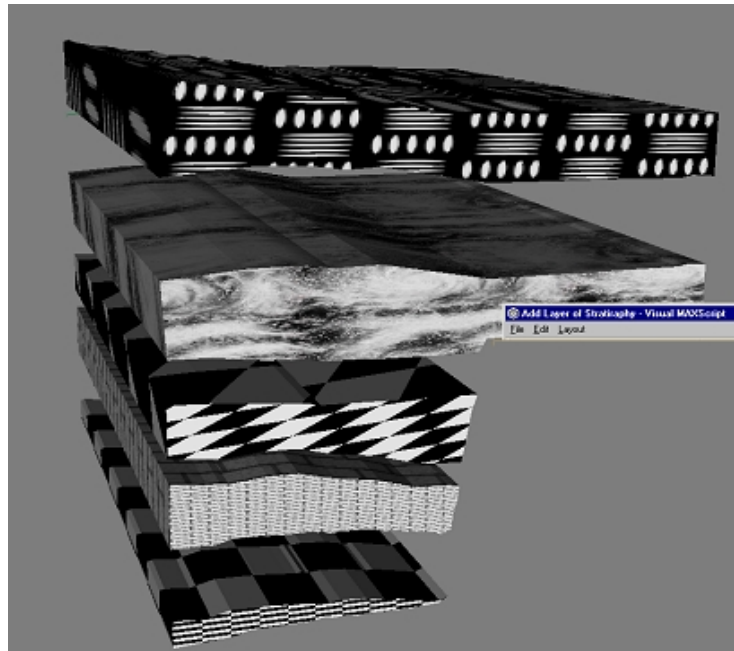


Figure 67. Hatching representing the layers.

### 5.1.2 Querying

A querying section whereby archaeologists are able to simply fill in some text fields to identify a new artifact they have discovered. In this case, the essential search criteria will probably be something like the nature of the artefact, always taking into account that categories can be eliminated and/or added at some later stage. The database should be able to be visually queried per layer / sector / type and texture.

### 5.1.3 Toolbar

Buttons used to hide pottery and buildings are prototyped in Figure 68. Additional buttons shown include buttons for most of the functionality; exploding strata, annotation, zooming, querying, theodolite data importation, cross-section creation, showing/hiding of building elements and so on.



Figure 68. A prototype of the *Strat* toolbar.

#### 5.1.4 Overlaying of Drawings.

Plans of actual situations could be overlaid with the 3D stratigraphic reconstructions, see Figure 69. Master plans can indicate where the building was located, which may help for the correct placement of reconstructed building elements if the objects were not registered. Plans of reconstructions could be overlaid with the actual 3D reconstructed model for validation as shown in Figure 70. The ability to annotate a layer or object in the scene would be of use as shown in Figure 71.



Figure 69. Stratigraphic reconstruction over a real situation.

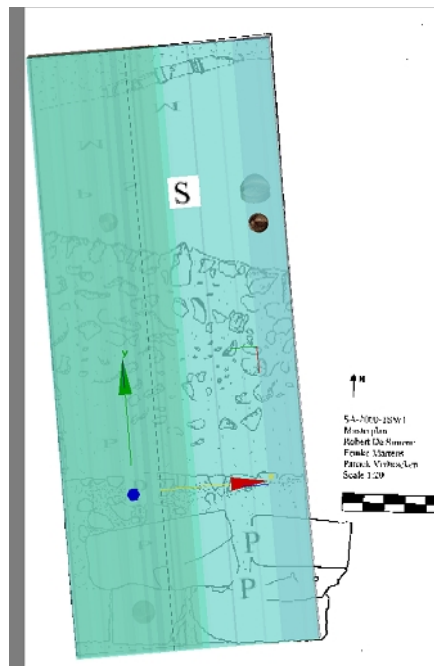


Figure 70. Stratigraphic reconstruction overlaid onto reconstructed plan drawings.

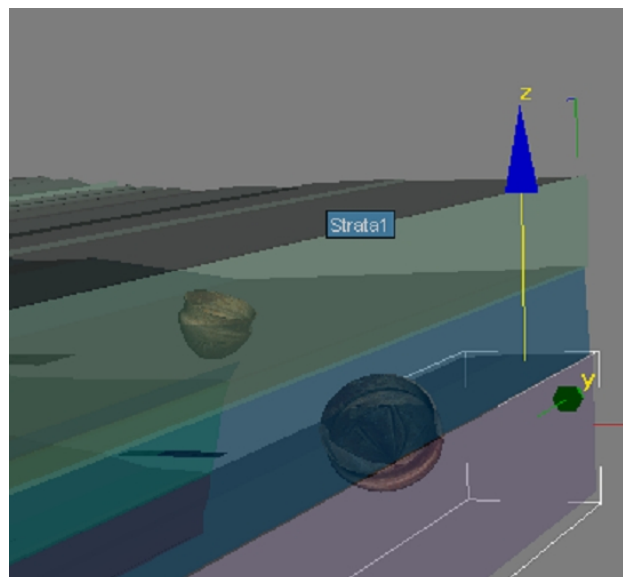


Figure 71. Annotating layers. Here the layer is annotated “Strata1”

### 5.1.5 Functionality

The ability to hide layers would be a useful facet; this is shown in Figure 72. A time-slider for the period throughout the excavation would be useful. This is spoken about in more detail in section . An example image is shown in Figure 73. Standard transformation tools should be used – rotate / translate



/ move around the dig site. Plan view and 3D views must also be possible (In a 3D environment this is trivial).

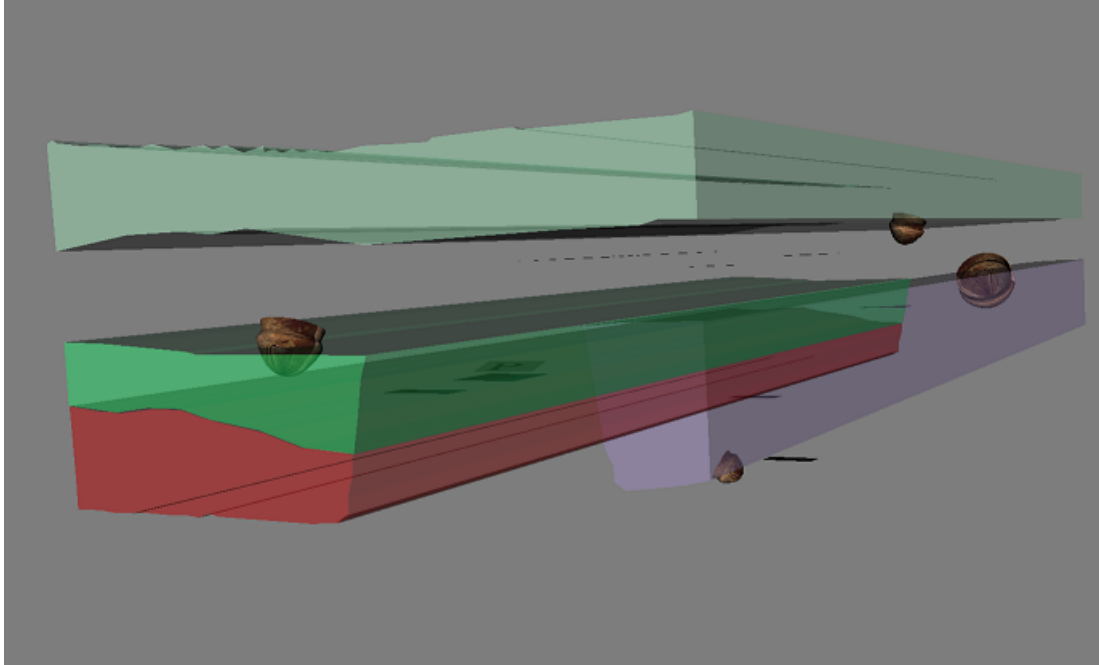


Figure 72. Hiding layers in excavation units.

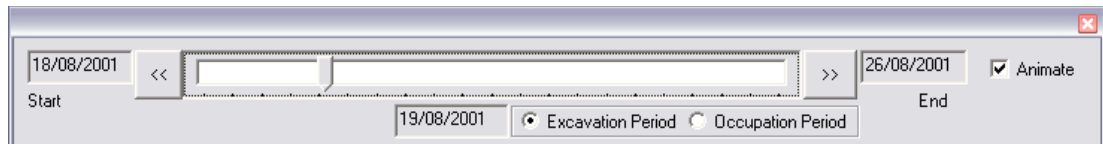


Figure 73. Time slider.

Lines need to be drawn across the plan view of the stratigraphy, which will then display a cross section of the stratigraphy from top to bottom. From this cross-section the user must be able to zoom in closer on regions of the stratigraphy. The ability to print and save cross-sections of the stratigraphy for later analysis is useful. This principle is shown in Figure 74.

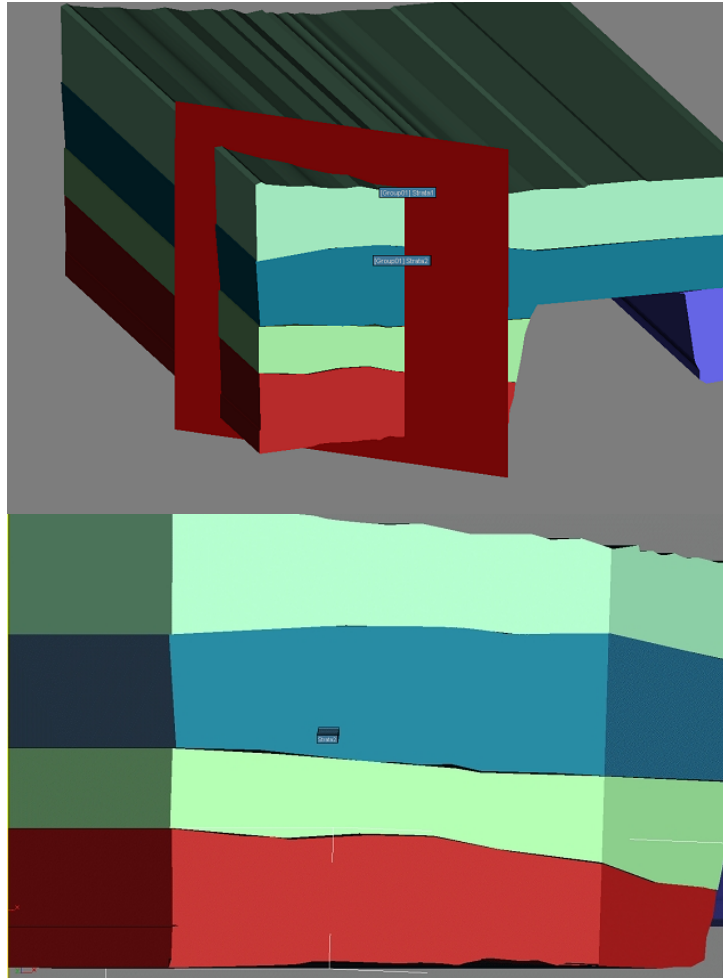


Figure 74. Cross sections through an excavation unit.

### 5.1.6 Linking the Harris Matrix to Visual Model

Ideally, a way to link the data analysis of the Harris matrix to the visual stratigraphic model would be useful. If this could be realized at some later stage, it would lift the stratigraphic module from being a purely visual instrument to an integrated research tool, with a high research potential in its own right. *Strat* accomplished this by linking with the popular ArchEd application described in section 3.2 and displaying the 2D matrix for the 3D representation, this is shown most clearly in Figure 75. In this example there are more stratigraphic units shown in the Harris graph than are currently shown on screen since some strata are hidden from view.

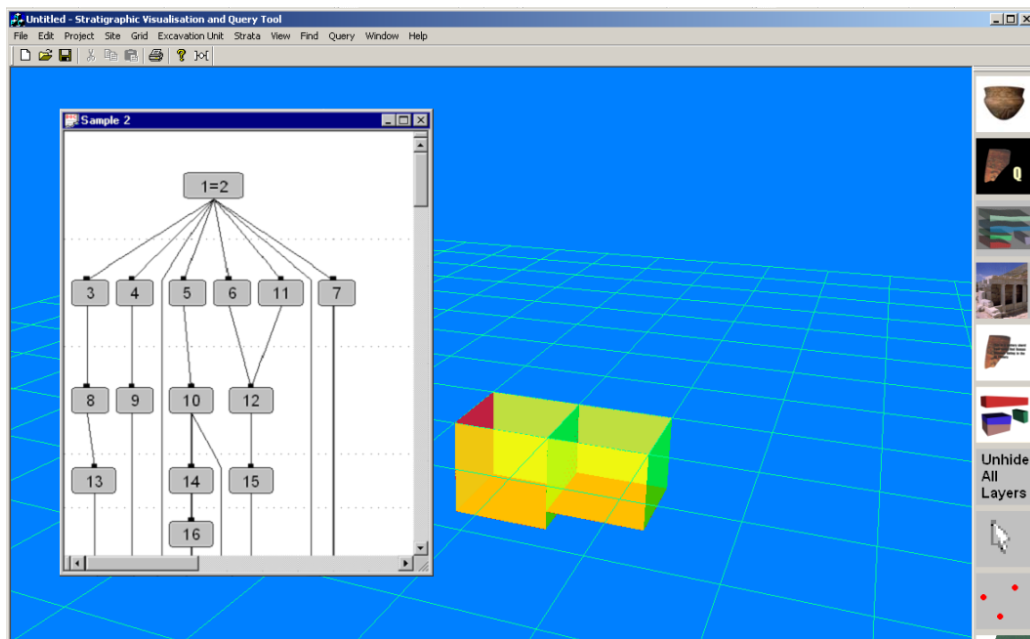


Figure 75. The *Strat* application launching *ArchEd*.

## 5.2 Prototyping

Before a vast amount of work was carried out in the implementation of this tool, the end result was visualised for approval by archaeologists to ensure that the right result would be achieved. Discreet's 3DSMax (Discreet, 2002) was used to create a prototype of an excavation unit containing five layers of stratigraphy, see Figure 76. This model was created by tracing the outline of

profile drawings of a test site at Sagalassos entitled “Theatre Streets West 1”. The markers with letters shown in the figure correspond to the following; P=Pottery, S=Stone, M=Metal. Three-dimensional models of ceramics are embedded in the layers of stratigraphy. If the 3D position has not been recorded, these models are randomly distributed within the stratum. On some archaeological sites, such as at the site of Heslerton in Yorkshire, under the supervision of Powlesland (Powlesland, 2001), the positions of all finds are recorded in 3D space. The exact position of every ceramic find is rarely recorded due to the vast quantities that are extracted. The ceramic model embedded in this image was lathed from a profile of a typical pot found at Sagalassos. This spline was traced from a photograph of the pot and a texture was applied to the resulting model. This was taken from the same photograph. Figure 77a shows the original photograph of the ceramic artefact uncovered at Sagalassos and Figure 77b shows the 3D reconstructed test model used for the purpose of prototyping the *Strat* tool. This is by no means a scientific reconstruction of the ceramic; it is merely used to indicate what is possible.

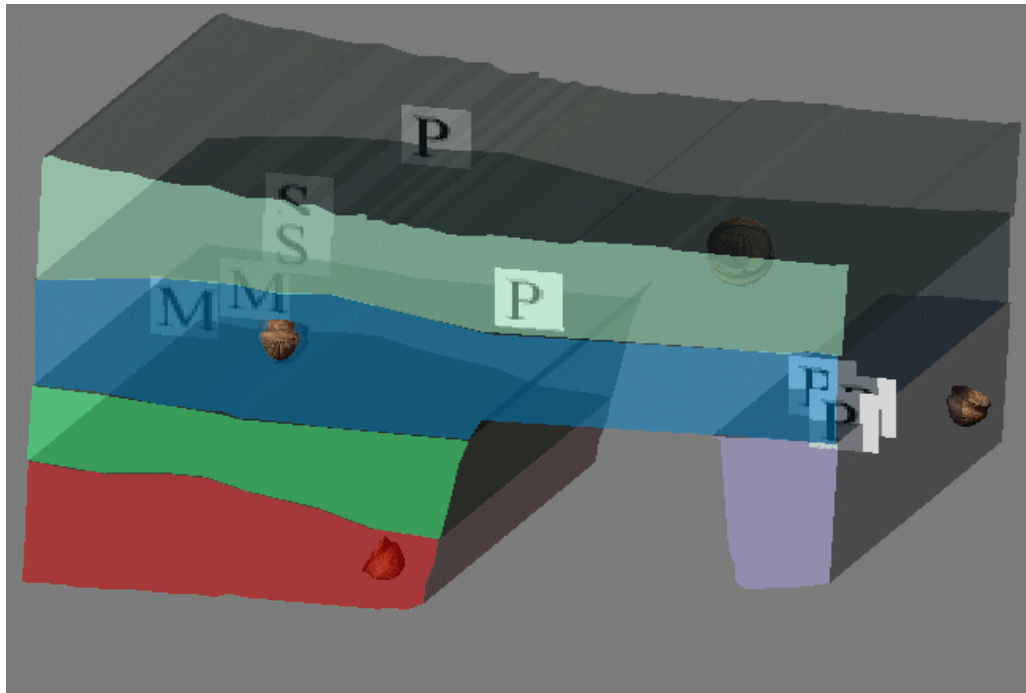


Figure 76. A prototype of the *Strat* tool visualizing stratigraphy with embedded artefacts.

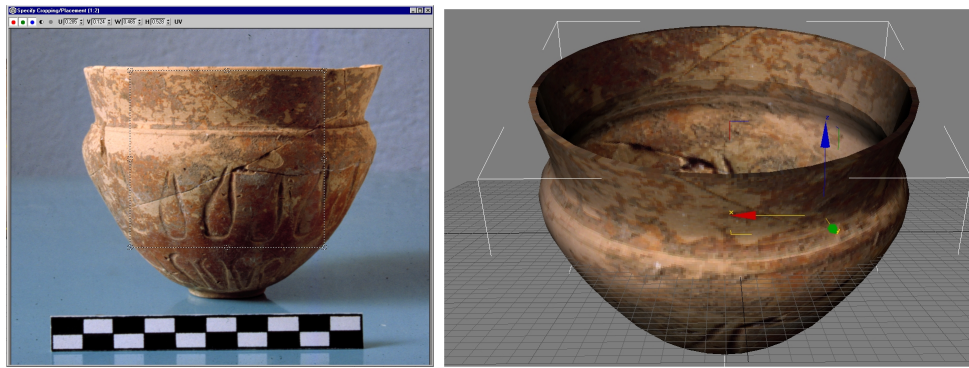


Figure 77. **a)** An original photograph of a ceramic found at Sagalassos. (Courtesy of the archaeological team at KU Leuven, Belgium. **b)** a 3D reconstructed model used for the purpose of prototyping the *Strat* tool.

### 5.2.1 Reusable Libraries and free APIs

Many attempts have been made in recent times to provide an open standard 3D graphics library for general use. OpenGL and Open Inventor™ are examples of these. The prototype of *Strat* was developed using the popular API - MFC. It does not require a license to distribute MFC programs keeping the price of the end-system low or free, (an important requirement when developing tools for archaeologists). A Windows application was built with it. An MFC starter application which utilised OpenGL was used as the base program about which all further development was launched. As the prototype developed there came a stage where more advanced functions were required, for example, the manipulation of objects using handles similar to that of 3DS Max. After discussion with colleagues it became apparent that Open Inventor™ handles much of this functionality with no programming required.

Open Inventor™ is an object-oriented 3D toolkit offering a comprehensive solution to interactive graphics programming problems. It presents a programming model based on a 3D scene database that dramatically simplifies graphics programming. It includes a rich set of objects such as cubes, polygons, text, materials, cameras, lights, trackballs, handle boxes, 3D viewers, and editors that speed up programming time and extend 3D programming capabilities. As well as using its interfaces, its standard file format for 3D data interchange, *.iv files* are used.

After several unsuccessful attempts to get Open Inventor™ samples working with ‘manipulators’ on Microsoft Windows using Windows libraries, attempts were made to use Open Inventor™ on Linux. Linux however did not have the necessary drivers for the graphics card of the Sgi Zx10’s Wildcat 4210 AGP Graphics card used in this research, such that a WIMP interface environment could not be installed. Other currently available open environments were investigated such as SoQT.

SoQt is a C++ GUI toolkit for using Coin with the Qt library. It can also be used on top of Open Inventor from SGI and TGS. The API is based on the InventorXt API originally from SGI.

Qt is a C++ toolkit for primarily the GUI parts of application development. Qt is a multi-platform library, available for X11-based systems (UNIX, Linux and \*BSDs, for instance), MS Windows, Mac OS X and embedded systems. After looking at QT for some time it became apparent that it was still a system in development and judging by the questions asked on the various FAQs, it was not going to be able to easily reproduce the kind of interface enjoyed by the prototype of *Strat*. However, it is portable such that an application developed using it will work under both Windows and Linux making the end-tool available to a wider audience. At the time of writing two possible solutions were considered; spend more effort trying to get OpenInventor working with *manipulators* in Windows (an achievable task) or get a stable version of Linux with a Windows manager working and continue development on a Linux platform. This would involve using a different machine and the learning of a new OS. Figure 78 shows more clearly the possible platform configurations.

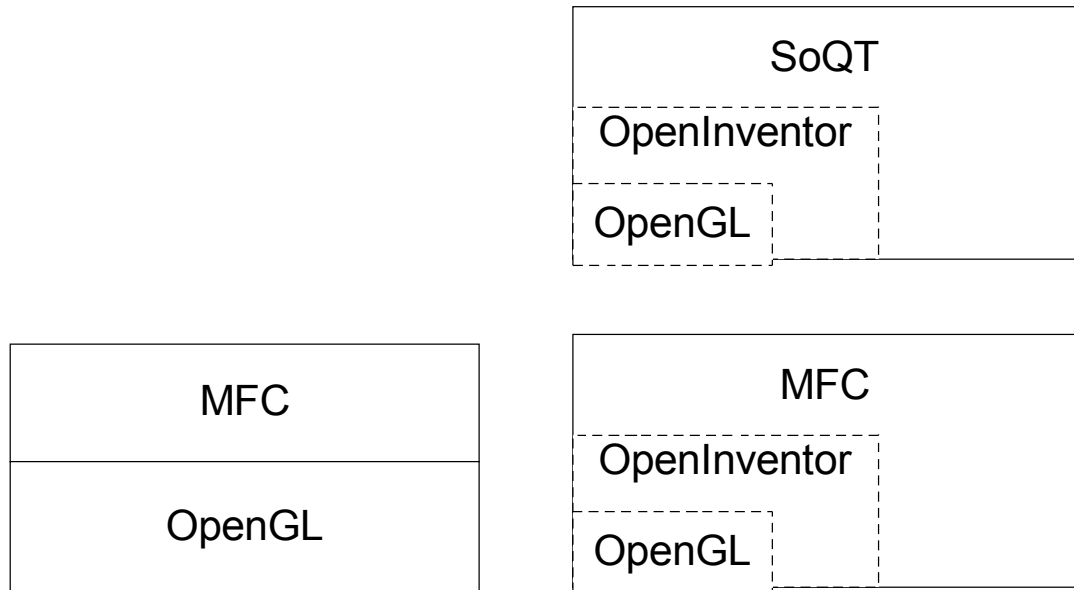


Figure 78. Possible platforms for future *Strat* development

### 5.2.2 Data Model

Data modelling answers a set of specific questions that are relevant to any data processing application. What are the primary data objects to be processed by the system? Where do the objects currently reside? What is the composition of each data object and what attributes describe the object? What are the relationships between each object and other objects? What are the relationships between the objects and the processes that transform them? To answer these questions, data modelling methods make use of the Entity Relationship Diagram (ERD). The ERD defines all data that are input, stored, transformed and produced within an application.

Modelling stratigraphy data is no trivial task. To do so requires studying as closely as possible the procedures used by archaeologists on as many sites as possible. Figure 81 is the result of this study and the following paragraphs justify in detail the reasoning behind the model.

Over the years for the Sagalassos excavation, archaeologists have used a variety of numbering schemes to label sectors. For example, from the excavation journal for the Upper Agora North (UAN) (Vanbalen, *et al.*, 1994) site at Sagalassos, the archaeologists used Roman numerals to label each sector. A problem arises with this method when the archaeologists

require the area of excavation to be expanded. As a point-in-case the Sagalassos archaeologists wanted to expand further to the east, and to do this had they labelled the adjacent sector *LXI\_E*, where *E* denotes East. They could not use the name *LX* since this was used for the start of the row beneath. The same method was used when they wished to expand west, creating new sectors *LXVI\_W* and *LXVII\_W1*. This makes interpreting this data highly confusing.

Much better is the method later used in the Theatre Street West site (TSW) excavation journal (Martens, 2000a). Here sectors are uniquely represented by their offset from the Primary Site Datum (PSD). For example, the Theatre Streets West 1 site shown in Figure 79 is located at sector 2560, 2655. This causes no difficulty when the site needs to be expanded, because the numbering system is infinite in all directions. In fact, the sector number inherently holds useful data; the offset from the origin in metres.



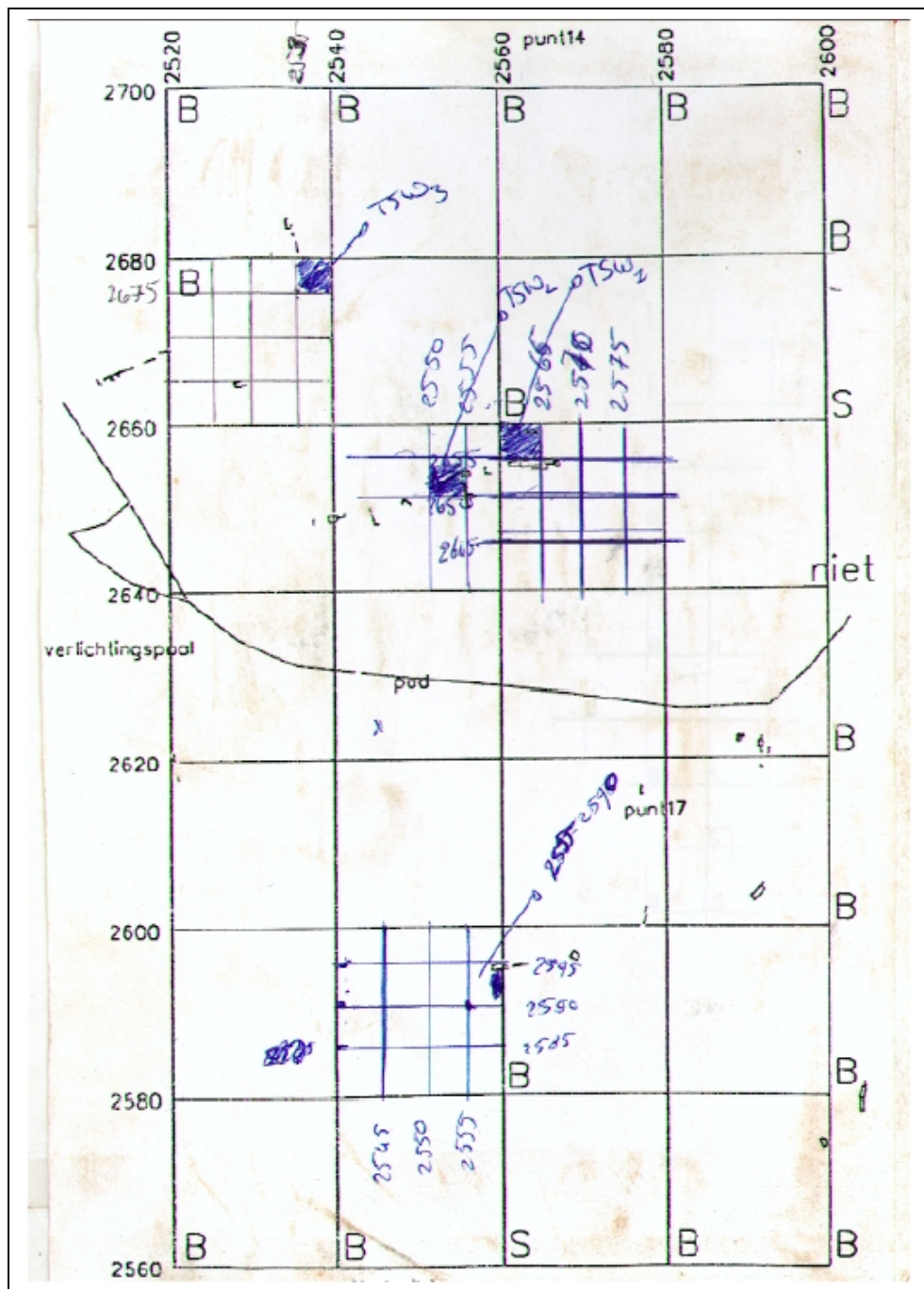


Figure 79. Theatre Streets West Excavation Journal Sector Layout, page 1

Generally speaking, an archaeological campaign can be broken up into a number of sub-sites. For example, a settlement may contain distinguishable places, such as Roman Baths, Potters Quarters and so on. Such conceptual distinctions are used to label contexts and regions on an archaeological site.

To avoid confusion, the overall site has been called a *Project*, for example ‘Sagalassos’. The site then falls under the jurisdiction of a grid. There can be only one grid per site; however, many sites may use the same grid. *Sagalassos* is such an example, but it may be the case that several grids are used on one project. The grid is orientated from its PSD (an absolute origin about which all other points are relative). This position is recorded as a GPS position in degrees latitude, longitude and altitude (metres), see page 21. It also includes the spacing of each sector, for example 5m x 5m.

The sector contains its x and y offset from the PSD, it has a name, for example if Roman numerals were used, *LXXXIV*. Conceptually speaking, a sector does not actually provide useful information. If the grid is uniform (invariably the case) the sectors within are uniformly spaced, and hence have a repetitive X and Y offset from the origin. The result of this is that it is trivial to generate sectors that can be later overlaid into the GIS model. Determining which objects or artefacts belong to which sector is a trivial task – A sector can be found given the X and Y position.

An *excavation unit* is a term used to describe a conceptual notion of excavation. It contains many layers (strata), from top to bottom. It may be described in terms of its offset from the origin and its extents.

Lastly a description is needed for arguably the most interesting item of data - the stratum. To accommodate legacy data, a stratum is composed of four depths which define its corners, a centre point, an average depth, an identifying number, for example ‘*2S*’, a description; information such as that recorded in excavation journals. For example, “*Layer 1 is a sandy loose brown soil with small meteor fragments, some small and medium sized stones. Also lots of finds, mostly ceramic and bone.*” the date it was excavated (this is very useful if it is intended to later replay the excavation), and a pointer or filename of a detailed 3D photogrammetric model. If the photogrammetric model exists (which currently is infrequent) then the height information is disregarded when rendering occurs. The height information can serve as a bounding box or a crude representation of the data on slow machines. The registration (positioning) of the photogrammetric model of

the strata has yet to be solved; however for longevity of the system position information is included.

The data model is broad enough that it holds for any archaeological dig site, and allows for more detailed future 3D models to be used.

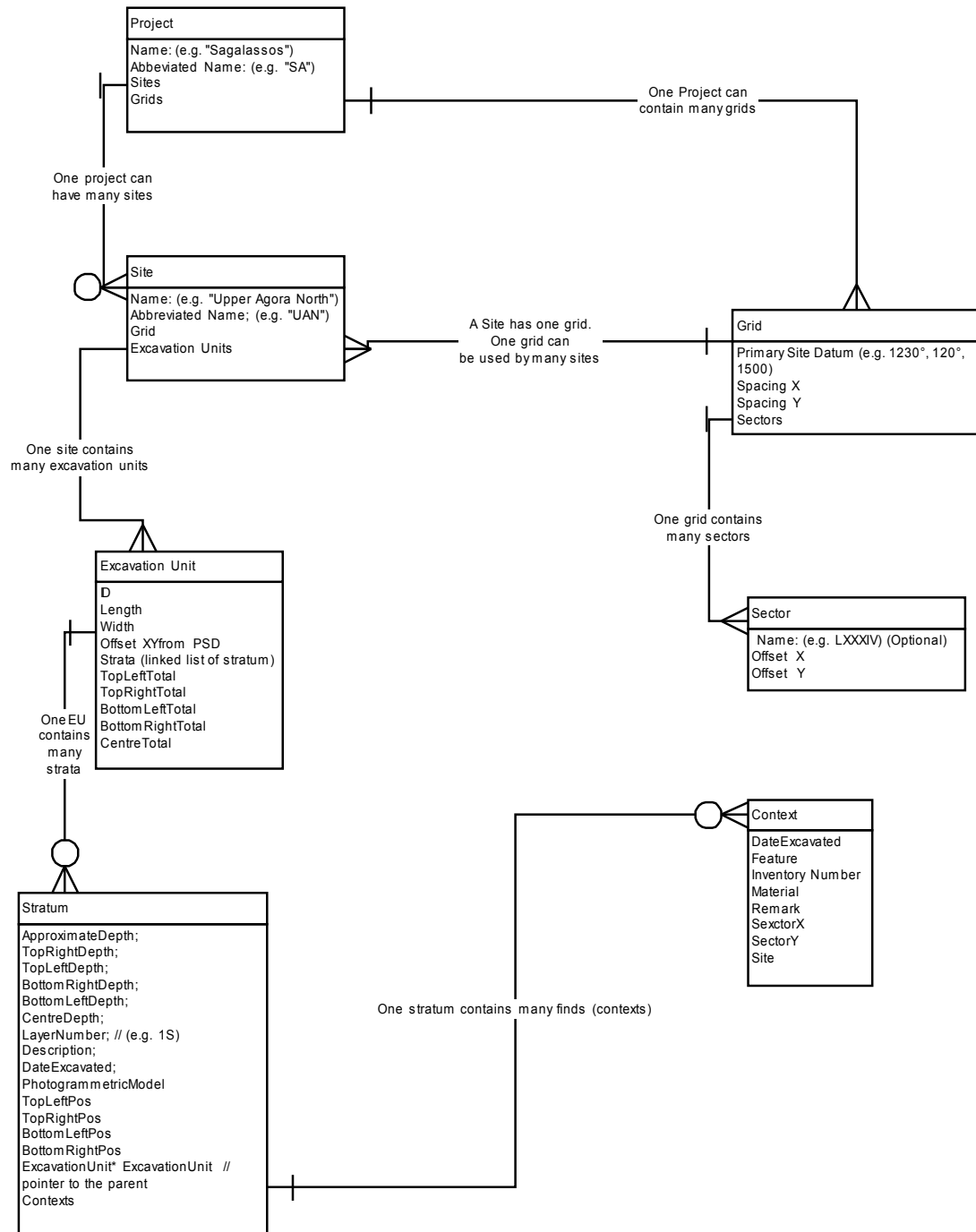


Figure 80. Entity Relationship Diagram showing the data structures used to store an archaeological campaign in the memory of *Strat*.

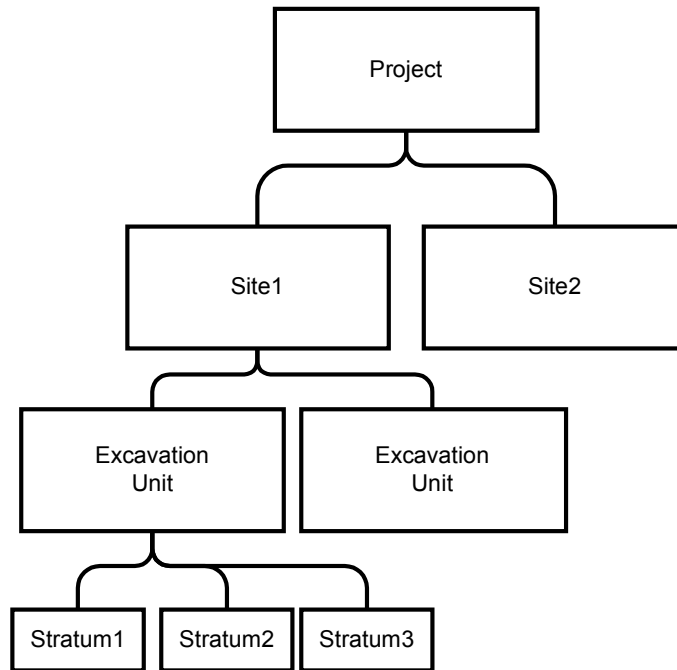


Figure 81. The conceptual model of the archaeological campaign data structures.

### 5.2.3 The Archaeological Database

In view of the fact that the end-user of this technology is the archaeologist, one of the biggest obstacles they are faced with is the cost of their software. Based on this premise a database has been chosen from the variety existing on the market that is free yet powerful, PostgreSQL fits this description. The prototype was however created using MS Access due to its familiarity and simplicity.

### 5.2.4 Graphical User Interface

Since the end-user of this system is inevitably the archaeologist, much thought and effort must go into making the graphical user interface of this tool very simple and familiar to use. Archaeologists are not great users of computers, and computers are not the reason why many of them entered the field. Therefore the system developed must have a very shallow learning curve and be simple to use. For a system that visualises and records 3D data, this presents somewhat of a problem. The first step is to look at how archaeologists work and which tools they are currently using. This was

reviewed in detail in Chapter. Currently, there are several methods of stratigraphic entry by the archaeologist, namely:

- By theodolite
- From legacy data previously recorded in logbooks
- Strat forms

### **5.2.5 Navigation of the System**

The most minimal of interaction is required for the tool; hence navigation is automatic wherever possible. The system developed is such that most of the screen is a visual representation of the archaeological site; this is indeed the manner in which archaeologists are used to seeing the site. Floating dockable toolbars are used and most of the interaction with the system can be achieved with the mouse.

### **5.2.6 Information Entry**

Once the user interface has been defined the next step to consider is how to enter the vital stratigraphic information into the system. There are two forms of stratigraphic data. There is legacy data that has been recorded in both stratigraphy forms and in individual excavation handbooks, as well as 3D surface models captured using photogrammetric approaches (Pollefeys *et al.*, 1998).

Entering photogrammetric models of strata into the tool is not as challenging as that of the legacy data. The 3D model can merely be selected from a directory list, Figure 82.

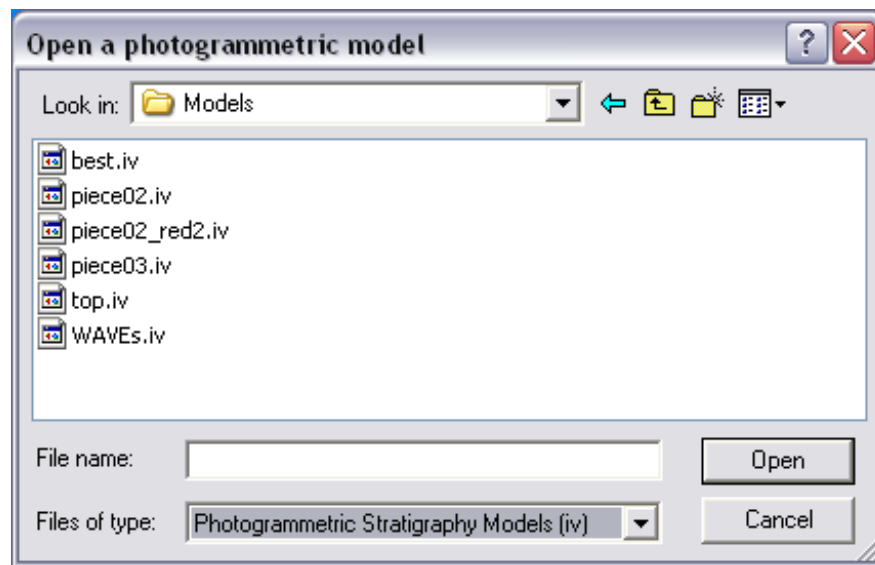


Figure 82. Loading 3D models of strata using *Strat*.

### 5.2.7 Designing the Legacy Data Input Format

The dialog box illustrated in Figure 83 is designed to record all possible types of data which archaeologists record in their excavation journals as well allowing the incorporation of modern high-resolution scanned 3D models.

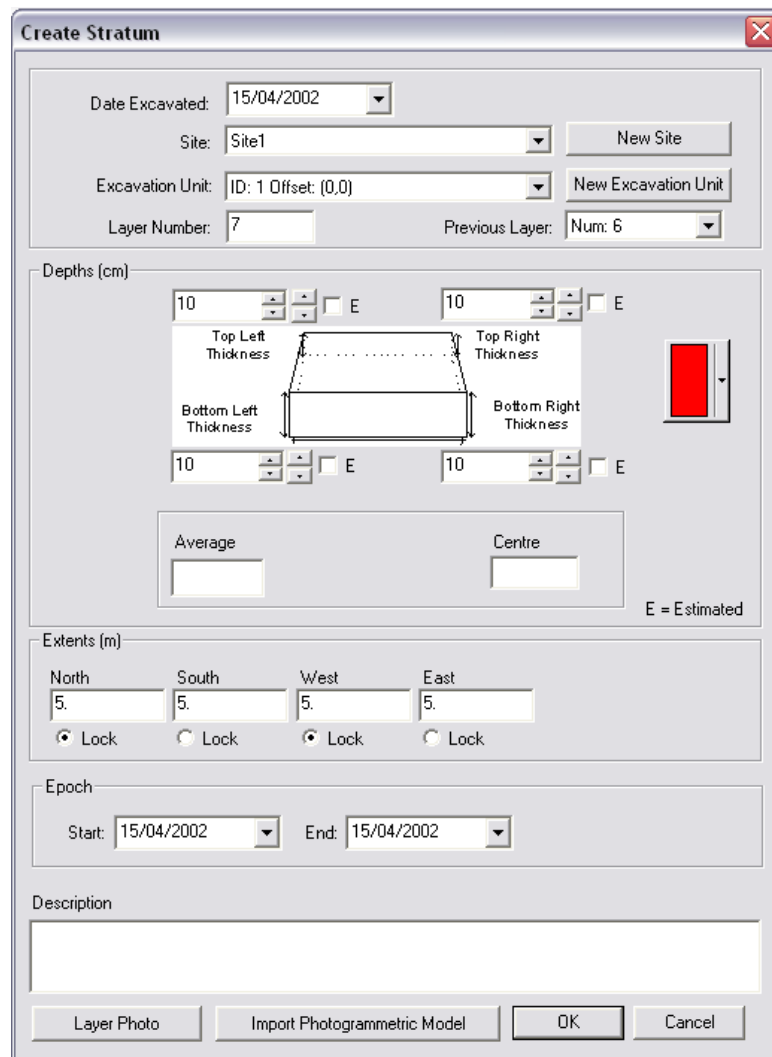


Figure 83. The dialog box for entering stratum data in the *Strat* tool.

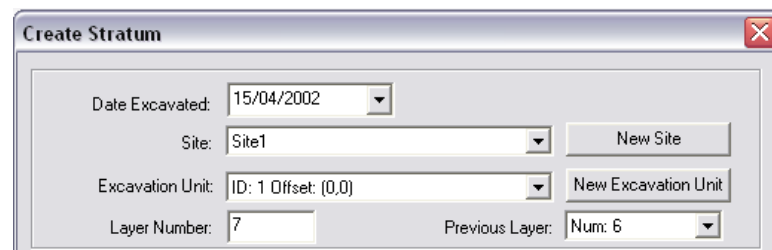


Figure 84. Recording the date, site, trench and layer of a stratum in *Strat*.



The date the stratum was excavated is simply chosen from a date-control as shown in Figure 85.



Figure 85. Selecting the date of excavation of a stratum in the *Strat* tool.

The site from which this layer of stratigraphy belongs is selected from a drop-down box. If this is a new site where work is about to begin, the user presses the *New Site* button. At which point the user is presented with a dialog-box with which to create a new site, Figure 91.

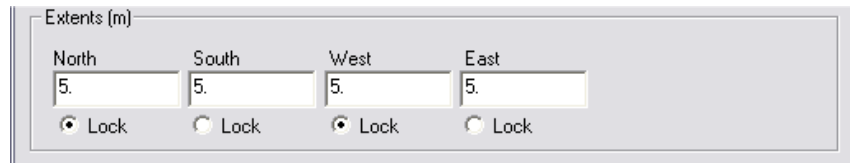


Figure 86. Recording extents in the *Strat* tool.

This new site is added to the list of sites in the database and will consequently appear in the drop-down box when the ok button is pushed. An excavation unit is selected from a previously defined list of excavation units, and once again if the user has omitted to define one they must then do so by clicking on the corresponding button. A layer number is generated based on how many layers have been excavated before-hand. The user using whatever convention is used on site can manually override this. Relations can be formed with the layer above by using the drop-down box. This box displays currently created layers. Relations can be formed later in the software if this is not immediately known.

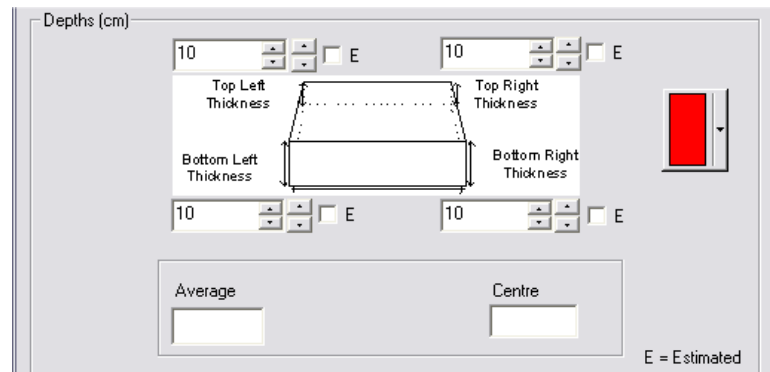


Figure 87. Recording depth information in *Strat*.

Depth information is recorded in one of two ways; using the four heights recorded by the archaeologist for the four corners of the stratum, or by specifying only an average, (not very accurate, but sometimes this is all that is recorded) as shown in Figure 87. Occasionally a centre depth is recorded so the system allows for this possibility. There has been much discussion of late regarding the representation of hypothesised data in archaeological sites. As such, check boxes have been included to tell the system whether or not the height has been estimated. A colour can be selected for the stratum from a colour picker dialog box. This is used for later visualisation. The extents of the stratum are then defined. Widths are defined in metres for the north, south, east and west sides of the stratum. Due to the nature of excavation, it is sometimes the case that a smaller stratum is excavated at the sides of the previous layer. Radio-buttons are used to tell the system that this layer is locked to this side for later rendering.

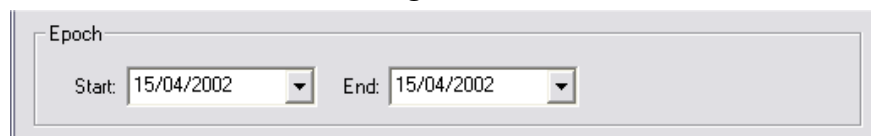


Figure 88. Entering an epoch for the archaeological layer in *Strat*.

An interesting facet of this dialog box is the fact that an epoch can be specified, Figure 88. Two date controls are used to specify as accurately as known the duration at which this stratum existed in ancient times. This is determined and modified as and when dating information is known about objects found in the layer. It is used when animating the 3D model of the site through time.

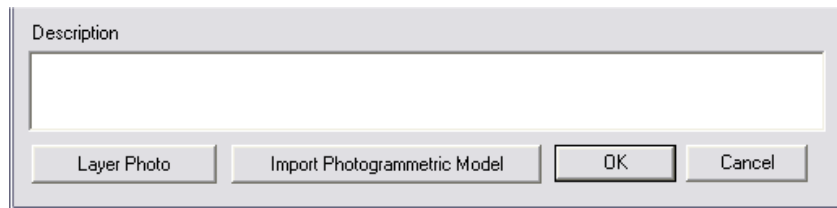


Figure 89. Entering description data and choosing 3D models for strata in the *Strat* tool.

A multi-line text field is used for recording general textual information about the layer as shown in Figure 89. A layer photo can be associated with the stratum by clicking on the layer-photo button. Once entered the user can then view this photo by one click of the mouse button on the stratum. The Import photogrammetric model button allows an Open Inventor™ model or VRML model to be loaded in place of the crudely defined model.

So as to avoid making the interface overly complex and hence confusing the user, data for reconstructing the archaeological site has been spread over several piece-meal dialog boxes as depicted in Figure 92, Figure 93 and Figure 94.

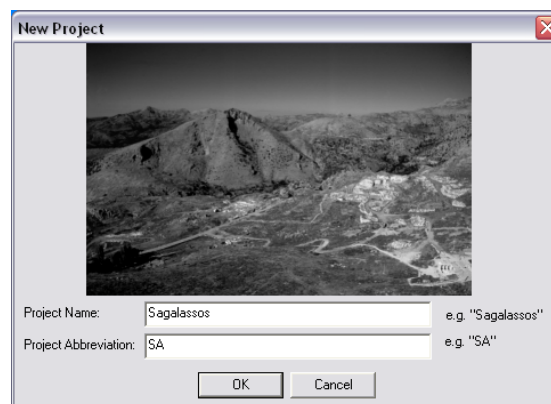


Figure 90. The project entry dialog of *Strat*



Figure 91. Creating a new site in the *Strat* tool.

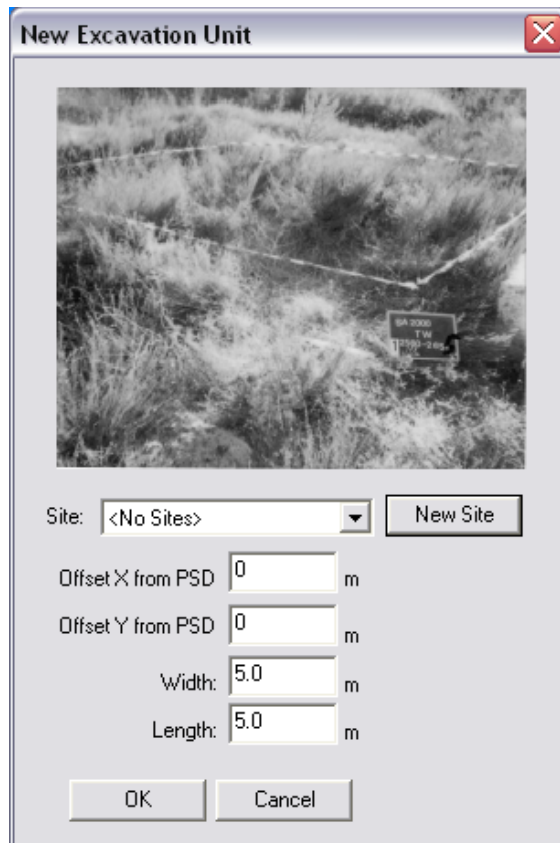


Figure 92. Defining a new excavation unit (trench) in *Strat*.

### 5.2.8 Querying the Data

Strata can be queried by the physical region; site, excavation unit or layer, and then by the type of the material. Materials can be dynamically added or deleted by the user with the push buttons on the right hand side and then

queried against, see Figure 93. Once both options have been selected, the scrollable multi-line text box below becomes filled with results, in the form of the names of the contexts. Each of these lines can be clicked on to display a window with the 3D reconstruction of this artefact (if it exists) alongside information about that context.

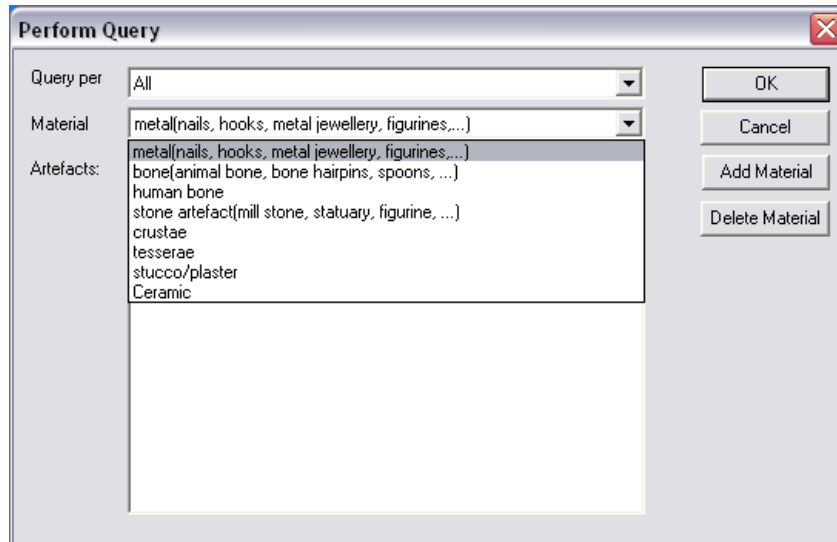


Figure 93. The Query dialog-box for the *Strat* Tool.

### 5.2.9 Importing 3D Objects

There are several types of 3D objects that are to be loaded into the *Strat* tool:

- Photogrammetric models of stratigraphy and buildings
- Photogrammetric models of artefacts
- Topographical grids triangulated from maps

So that the *Strat* software is not tied to any particular company, the open-standard of Open Inventor™ (Open Inventor, 2001) has been chosen to store 3D models.

### 5.2.10 Grids

GPS systems were discussed in detail in Section 2.12. Grids are defined in the *Strat* tool in a similar manner to those which the archaeologists employ. Figure 94 shows the dialog box used for creating grids.

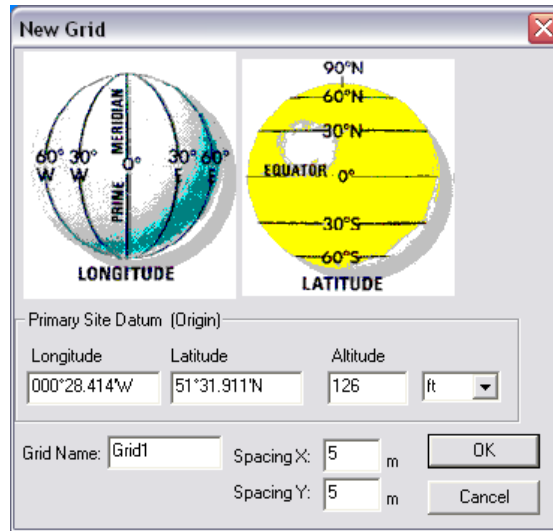


Figure 94. New grid dialog-box in *Strat*

The PSD is entered about which the grid is oriented. The spacing is defined such that a regular grid pattern can be draped over the digital terrain map (Figure 95). In the case of Sagalassos, a regular grid of 5m x 5m is currently used. More than one grid may be used on any one site and this is reflected in the internal structure of the data.

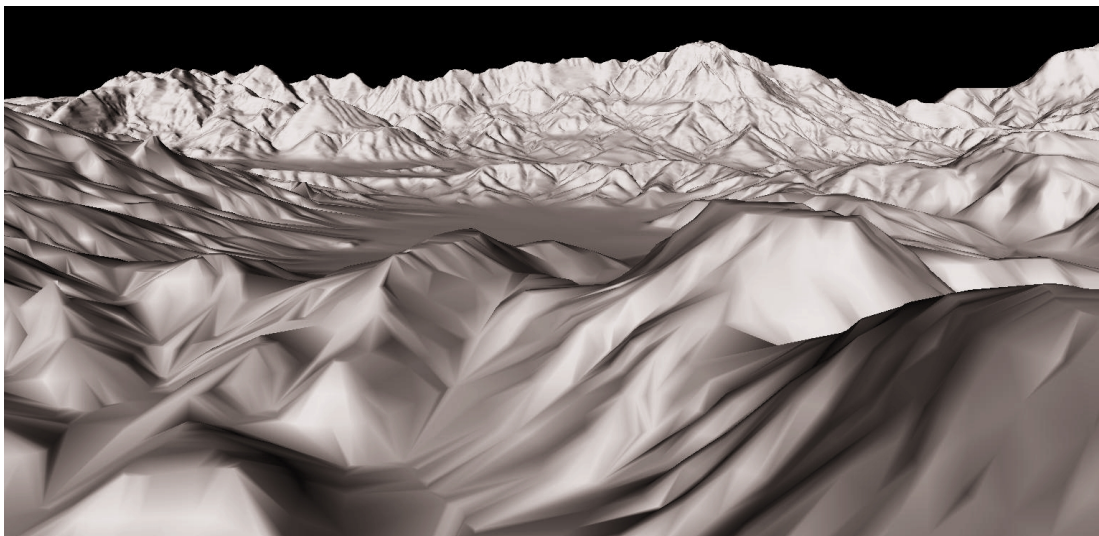


Figure 95. A DTM facing the Ağlasun valley in Turkey.

### 5.2.11 The Timeline

There are two forms of temporal data relating to contexts on an archaeological site that can possibly be reconstructed. One temporal period extends throughout the duration of the excavation, for example, 1990 – 2005. The other temporal period is that of the ancient times, that is to say the actual dates of the occupation period for the stratum. As written in Section 2.9, the stratum is most often dated by the artefacts which lie within it.

One feature of this system is the ability to replay an excavation from start to finish. As has been previously discussed, much effort has been spent entering stratigraphic data in its different forms, and now that the site can be defined in its entirety it is of great interest to see this excavation replayed. The date on which the strata were uncovered has been recorded individually on the *Strat* forms and on the Find forms and is subsequently stored in the database. Replaying the excavation over a period of time involves hiding the contexts that appear later than the position of the time slider pointer. But by adding a time slider to the software the problem arises as to what might happen if the user accidentally moved the time slider to an earlier date and is then unable to see strata that they have created. They may then begin adding duplicate strata to the excavation that they may have incorrectly thought they had forgotten to enter.

One way to overcome this is, on the creation of a new stratum or find, the tool automatically moves the time slider to the end, that is to say, to the end of the excavation, so that the entire site can be viewed as it has been excavated up until the present date.

Another possibility is to have two modes; an animation mode, capable of replaying the excavation, and an editing / reconstruction mode allowing for the entry of stratum data.

Figure 96 shows the dockable *Strat* time-slider. There are two read-only edit controls at either end displaying the minimum and maximum dates of every context which has been recorded into the *Strat* tool so far. This is calculated by traversing the hierarchy of contexts in memory, and keeping track of the highest and lowest date currently encountered. Another read-

only edit-control is used to display the date at which the pointer is currently positioned. The animation check-box allows this time slider to become active. Once unchecked, all currently excavated strata are revealed.

Stratigraphic analysis deals only with chronology, therefore it is a one-dimensional problem. (Herzog, 2001). This one dimensional time slider is the perfect tool for swiftly understanding the change in spatial relation over a chronology for both excavation and occupation period. Two buttons at each end of the slider move the time period to the start or end. The two temporal types can be chosen using the radio control toggle at the bottom.

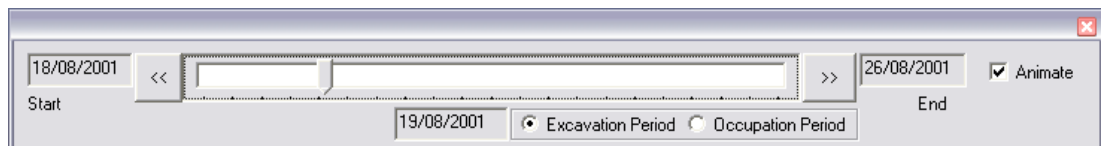
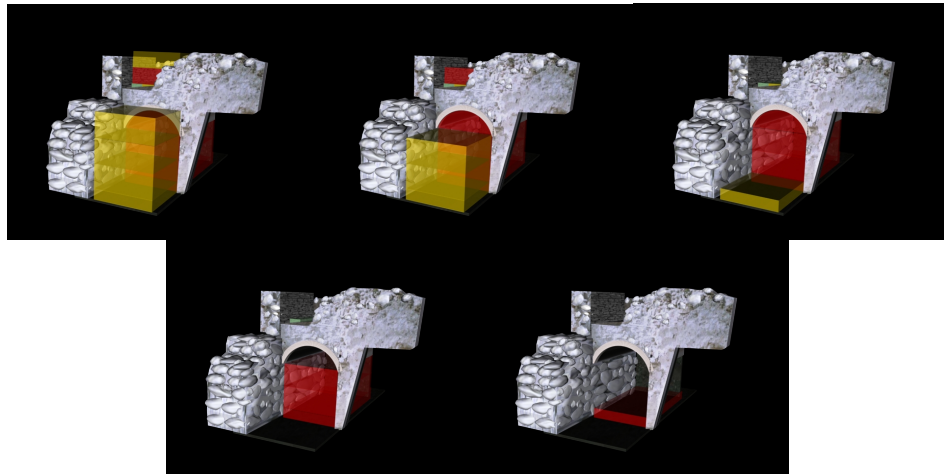


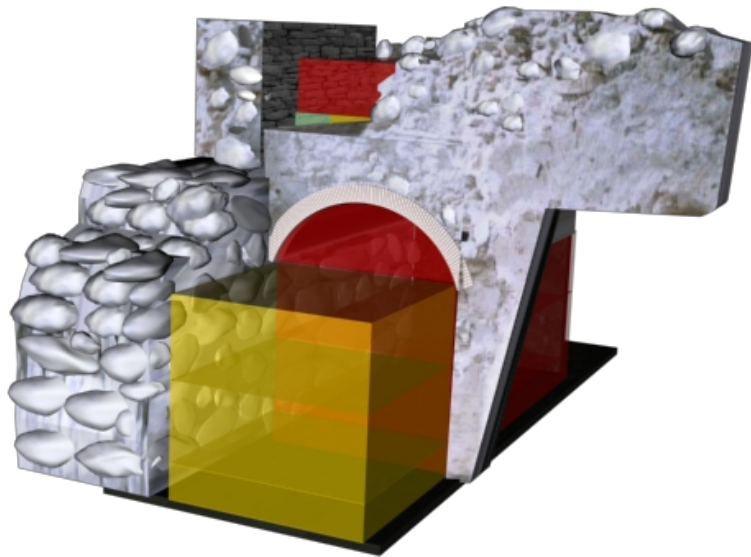
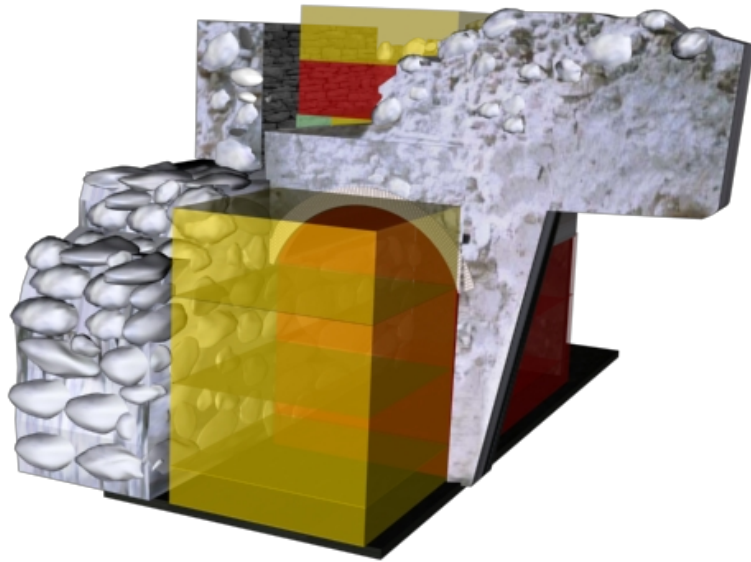
Figure 96. The *Strat* tool's timeline

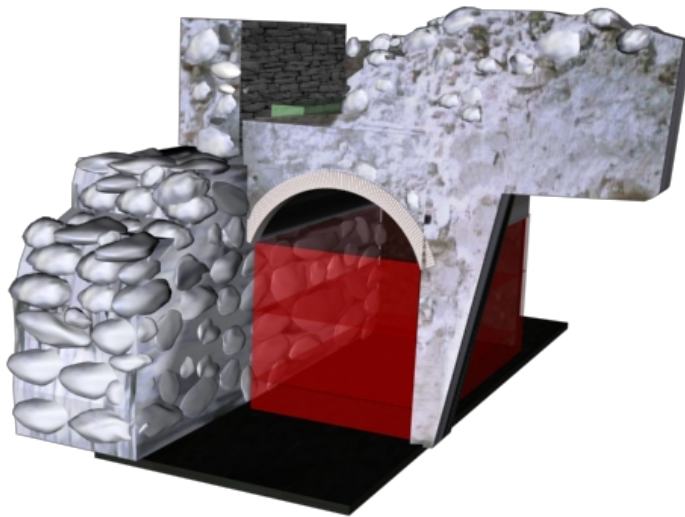
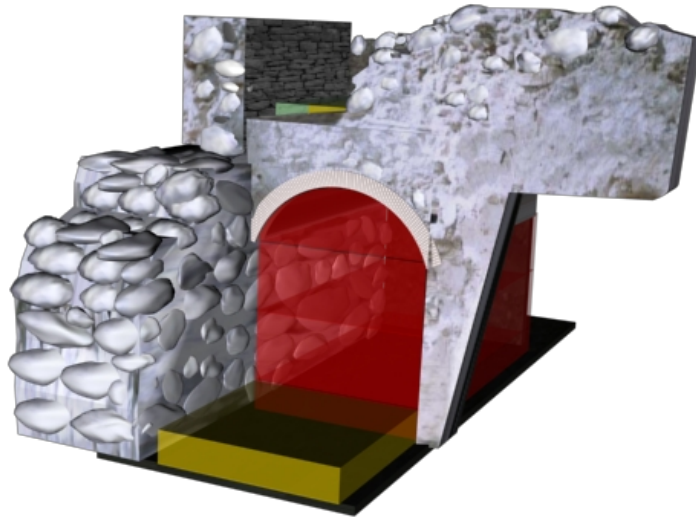
### 5.3 Results

Figure 97 shows the results of archaeological layers being peeled off one by one.









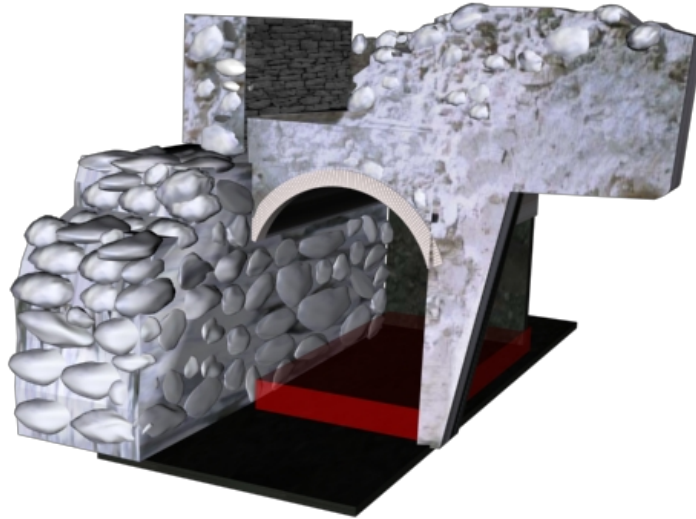


Figure 97. Replaying an archaeological excavation stratigraphically.

## 5.4 Performance Evaluation

To ascertain the strengths and weaknesses of the *Strat* tool a questionnaire was designed as shown in Appendix B.1. The target population was a group of professional archaeologists and was performed on site, at the excavation of Sagalassos in the season of 2002. A group of non-archaeologists also participated as a pilot group. The participants followed predefined exercises as reproduced in Appendix B.2. Since the aim was to gain an understanding of the ease of use of system, not to express the results of a large number of users in figures, a qualitative study was undertaken. Qualitative research is sufficient to uncover significant flaws in the prototype's design. Soliciting the time of a high numbers of professional archaeologists was simply not possible due to limited access to many at one time and physical constraints. With the set of 13 participants, some very interesting observations were made and inevitably on some occasions, discussion took place. In order to maximise response and gain the most detail, data collection was made in person, in a one-to-one interview environment. The core focus of the study was to test the effectiveness, ease of use and possible omissions of the *Strat* tool.

Thanks are due to the following people for taking the time to participate in this survey:

Semra Saral (*classical archaeologist*), Kris Philippaerts (*Computer Scientist*), Johan Van Neck (*Engineer*), Dr. Roland Degeest (*Archaeologist*), Nathalie Kellens (*archaeologist*), In Ae (*archaeologist*), Mohammed Akhtar (*computer scientist*), Dr. Morr Reyhani (*scientist*), Maite San Trujillo (*computer scientist*), Toon Beddegenoodts, (*depot manager*), Dominique Similok (*Geologist*) Ines Vandewoestijne (*conservationist*), Hannelore Vanhaverbeke (*archaeologist*).

#### **5.4.1 The Pilot Study**

A pilot study was carried out to find major flaws in the questionnaire and the questions itself, before travelling to Sagalassos in 2002. The pilot study was a very useful exercise and as a result the questionnaire was revised. The pilot study was carried out on non-archaeologists, which made the exercise more useful because an experienced technical perspective was introduced. The revised user handbook was as a result made clearer in its instruction.

One of the main alterations to the questionnaire was the introduction of a list of software that the user may have previously used. This is a useful exercise to determine the types of interface and levels of complexity with which the archaeologists are already familiar. The user omits this section if they are not familiar with any software, a question was asked beforehand to determine this. Additional to archaeological software, the user was asked what other software they use on a regular basis. Suggestions to software improvement were made as well changes that needed to be made to the questionnaire. These detailed points are listed in Appendix B.3.

#### **5.4.2 Results of Study**

Comments arising from the study are given in this section. On performing the set tasks; to create a project, site, excavation unit and stratum, users responded with comments, suggestions and problems with the software. The range of comments were broad, and no major design flaws were uncovered. The specific technical details are listed in Appendix B.4.

### 5.4.3 Conclusions to Survey

On one or two occasions, the participants created a large amount of comments and suggestions and criticism. Whilst in other cases, the comments page was entirely empty. This does not always correlate to the experience of the archaeologist, although one archaeologist with experience of databases in the field of statue restoration provided a great amount of input whilst a trainee archaeologist on site provided none. It was quite unexpected to see the number of different approaches users made in attempting to carry out the tasks provided within the *Strat* tool. As a result, bugs were discovered and new ideas suggested. More experienced software users preferred to disregard the instructions and figure it out themselves, whilst less experienced computer users needed to be instructed to turn the page of the instructions. Nonetheless, novice users managed to provide many useful comments and opinions despite their lack of familiarity with computers. In fact it is probably due to this naivety that several problems were uncovered. Whilst all users had some experience with computer software, (mostly Microsoft's Office and Windows products), the majority had not used archaeological software. AutoCAD and Mapinfo were the most commonly used archaeology software. AutoCAD does not maintain a consistent Window's GUI interface, and as a result makes for a steeper learning curve for the software. As with any professional software there will be some learning curve but the overwhelmingly positive reactions of the archaeologists to the ease of the use of the *Strat* system demonstrates its accessibility and carefully constructed design.

The results to the section of the survey aimed at determining the level of experience with archaeological computer software is shown visually in Figure 98. The results to the section of the survey aimed at determining the level of experience with general computer software is represented in Figure 99. It should be stressed that this survey was carried out on an unrepresentative group of archaeologists. It may appear that the large amount of useful stratigraphic software available to archaeologists, as described in Chapter 3 are completely overlooked by this group of

archaeologists. This is explained by the fact that it was simply not possible to interview the more professional archaeologists at the time of survey due to high pressure of workload during the limited excavation season. All archaeologists were from the same group (at Sagalassos), trained at the same university spending time carrying out fieldwork. On consultation with other archaeologists, familiarity with computer software is higher and more varied. A more broad study across multiple institutions would provide a more representative view.

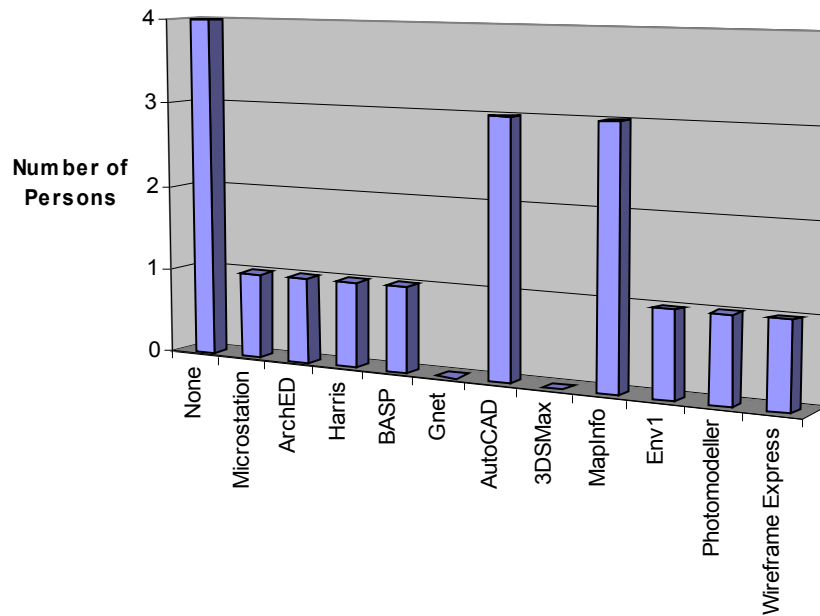


Figure 98. Archaeological software use amongst archaeologists from 13 archaeologists.

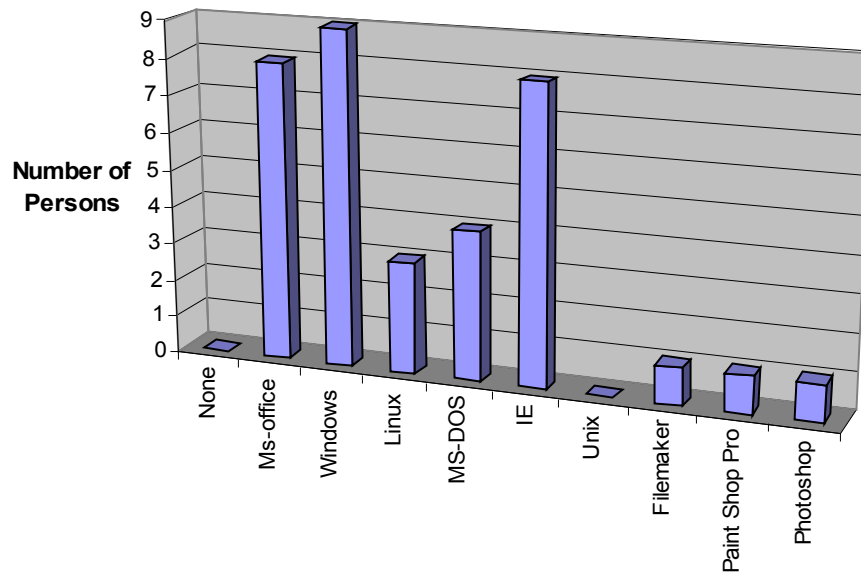


Figure 99. General software use amongst archaeologists from 13 archaeologists.

## 5.5 Conclusion

The *Strat* tool has wide ranging functionality. At its heart is an archaeological database capable of storing all information recorded on an excavation, yet it is capable of visualising the site as close to how it looked as is possible. Without the use of complex acronyms or symbology to depict objects, it is straightforward to see what is happening from both a professional and an amateur's point of view. At its lowest form it is an educational aid to students about to enter their fieldwork on the site and to get an idea how the excavation has progressed so far. At its highest form it is a powerful tool capable of producing cross-sections and plan drawings at any part of the map. The full benefits will be realised in the ensuing years when the software is tested in various archaeological sites.

During the progress of this research the application underwent several iterations due to more power being delivered by using certain APIs. The system has been built from scratch making use of freely distributable components. The ArchEd software can be optionally delivered with *Strat* for traditional 2D Harris matrix visualisation, but *Strat* is not dependent on any of the tools described in the literature review sections to operate.

One of *Strat's* strengths is its carefully thought out stratigraphic input section that accommodates both old and new data. Laser scanning, photogrammetry and paper based records all provide varying levels of detail for constructing stratigraphic layering, and all can be visualised within the same environment.

The functionalities described in this chapter been implemented in one of the developed prototypes; although the complete system is still in the process of being finalised. The application continues to grow as new ideas and comments are introduced and the software remains as a dynamic research tool.

There are issues with the speed of the system that have not been fully explored. This is dependent on the speed of the machine and hardware in use. By using the OpenInventor API dynamic model reduction is inherent, meaning that quality of reconstruction is dependent on the target machine.



# Chapter 6

## Reconstructing Current Stratigraphic Data

T

HIS chapter provides a short look at the levels of possible reconstructions available using current archaeological recording methods. It makes use of two examples, a pit from Maiden Castle Dorset and another example profile with interesting layers. This work was presented at the Computer Applications and Quantitative Methods in Archaeology Conference, 2002.

### 6.1 Maiden Castle Dorset

The pit at the site of Maiden Castle is a good choice for visualising possible stratigraphic reconstructions since it has many layers of varying shapes and sizes. Figure 100 shows the profile drawing of the site. This image was taken from Harris's book (Harris, 1989a). The ideal representation has been reconstructed in 3D using the 3DSMax software and is illustrated in Figure 101. Every contour and spike can be seen, deposits have been coloured so that they can be clearly delineated from one another. This is the kind of representation possible, if all factors are right – if every stratigraphic surface has been photogrammetrically recorded and the deposits have been reconstructed. With this level of reconstruction, profile drawings can be made through the model at any angle and drawings are produced which are actually useful.

A different picture is painted in Figure 102. This model was created assuming that only four points were used for the reconstruction

(archaeologists usually only record four heights per stratigraphic layer). The first layer is perfectly reconstructed, since it is nearly of cuboid proportions. The differences begin at layer two. It is evident that using four points, the gentle curve of the layer is not accurately represented. The difference is very noticeable with the layer that lies next to the chalk rock – in this case, nearly all of the detail is lost. The reconstruction is very poor close to the bottom of the pit, where the layers are more S – shaped or concave. This causes most of the reconstructed deposits to overlap one-another, providing more of an inaccurate than accurate reconstruction of the deposits.

To create the solid deposits as shown in Figure 101, either a surface must be taken all around the sides of the excavated deposit or surfaces must be stitched together afterwards. Figure 103 shows how the surfaces look reconstructed in 3D for this example, without reconstructing the solid deposit. Despite the fact that this reconstruction uses more points than would normally be recorded (it makes use of a fifth centre point) the reconstruction is quite inaccurate from layer two onwards. This is particularly exemplified in the bottom-most layer. Instead of being a soft concave surface at the bottom, mostly flat, the reconstruction is simply a sharp triangle.

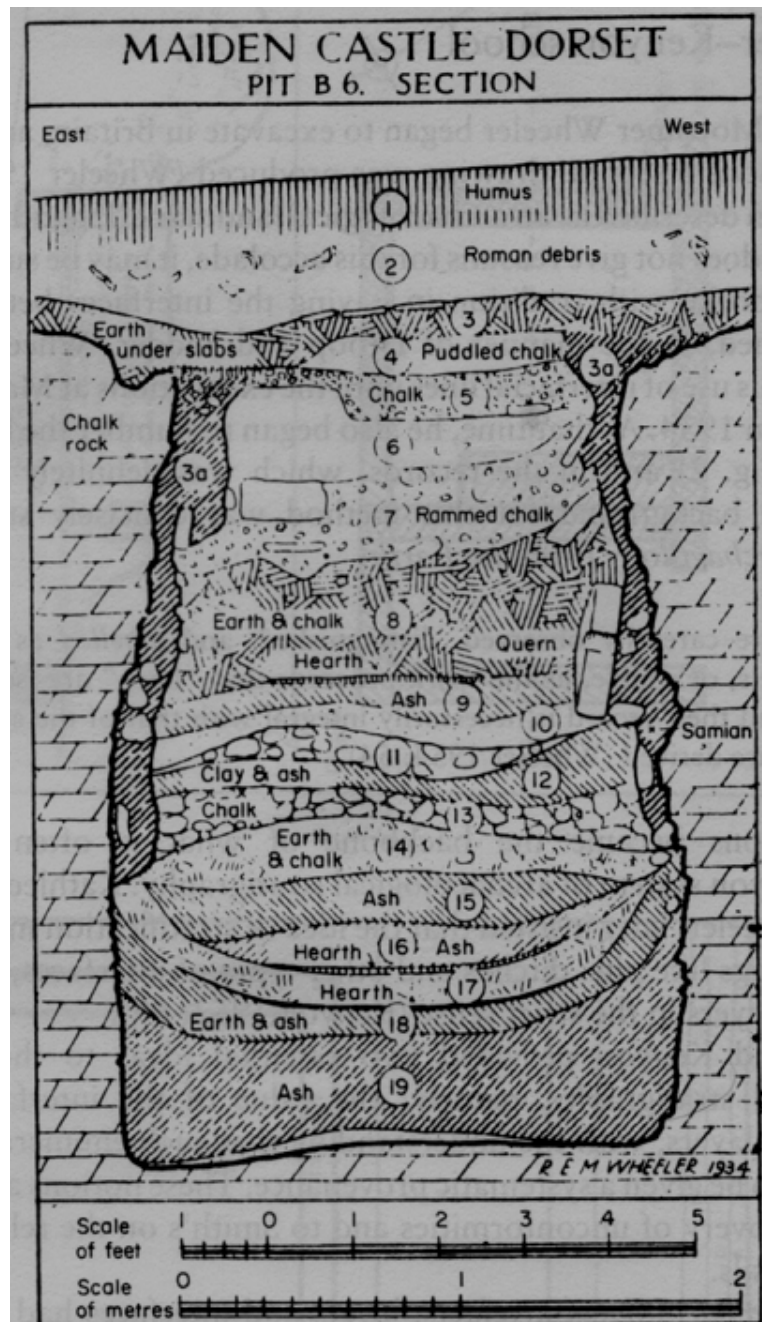


Figure 100. A stratigraphic profile from Maiden Castle Dorset.

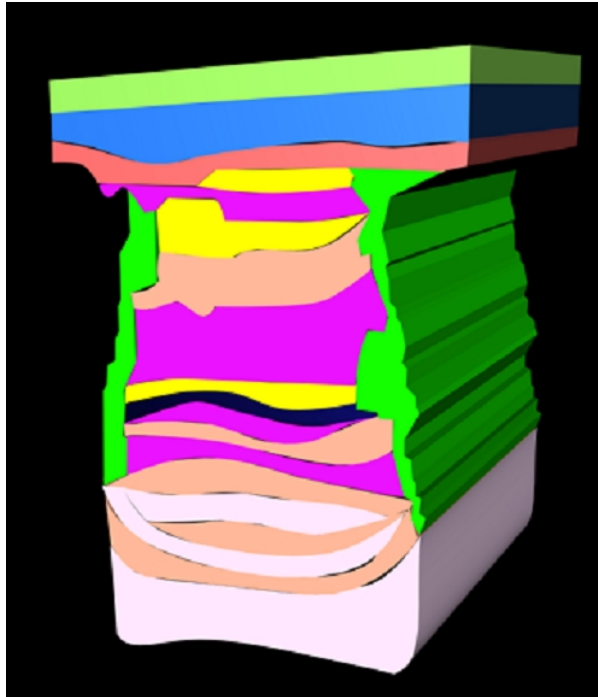


Figure 101. Ideal 3D reconstruction of the Maiden Castle stratigraphic profile.

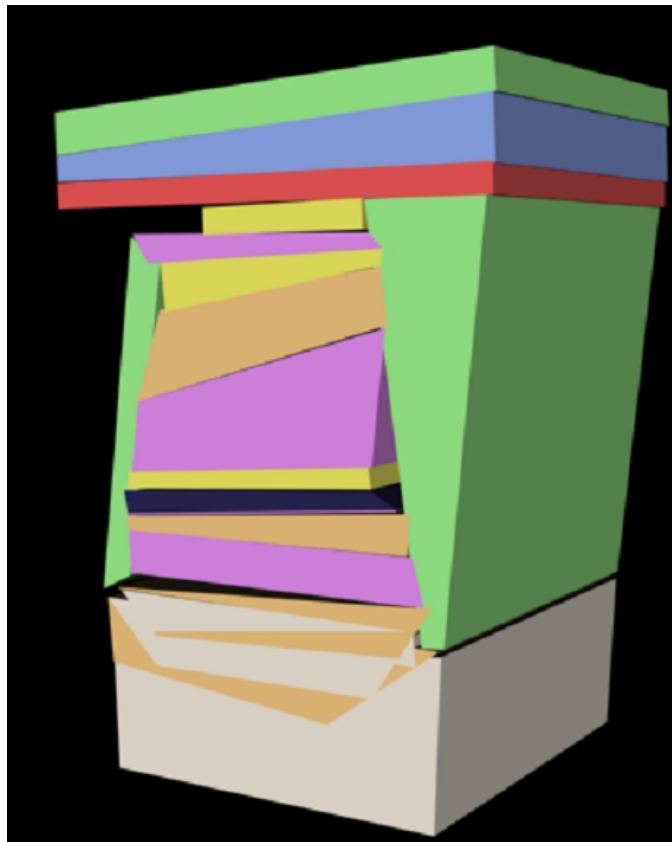


Figure 102. Maiden Castle Dorset reconstructed with four points per stratum.

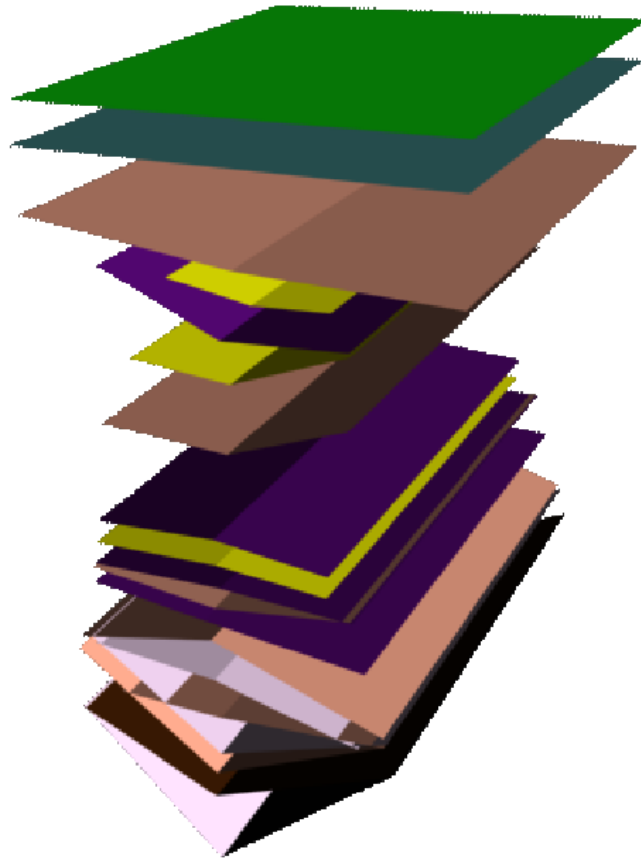


Figure 103. Maiden Castle Dorset surfaces.

## 6.2 Profile Example Two

A second example profile is shown in Figure 104. This example is useful because it has many varying shaped strata. Figure 105 shows how the reconstruction looks if only four points are recorded. The measuring tape is still the most popular recording instrument for archaeologists, so heights and cuboid models form the only reconstruction possible from this data. The amount of black space and the overlapping layers in this example clearly indicates the inaccuracy of the reconstructions when presented with such coarse input data. This representation has attempted to fit the layers as best as is possible assuming that theodolite points have been used to define the end points of the layers. Of course in most cases, only height measurements would have been recorded, disallowing any movement in the x and z directions. Hence this representation is better than would be possible in most

cases of current archaeological recording practice. It is clear from this picture that by taking a few more theodolite points per layer, the reconstruction could be made much more accurate, although this would take a little more time on the part of the archaeologist.

The ideal representation of the stratigraphy is shown in Figure 106. The layers are transparent so artefacts embedded in them such as the posts can be visualised. This model can be rotated and seen in a lot more detail post-excavation.

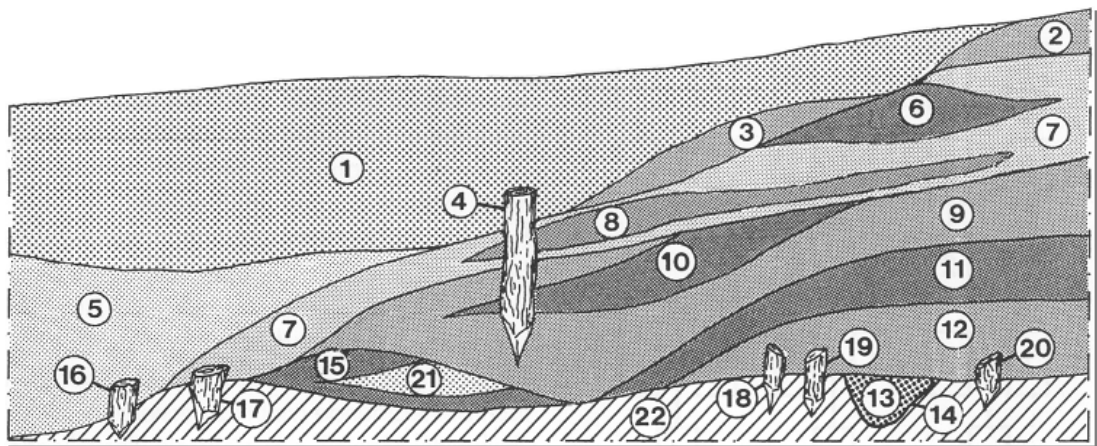


Figure 104. A second example of a stratigraphic profile.

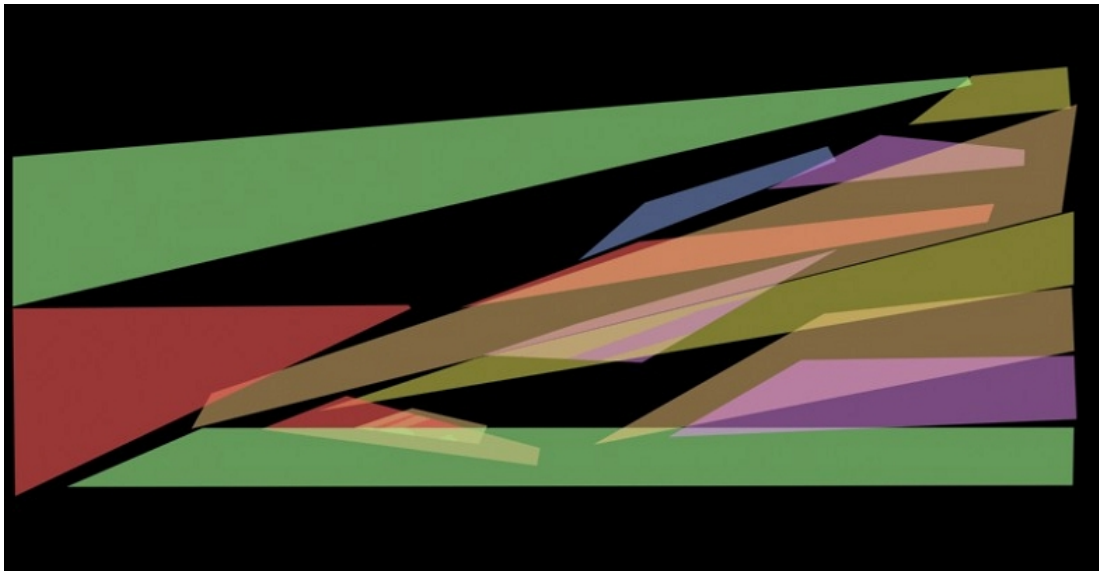


Figure 105. A reconstruction using four points.

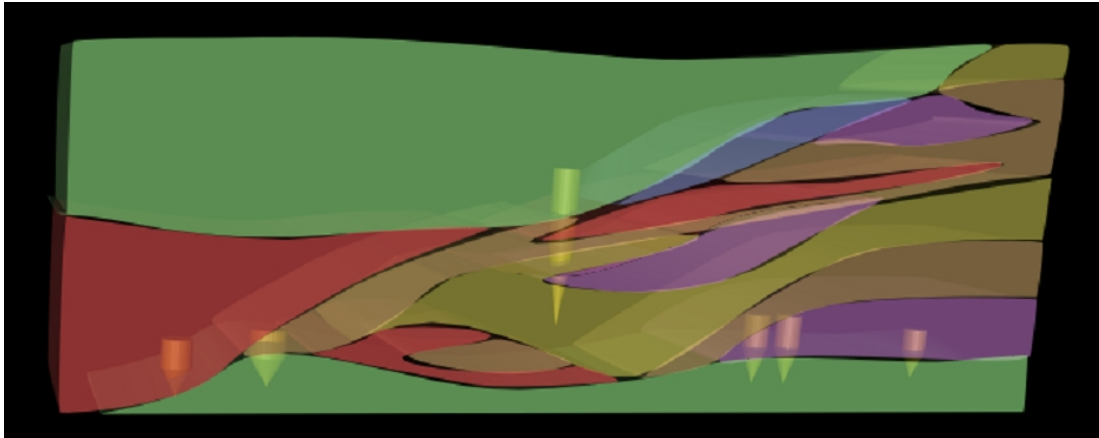


Figure 106. The ideal 3D reconstruction of the same profile section.

### 6.3 Conclusion

It can be seen from these reconstructions that current recording methods of stratigraphy at best, form very bad approximations, such that in many cases, for reconstructive purposes, they may as well have not been recorded at all. This strengthens the argument for photogrammetric model capture, compact portable laser scanning and advanced recording techniques to be used to capture the results of the unrepeatable experiment which is archaeological excavation.

# Chapter 7

## Visualizing Legacy Stratigraphic Data from Archaeological Handbooks

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HIS chapter highlights problems associated with the recording of stratigraphic entry, indicating recording differences in previously recorded archaeological records and shows how inaccuracies are represented so that later misinterpretation can be avoided. The validity is exemplified by stratigraphic reconstructions visualised using actual stratigraphic data recorded by archaeologists from the year 2000 season of the Sagalassos archaeological campaign in Turkey as its input. This chapter discusses the problems associated with the entry of this legacy stratigraphy data, which is probably the most haphazardly recorded and challenging of all stratigraphic legacy data. Results are presented in the form of screenshots from an early prototype of the *Strat* tool. This chapter was published in a reduced form at the *Computer Applications and Quantitative Methods in Archaeology* conference in April 2002 (Green, 2002a).

### 7.1 Introduction

During an archaeological campaign, data relating to stratigraphic positioning (SP) is recorded in a variety of ways. The exact practice varies from site to site but generally this data is recorded in a number of ways:

- In individual excavation hand books



- Pre-prepared stratigraphy forms
- With a theodolite.

The widely used practice of analysis and representation of SP is the Harris Matrix approach (Harris, 2001a). This is a valuable technique to analyse and compare 2D SP data. With the advent of cheap and powerful 3D computing, there is a growing need for the archaeologist on site to test hypotheses and gain immediate results. The 3D representation and analysis of this SP data, with the ability to perform real-time hypotheses without prolonged sifting through hard copies of excavation handbooks presents a real innovation to future archaeological interpretation.

The development of *Strat* allows for importation of highly detailed 3D stratigraphic reconstructions retrieved from image sequences (Green, 2001a) (Pollefeys *et al.*, 1998a). However, for complete site visualization, legacy data also needs to be considered and visualized within the same system. Often, the only data recorded for a site is in the archaeologist's personal handbook..

## 7.2 Archaeological Notebook Data

For each site on a campaign, a hardbound paper handbook is used for the recording of a variety of archaeological information. It includes a grid drawing with site locations and their relative positions from the origin, the names of the archaeologists working on that site, Polaroid photographs of each stratigraphic layer with sector and layer numbers indicated, hand drawings indicating the extents of excavation units, textual descriptions of how work was carried out, a list of contexts (finds) for each layer with their unique context numbers, textual descriptions of the layer, hand drawings of the layer with thickness recorded in centimetres and volume of tiles recorded in number of boxes.

At first glance this data can appear disorganised and may require repeated reading to understand. Photographs are not always taken from the same angle so it can be hard to determine which side is north. For the recorded depths of stratigraphy, sometimes the archaeologists average the

four depths and give only one depth. On some occasions the extents of the strata are defined, and on other occasions omitted.

### 7.3 Strat Forms

Once the archaeologist has excavated a layer they complete what is known as a STRAT (stratigraphy) form. These vary from campaign to campaign. One example can be seen in (Harris, 1989b). On the STRAT form developed for Sagalassos the archaeologists fill out the site name, sector number, layer number, archaeologist name, date, page number of plan and photograph. It also contains a section for the layer description that includes space for textual descriptions of the compaction, colour, composition, inclusions and an interpretation. It includes a field for the recording of the thickness and extent of the layer. The final section of the form is used to describe stratigraphic sequence; layers are connected to one another with lines describing their relationship, for example, superposition or original continuity.

### 7.4 Physical Legacy Data Entry

Some test data for entry into the *Strat* tool was collated from a handbook used on a previous year's excavation at Sagalassos. Based on pre-prepared stratigraphy forms recorded by the archaeologists, Table 2 has been compiled for the site of "Theatre Streets West1", located at sector 2560, 2655 on the Sagalassos grid, hereafter known as TSW1. Based on hand-recorded stratigraphy measurements from the TSW excavation handbook (Martens, 2000a) Table 3 has been compiled for the same excavation unit.

There also exists a third set of data reporting the height measurements contained within an internal report, see Table 4. This data has been taken directly from the excavation handbook. However this data appears to be more closely related to the data recorded on the STRAT forms. Layers three and four may have been transcribed incorrectly by the archaeologist, because according to the report, the extents are written:

*extent: 1m/2m x 1.70m in the northern part of the trench*

The Sagalassos archaeologist records extents in the order E/W x N/S. However, for layers three and four, the data for the North and South faces seems to have been swapped with the East and West faces. This would result in a rotation of 90 degrees for the stratum. This highlights problems associated with the duplication of data and of inconsistently writing extents without indication of which side is north. The archaeologist should carefully resolve this, preferably after the day's excavation whilst the site is still fresh in their minds.

### 7.5 Explanation of Tables

Typically, one length and width are recorded on a stratigraphy form, but for oddly shaped excavation units, differing lengths are written (for example in layer three where a different measurement is recorded for the east wall than that for the west). Where only one width has been recorded (for example the top width) the figure has been duplicated into the bottom width and vice versa. This is also the case with the length of the excavation unit. Where a table cell is empty, the archaeologist has omitted data. Sometimes, this happens if, for example, the stratum's dimensions are the same as the previous stratum. A clear picture of the dimensions of interest is provided in Figure 107.

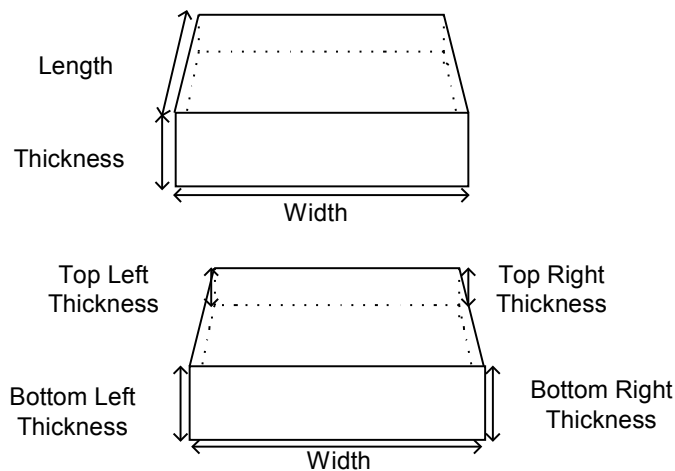


Figure 107. Strata dimensions

| Strata No. | Average Thickness (cm) | Width (m) |     | Length (m) |     |
|------------|------------------------|-----------|-----|------------|-----|
|            |                        | N         | S   | W          | E   |
| 1          | 40                     | 2.5       | 2.5 | 4.5        | 4.5 |
| 2          | 55                     | 2.5       | 2.5 | 4.0        | 4.0 |
| 3          | 40                     | 2         | 2   | 1          | 1.7 |
| 4          | 70                     | ..        | ..  | 1          | 1.7 |
| 5          | 75                     | 2.2       | 2.2 | 0.6        | 0.6 |

Table 2. Strata measurements extracted from the stratigraphy

forms for the TSW1 site on the Sagalassos campaign.

| Strata No. | Thickness (cm) |      |       |        |        | Width (m) |     | Length (m) |     |
|------------|----------------|------|-------|--------|--------|-----------|-----|------------|-----|
|            | Average        | Top  | Top   | Bottom | Bottom | N         | S   | W          | E   |
|            |                | Left | Right | Left   | Right  |           |     |            |     |
| 1          | 40             | 35   | 60    | 40     | 45     | 2.5       | 2.5 | 3.5        | 3.5 |
| 2          | 50             | 60   | 50    | 40     | 55     | ...       | ... | ...        | ... |
| 3          | ...            | 35   | 35    | 40     | 35     | ...       | ... | 2.5        | 1.9 |
| 4          | ...            | 75   | 85    | 70     | 65     | 1.7       | 1.7 | ...        | ... |
| 5          | 75             | ...  | ...   | ...    | ...    | ...       | ... | 1          | 2   |

Table 3. Strata measurements compiled from figures recorded in the excavation handbook (Martens *et al.*, 2000a) for site TSW1 on the Sagalassos campaign.

| Strata No. | Thickness (cm) | Width (m) |     | Length (m) |     |
|------------|----------------|-----------|-----|------------|-----|
|            | Average        | N         | S   | W          | E   |
| 1          | 40             | 2.5       | 2.5 | 4.5        | 4.5 |
| 2          | 55             | 2.5       | 2.5 | 4.0        | 4.0 |
| 3          | 40             | 1.7       | 1.7 | 1          | 2   |
| 4          | 70             | 1.7       | 1.7 | 1          | 2   |
| 5          | 75             | 2.2       | 2.2 | 0.6        | 0.6 |

Table 4. Strata measurements according to an internal report for site TSW1 on the Sagalassos campaign.

## 7.6 Recording Errors in Existing Data

Due to the duplication of data that occurs on site and problems that arise by transmitting data between archaeologists by word of mouth, errors in recording occur. This can be clearly seen between the measurements recorded in the excavation handbook compared with the same measurements recorded on STRAT forms, Figure 108 shows a bar chart indicating the error differences.

Figure 109 shows how the average recorded by archaeologists in their handbook differs from the computed mean average of the four recorded height measurements. In other words, the archaeologist has made a mental attempt of computing the average of the four depths, which is not necessarily mathematically correct. This is of no consequence as long as the four height measurements are recorded. These figures are computed from tables 1 and 2. This level of error in recording indicates that any attempted visualisation is already going to include errors of several centimetres.

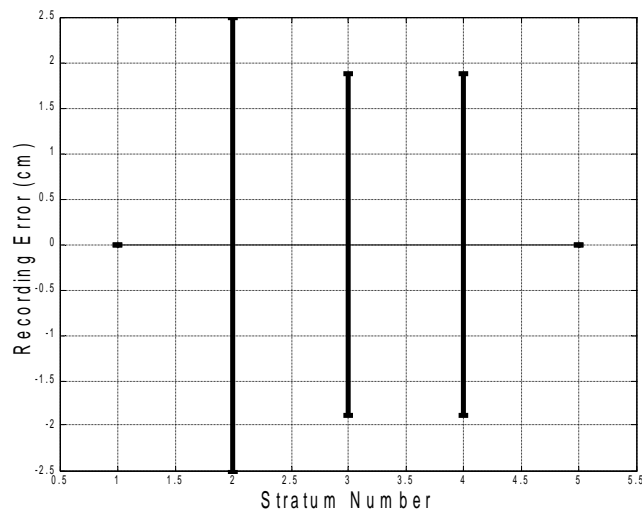


Figure 108. Strata thickness errors from data recorded on STRAT forms compared with data recorded in the handbook for TSW1, sector 2560/2655.

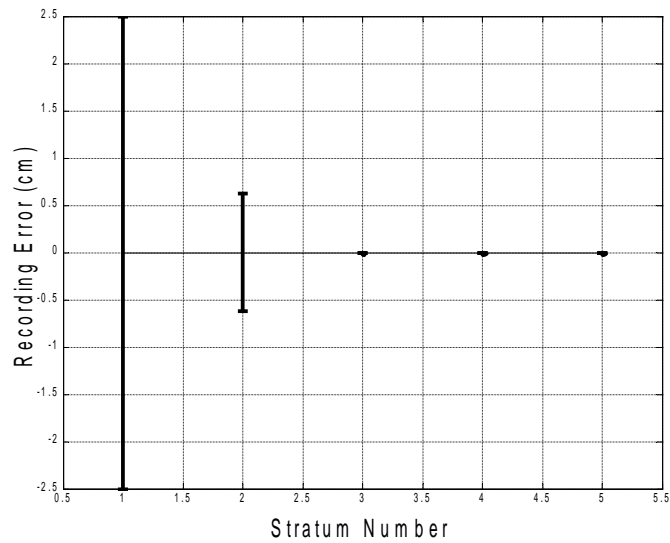


Figure 109. The error between the average recording of archaeological strata and mean average.

## 7.7 The System Structure

The archaeological project or campaign is structured hierarchically in the computer's memory in the *Strat* tool as illustrated in Figure 110. At the top level of the hierarchy is the project, which is a generic name for the campaign; this includes the name and abbreviation of the project, for example "Sagalassos" and "SA". A project can include one or more sites, for example, "Upper Agora North" and "Theatre Streets West1". These are clearly defined separate excavations within the campaign. A site such as this in turn inevitably includes individual excavation units of a fixed width and length of which the archaeologist then begins to excavate on a stratum-by-stratum basis. Finds are uncovered within strata.

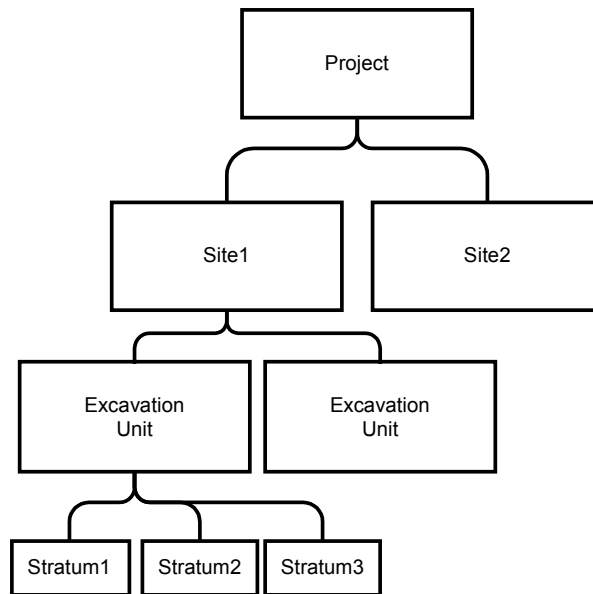


Figure 110. Modelling an archaeological campaign.

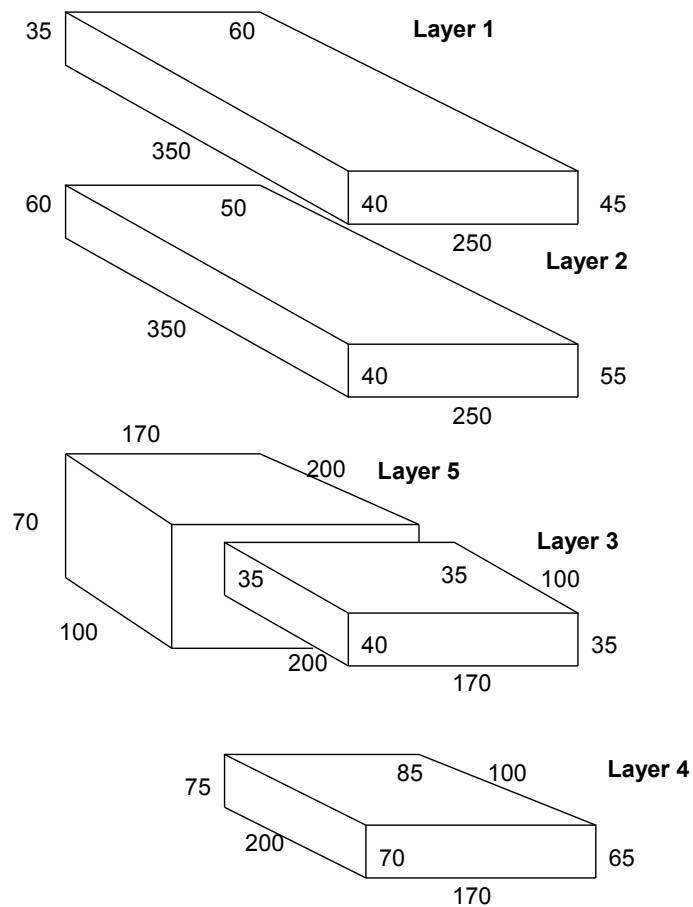


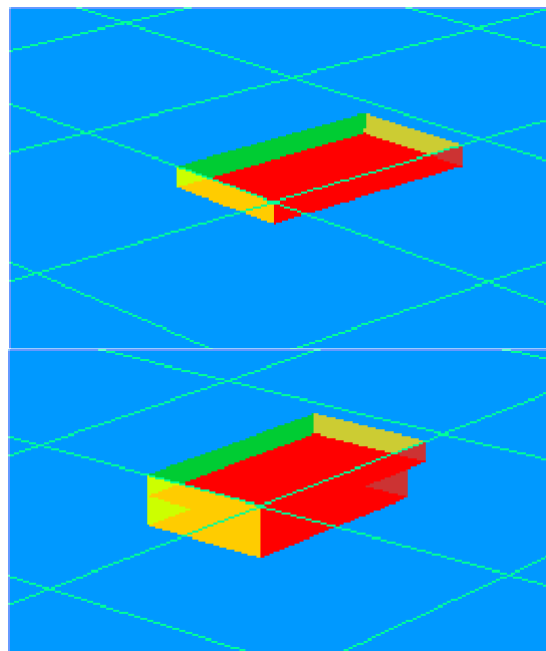
Figure 111. The TSW1 site showing exploded strata with measurements in centimetres.

## 7.8 Visualization of Legacy Data

Figure 111 shows the strata for the excavation unit with measurements in centimetres. Figure 112 shows the resulting 3D model of the stratigraphic data for the TSW1 site visualized using the *Strat* tool. This data can be easily navigated and magnified. The walls are transparent and the bottoms of the layers are opaque so interfaces can be easily seen.

The grid shown is defined in five metre units. It can be seen that the west and east faces of stratum one nearly fits lengthways to this excavation unit, having a length of 4.5m. This grid can be replaced with a topographic map if available.

Figure 113 and Figure 114 show alternative views possible in the *Strat* tool, viewing from both the top and from the sides. Figure 115 shows a profile drawing superimposed with a cuboid representation of each stratum. Discrepancies between the cuboid representation and the actual contour can easily be seen in this representation. Figure 116 shows a 3D perspective drawing of TSW1 with embedded artefacts. If available, reconstructed models of artefacts are visualized, otherwise markers are used with a letter representing the material type.





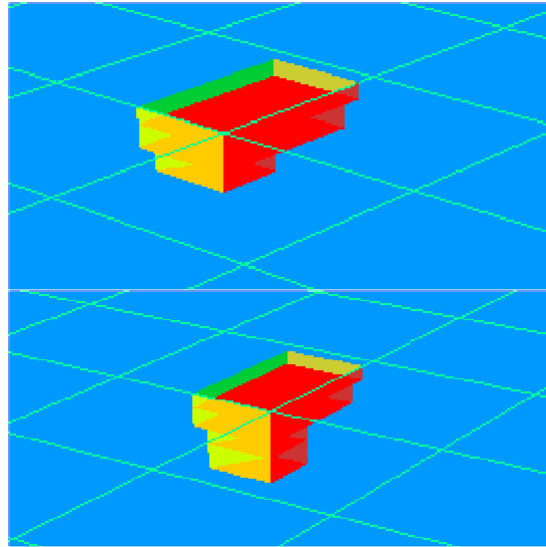


Figure 112. Strata 1-4 of the TSW1 sector at Sagalassos entered and visualized using the *Strat* tool.

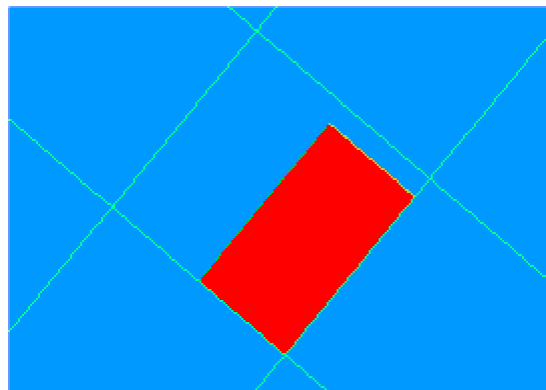


Figure 113. Plan view of the excavation unit at the TSW1 site at Sagalassos entered and visualized using the *Strat* tool.

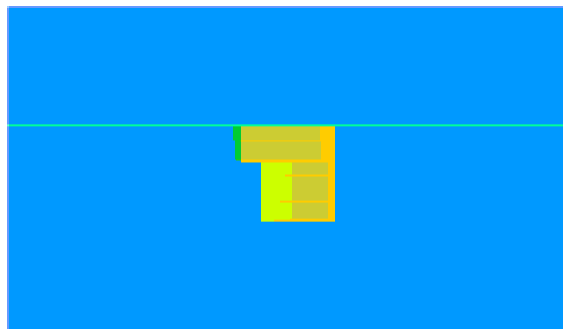


Figure 114. A profile view of the excavation unit at the TSW1 site at Sagalassos entered and visualized using the *Strat* tool.

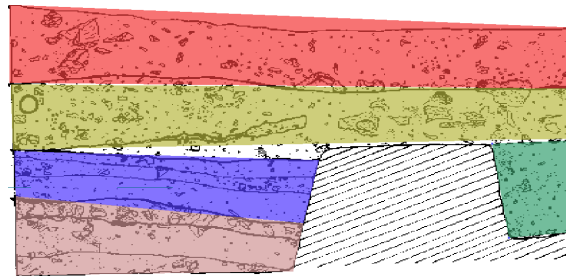


Figure 115. A profile drawing (Martens *et al.* 2000b) of TSW1 superimposed with a cuboid representation of the stratum.

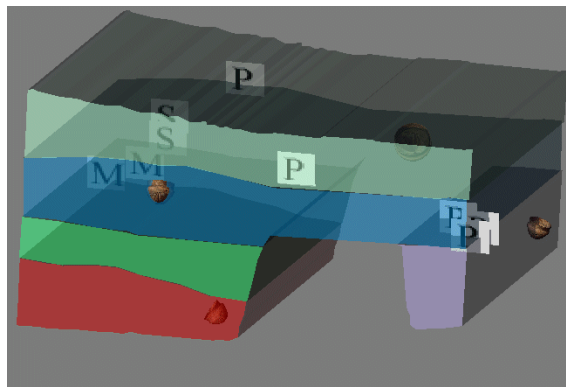


Figure 116. A 3D perspective render of the TSW1 site showing embedded artefacts.

## 7.9 Conclusion

This chapter explicitly outlined the problems with current stratigraphic recording, comparing differences in recording for the same physical location. It described some of the problems with the entry, reconstruction and visualization of 3D stratigraphic layers from physical records, based on the varying and sometimes incomplete records of the field archaeologist.

Allowing for the highly detailed models produced with the self-calibrating photogrammetric work of Pollefeys *et al.* (1998) or if available, the tessellated 3D models produced by modern laser scanning devices, a complete reconstruction of an entire archaeological excavation can be constructed to a much greater level of detail than ever before. The in-depth discussion of 3D capturing techniques has been omitted from this thesis for the purposes of brevity, suffice to say that the *Strat* system is capable of importing 3D models in standard computer format (VRML) thus allowing for changes in recording technology. In this way the system is independent of

hardware recording device, be it shape from video, shape from structure light or a tessellate laser point cloud.

# Chapter 8

## Methods for the Effective Recording of Theodolite Data for Stratigraphic Reconstruction

**V**ERY often on an archaeological site, a theodolite is used to record position data for the corners of building elements and points that the site surveyor deems necessary. Points are also taken using a theodolite for the corners of stratigraphic units. This data is stored in the datalogger of the theodolite as a list, and it can be difficult to later make sense of this data or recognise which data represents a stratigraphic unit, for instance. This chapter proposes various methods of recording theodolite data so as to be of future use to GIS systems or indeed for any later stratigraphic interpretation. This chapter was published at the Interpreting Stratigraphy Conference in London on September 7<sup>th</sup>, 2002.

### 8.1 Introduction

One of the main elements of any kind of archaeological work concerns the systematic and correct registration of all archaeological features in space. This is a prerequisite for the development of the stratigraphy of a site and

thus an essential part of archaeological training. However, survey work is technically speaking part of engineering, and this sometimes conflicts with the basic interests of the archaeologically minded. Even professionals tend to farm out survey work whenever possible. This leads to the situation where even in teaching manuals on archaeology, survey work is often underrepresented. In most cases the basic principles of surveying for archaeology are mentioned, but more elaborate systems and instruments are scarcely covered. Exceptions do exist such as the field archaeology manual (Joukowsky, 1980), but these remain rare and are often out of date. For example, the latest edition of "Techniques of Archaeological Excavation", a popular text for the teaching of archaeology to students of the subject (Barker, 2001) makes no mention of either theodolites or the Total Station Theodolite, although archaeologists have been using theodolites or similar surveying instruments to record 3D position data for many years now.

In reality the use of sophisticated surveying instruments is gradually proliferating as they become within financial reach of more of the archaeological community. Together with the growth of computer applications aimed at presenting the archaeological information in more accessible ways to the public, the archaeologists are expected to provide evermore accurate and comprehensive survey data sets. This does not imply that traditional, simple measuring instruments like measuring tapes will suddenly lose their importance, but it does mean that indirect comprehensive means of recording spatial data will become more and more prevalent in the archaeological profession.

The increasing complexity of both archaeology and surveying causes more and more problems at the interface of disciplines. Archaeologists need intuitive instruments to aid in the complex procedure of surveying and interpreting the stratigraphy of a site to solve this problem.

Currently, advanced photogrammetric techniques making use of photograph sequences are being tested in the field (Pollefeys *et al.*, 1998). The procedures necessary to carry out this recording are sometimes impractical - many carefully selected un-blurred shots must be taken at small

intervals around the circumference of the object of interest to reproduce a 3D computer model. This model must then be registered, cleaned and made sense of. Currently, photogrammetric software and techniques are not at a stage where they are well established for the recording of stratigraphy. Until such methods are established, and prove straightforward enough for use by archaeologists, it makes sense to introduce intermediate measures such that data recorded with the common theodolite holds useful information regarding the nature of the points recorded, that is to say, describing which points belong to which stratum interface.

Theodolites have been in use for many years without getting more integrated. This is possibly due to the lack of software tools that can usefully reconstruct the structure of a site from this data. High-resolution 3D capture of parts of archaeological sites is, in the history of archaeology, only a recent phenomenon. In actuality, archaeologists have not been trained to use such technology, nor have many witnessed the high quality results and benefits possible from such methods. This is partly due to the fact that the surrounding software is not developed or within reach of an archaeological budget, or because such devices are simply too bulky and complicated to use. As the discipline evolves, it is hoped that computer-based recording techniques be smoothly integrated with traditional excavation methods. This is likely to take many years to happen, the willingness on the part of site directors to spend their time testing new technologies being essential. Ideally a device that knows its own spatial location and that can be swept across a site's surface regardless of lighting conditions, which is portable and low cost, is the ideal solution. Realistically, such a device is still many years away. This chapter describes a way that established devices in the field could provide added value - providing a framework for the collection of survey data. The reality is that without such new methods being employed, survey data is often wasted because the data collected holds no suitable information for later reconstruction.

The next sections look at a way of making use of theodolite data for stratigraphic reconstruction.

## 8.2 The Theodolite Measurement

It makes sense to first look at the format of data produced by the recording device. It is of the format:

$$\{i, x, y, z, t\}$$

where  $i$  is the point number which increments automatically after every position is recorded. The next three values represent the position in 3D space; the  $(x, y, z)$  position of the recorded point. The last value,  $t$ , is alphanumeric, allowing a textual description to be given to the point. Table 5 illustrates a real example of a data-logged point. In most cases the order of values can be changed, either directly in the datalogger/total station, or afterwards. Future GISs will allow the user to determine the order in which the 3D coordinates were recorded.

| $i$ | $x$      | $y$      | $z$      | $t$     |
|-----|----------|----------|----------|---------|
| 12  | 2556.507 | 2653.892 | 1548.452 | sondage |

Table 5. A typical data-logged point.

## 8.3 Possibilities for Metadata

There are several possibilities for recording metadata about our stratigraphy, without modifying our recording device, which are described as follows:

### 8.3.1 Possibility One

The order of the recordings can be used to store stratum information, that is to say, four points are recorded for each stratum interface, and in this manner strata data can be recovered without the need for entering additional data. Stratum data is extracted by taking groups of four points, hence recovering our layer. Table 6 illustrates this principle with the subsequent layer outlined in bold. S1 means Stratum number one and  $x_1, y_1$  and  $z_1$  define its position.

A disadvantage to this method is that recording one additional or one too few measurements would invalidate the method, such that stratum corners for one layer incorrectly become the property of the one following it or

preceding it respectively. It also has the possibly undesired effect that surveyors need to focus on recording stratum points before other features, such as building elements.

| <i>i</i> | <i>x</i>               | <i>y</i>               | <i>z</i>               | <i>t</i> |
|----------|------------------------|------------------------|------------------------|----------|
| ..       | S1 <sub>x1</sub>       | S1 <sub>y1</sub>       | S1 <sub>z1</sub>       | ..       |
| ..       | S1 <sub>x2</sub>       | S1 <sub>y2</sub>       | S1 <sub>z2</sub>       | ..       |
| ..       | S1 <sub>x3</sub>       | S1 <sub>y3</sub>       | S1 <sub>z3</sub>       | ..       |
| ..       | S1 <sub>x4</sub>       | S1 <sub>y4</sub>       | S1 <sub>z4</sub>       | ..       |
| ..       | <b>S2<sub>x1</sub></b> | <b>S2<sub>y1</sub></b> | <b>S2<sub>z1</sub></b> | ..       |
| ..       | <b>S2<sub>x2</sub></b> | <b>S2<sub>y2</sub></b> | <b>S2<sub>z2</sub></b> | ..       |
| ..       | <b>S2<sub>x3</sub></b> | <b>S2<sub>y3</sub></b> | <b>S2<sub>z3</sub></b> | ..       |
| ..       | <b>S2<sub>x4</sub></b> | <b>S2<sub>y4</sub></b> | <b>S2<sub>z4</sub></b> | ..       |

Table 6. Retrieving stratum data from data-logged list by recording points in fixed sized blocks, in this case, four.

Another disadvantage of this method is the assumption that any stratum is defined by a fixed number of points, for example four, and only four, points. This is very often the case, for example when excavating grid squares or in buildings where strata cover the entire surface of mostly rectangular rooms. Unfortunately, strata need not be rectangular and so in many cases it is necessary to survey a varying number of points to define each stratum.

### 8.3.2 Possibility Two

Possibly more time-consuming for the surveyor would be the method whereby, in the fifth, alphanumeric field, the surveyor keys in the stratum number. This principle is illustrated in Table 7 with the number of interest marked in bold. This has the drawback that this field could no longer be used for the recording of other potentially useful information - some surveyors store comments or a code in this field, due to the layout and the limited memories of many data-loggers. For automated CAD-drawing Bibby uses Archaeocad, based on Autocad which can interpret the field data from the total station and automatically produce excavation drawings according to the



archaeological criteria represented by the codes typed into the tachymeter in the field (Bibby, 2001).

| <i>i</i> | <i>x</i>         | <i>y</i>         | <i>z</i>         | <i>t</i>  |
|----------|------------------|------------------|------------------|-----------|
| ..       | S1 <sub>x1</sub> | S1 <sub>y1</sub> | S1 <sub>z1</sub> | <b>9</b>  |
| ..       | S1 <sub>x2</sub> | S1 <sub>y2</sub> | S1 <sub>z2</sub> | <b>9</b>  |
| ..       | S1 <sub>x3</sub> | S1 <sub>y3</sub> | S1 <sub>z3</sub> | <b>9</b>  |
| ..       | S1 <sub>x4</sub> | S1 <sub>y4</sub> | S1 <sub>z4</sub> | <b>9</b>  |
| ..       | S2 <sub>x1</sub> | S2 <sub>y1</sub> | S2 <sub>z1</sub> | <b>10</b> |
| ..       | S2 <sub>x2</sub> | S2 <sub>y2</sub> | S2 <sub>z2</sub> | <b>10</b> |
| ..       | S2 <sub>x3</sub> | S2 <sub>y3</sub> | S2 <sub>z3</sub> | <b>10</b> |
| ..       | S2 <sub>x4</sub> | S2 <sub>y4</sub> | S2 <sub>z4</sub> | <b>10</b> |

Table 7. Retrieving stratum data from a datalogged list by storing the stratum number in the final field.

The advantage of this method is that all relevant information is collected on site in one place thus reducing the number of potential errors. Another advantage is the fact that the number of points defining a stratum is not fixed. A disadvantage is that extra care must be taken to ensure that the stratum information input is correct at the time of recording.

### 8.3.3 Possibility Three

Perhaps a more practical, intuitive method would be to create a table in a separate document, such as the excavation journal, with a list of strata and their respective theodolite point numbers. In this manner, it is possible to record varying numbers of points to define a stratum, depending on the complexity of the surface. For example, some sections of stratigraphy, may be nearly flat and featureless in which case four points is sufficient to record its surface, whereas in other examples, several more would better represent the stratum's surface. This also means that the points do not necessarily need to be measured in stratum order. Table 8 and Table 9 illustrate two methods in which this could be accomplished; in stratum order or in order of measured theodolite point. Stratum 10 is shown out of sequence to highlight the fact that the order of recording the points is of no consequence to the end result.

The main disadvantage of this method arises from the use in the field of the two separate recording media, that is to say the data-logged points and the written records. This would require more care on the part of the surveying team to avoid costly mistakes. A similar procedure was tried on the excavation site of Sagalassos (Turkey), during the 2001 field season with fairly limited success. In this case, Polaroid pictures of every stratum were taken, with physical annotation of the surveyed points on the image. Added were the date of recording, the stratum identification and the file identification of the data downloaded from the data-logger, a Sokkia SDR33 Expert. The system proved cumbersome; at Sagalassos the survey team consists normally of two persons, one of whom was handling the reflecting prism at the site, whilst the other used the total-station (A Sokkia SET 4B) and fill in the field book. Due to the fact that time was short and work pressure high, mistakes were made.

| Stratum Number | Theodolite Point Number |
|----------------|-------------------------|
| <b>9</b>       | <b>124</b>              |
| <b>9</b>       | <b>125</b>              |
| <b>9</b>       | <b>128</b>              |
| <b>9</b>       | <b>127</b>              |
| <b>10</b>      | <b>126</b>              |

Table 8. Recording strata information in stratum order.

| Theodolite Point Number | Stratum Number |
|-------------------------|----------------|
| <b>124</b>              | <b>9</b>       |
| <b>125</b>              | <b>9</b>       |
| <b>126</b>              | <b>10</b>      |
| <b>127</b>              | <b>9</b>       |
| <b>128</b>              | <b>9</b>       |

Table 9. Recording stratum information, in theodolite point order.

## 8.4 Conclusion to Possibilities

As yet there is no ideal solution. What is needed for ease of operation and reliability in the field is in fact a registration system that is compact and rugged, with the entire necessary input in one place. A simple data-logger of the type used in these test is only barely adequate, while a paper based approach is time consuming and error-prone. A more ideal solution would involve the use of a portable computer connected to the total station, a data-logger is in fact a primitive computer, but this adds to the already considerable amount of equipment that the survey team has to lug around on site. Most of the currently available notebook computers are not able to

withstand the rigours of on-site work. What is essentially needed is an extended, programmable type of data-logger / computer that can interface directly with a surveying instrument and download the obtained data into a stratigraphic recording tool, such as *Strat*. Existing types of data-logger in some instances allow for the implementation of user programs that may provide the necessary functionality.

### 8.5 Implications for Geographic Information Systems

The accuracy of reconstructed models of archaeological sites and stratigraphy is only as good as the data input. It is possible for GISs to approximate surfaces from a selection of points, but it would not necessarily be any more accurate or provide any additional useful information, see Figure 118. In fact, it may just make visually appealing the representation of stratigraphy and could in fact misrepresent the soil surface.

By recording only four theodolite points per stratum, the possibilities for stratigraphic reconstruction are small. Without any interpolation and by using only four points a surface can be reconstructed composed of only one or two planes, see Figure 117. To create a smoother transition between angled planes, two planes can be interpolated between, by approximating the surface through subdivision, essentially creating a NURBS surface. This might be suitable in some cases, but not in all.

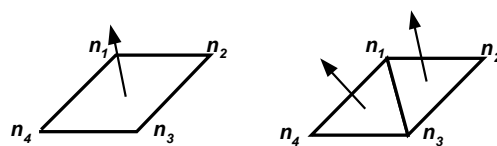


Figure 117. A stratum surface reconstructed from four theodolite points can be mono or coplanar.



Figure 118. Reconstructing stratigraphic surfaces from four theodolite-recorded points; i) The interface is rendered as two separate flat polygons ii) approximated by a NURBS surface.

## 8.6 Sagalassos

As a case in point, the recently discovered domestic-area at Sagalassos has been selected using the previous season's theodolite recordings, Figure 119. This is a good example because it shows a variety of excavation situations. Primarily the surface of the site is laid out in grid squares and excavated as such. When building features appear, the excavation continues within the spaces enclosed by the wall elements. Furthermore, because most ruins are preserved to a considerable height due to fills, the excavated depths are considerable, posing extra problems for the survey and photography of strata. Hypothesised strata are represented in Figure 120 with transparent cuboids.



Figure 119. The Domestic Area in Sagalassos, Turkey.

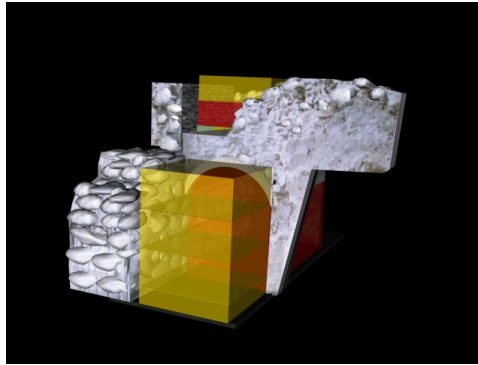


Figure 120. A 3D model of the domestic area illustrating hypothesised solid strata.

The area shown was excavated on a room-by-room basis. The vaulted room was numbered 28. This room was excavated after room 25 (the room in front).

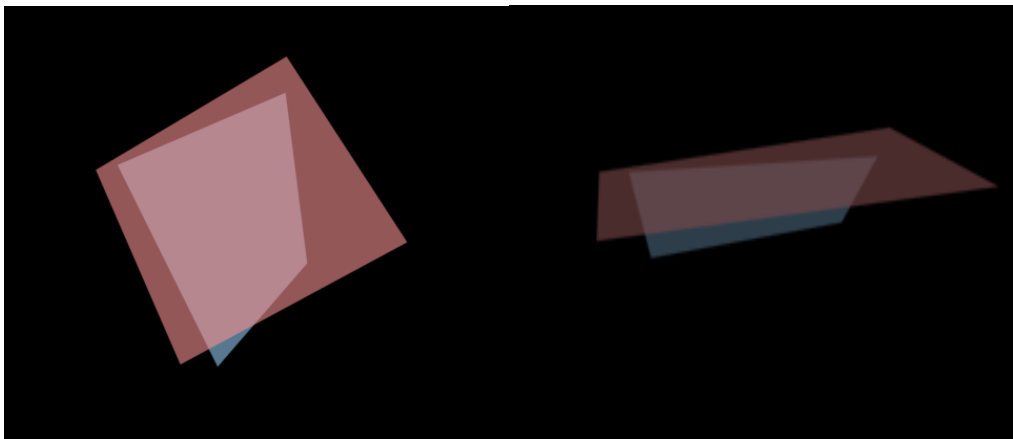


Figure 121. Two stratum interfaces reconstructed using theodolite points.

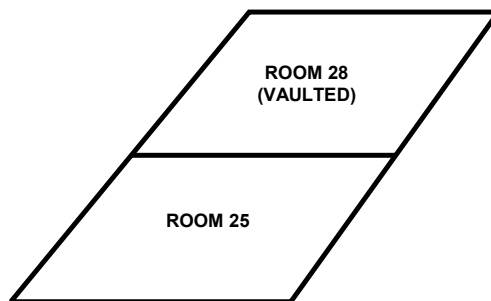


Figure 122. Plan diagram of rooms in the Domestic Area.

## **8.7 Conclusion**

With the effort that goes into the drawing of every stone, on plan and profile illustrations, it seems peculiar that this effort does not instead go into definitively surveying enough 3D points to reconstruct a stratigraphic layer. This chapter has presented methods to be used for the recording of stratigraphic data through the use of theodolites such that at the very least strata and excavation units can be simplistically reconstructed in 3D space by GISs.

# Chapter 9

## Conclusions and Further Work

**T**HIS chapter addresses the different areas of future work that have emerged during the study for this dissertation and concludes the body of work explored within this thesis.

### 9.1 Further Work

These works set out to investigate and develop new ways of recording, reconstructing and visualising stratigraphy such that new correlations can be formed due to the spatial relations between strata.

In view of the overwhelming response from archaeologists at conferences and in the field when demonstrating the *Strat* software described in these works, it would be a loss if this work were not continued. Accomplishments of the goals hoped for by archaeologists first require several further problems to be solved, which are summarised as follows.

- Development of comprehensive guidelines for the process of stratigraphic spatial registration such that it is of benefit to GISs.
- The correct registration and post-processing of photogrammetric models such that such methods are easy to use for archaeologists.
- The reduction in size and weight of laser scanning devices, preferably being made hand-held.
- The reduction in cost of photogrammetric software.

### 9.1.1 Photogrammetric Models for Stratigraphic Reconstruction

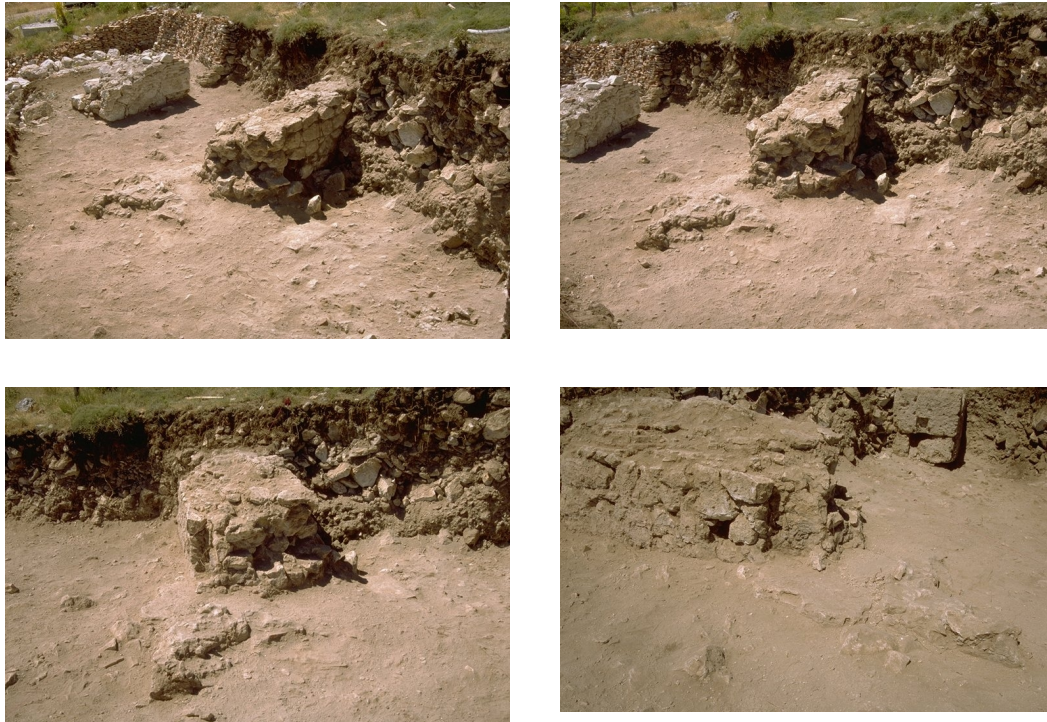


Figure 123. Multiple photographs used to photogrammetrically reconstruct surfaces. (Pollefeys, 1998).

The ideal would be if every stratigraphic interface could be modelled, labelled, registered and imported into a 3D GIS for hypothesis in a single-step. The resulting 3D mesh of a layer of stratigraphy using a photogrammetric approach is shown in Figure 126. There are several problems with this resulting model, described in the following sections.

### 9.1.2 Boundaries

There is no clear distinction as to the boundaries of the stratigraphic interface, or in fact whether buildings element such as the one seen here is supposed to be part of the layer of stratigraphy.

To solve this problem, markers may be positioned in view of the recording instrument so as to define the extents of the stratum. This would then create complications involving the removal of the markers from the 3D model.



### 9.1.3 Registration

The mesh is not registered in space, that is to say it is not known from where the model came. Registration of the model needs to occur if GISs are to be able to correctly reconstruct an archaeological site's stratigraphy. Markers which are recorded in world coordinates on the mesh would accomplish this.

### 9.1.4 Markers

Correct output of a 3D model may require the use of markers to delineate boundaries. Since photogrammetric techniques are used, any markers placed in the scene would then form part of the resulting model. Detection of the markers is one problem needing to be solved, and in the same manner, this object would then have to be removed from the resulting model. Using geometric objects, which could then be easily detected, for example, cylinders, cubes and so on, see Figure 124.

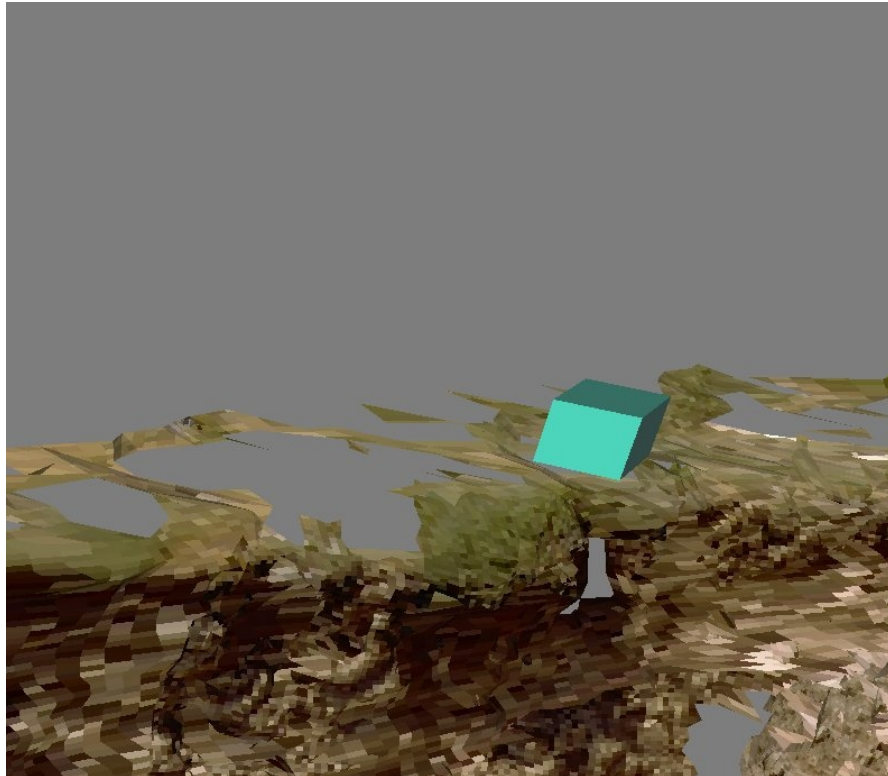


Figure 124. Markers used to delineate stratigraphic boundaries.

The 3D discovery of geometric objects may not be the optimum solution because;

- a. the process could become time-consuming, and
- b. it is dependent on the complexity of the mesh. That is to say, if the resolution of the resulting model is not high enough then the object may not be detected at all, and the time-consuming process of photogrammetry would have to be repeated. This may not be possible, if excavation has finished at this time.

What other registration solutions exist besides the use of physical geometric objects?

In some fashion, audio-emitting devices placed at the position of the marker could be triangulated with audio receivers to recover the marker's position.

Heat, or Infra Red emitters and detectors could be used to triangulate a marker's position without effecting geometry.

Electromagnetic emitters and detectors could be used to triangulate a marker's position without effecting geometry.

Light may be used in the scene; that is to say, a high intensity of light could be detected at a position. This position would delineate the corners of the stratigraphic layer.

Markers of regularly defined patterned surfaces could be placed. This would have the benefit that it would not affect the geometry of the surface and an additional recording method would not need to be used. The marker would be pinpointed automatically by pattern detection software. The marker could be pushed into the soils surface if attached to a thin rod thus being unaffected by soil topography.

Laser pointers connected to EDMs could possibly be used.

The use of a theodolite, a commonplace device in the field may provide the most natural and easy solution. In an ordered manner, theodolite points could be recorded which would then delineate the extents of the surface.

Some of these ideas create more problems since surveyors would need to use another recording device alongside the current photogrammetric approach to recover the marker positions.

The vertical positioning of the markers may also cause a problem. Would the surface be defined as the area delineated by the part that appears directly below the markers in a rectangular fashion?

If the excavation was a sharp cut then 3D geometric algorithms may be used to detect the sharp corner (90 degree detection), but this method would fail in many instances, so is not a comprehensive solution.

### 9.1.5 Mesh Recovery

Once the markers have been discovered within the mesh, the problem arises as to how the surface model is cropped to provide the resulting stratigraphic surface model. There are several ways of doing this:

- Strip away only those polygons that fall completely outside the boundary. This would result in the model shown in Figure 125.
- Strip away only those polygons that fall completely outside of the boundary. This may result in important polygons that define the surface to be lost.
- Perform a clipping algorithm such as those used in common 3D rendering pipelines, to trim polygons at the boundaries. This would most likely offer the neatest solution. But is this step required? Is it sufficient to leave the mesh in its untrimmed state?

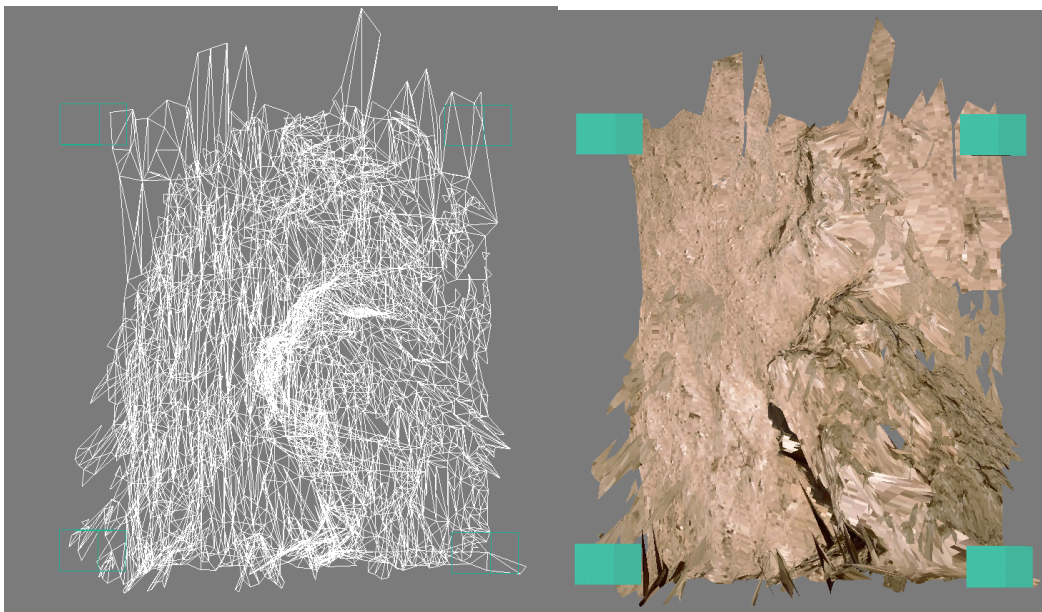


Figure 125. Geometric markers defining the extents of a stratigraphic surface.

### 9.1.6 Post-processing

There are artefacts in the model, spikes, which are caused by problems with the recording method, Figure 126. There are gaps. These have to then be filled in some manner automatically or manually. An automatic approach is of course the optimum, since modifying 3D models is not a task suited to archaeologists.

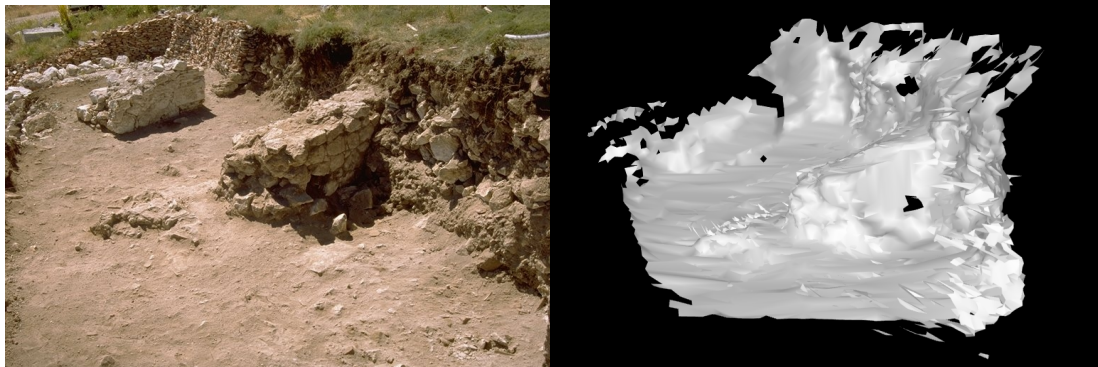


Figure 126. Photogrammetrically derived stratigraphy.

### 9.1.7 Reconstruction of deposits from stratigraphic interfaces

This is a complicated and possibly contentious issue. It is a trivial task to reconstruct the form of the solid deposit where the excavation unit is of a fixed width and height - by simply tessellating between the extremes of the top and bottom stratigraphic surfaces, Figure 127. If the shapes of the stratigraphic surfaces are irregular, it is not always accurate to recreate solid deposits by polygonising the sides of the two surfaces. It can be argued that it is unnecessary to reconstruct deposits since the shape of the sides of the deposit can never be known for certain without great user-intervention. The creation of this deposit would perhaps not provide any more useful information than its omission. It is nevertheless easy to understand what is illustrated in the scene due to the visual and interactive nature.

Archaeologically speaking there is some confusion regarding the recording of stratigraphic contexts. A stratigraphic deposit is bounded above and below by stratigraphic surfaces or *interfaces*. When using recording methods, it is the interfaces which are being recorded, not the solid deposit. Often when archaeologists create a Harris matrix, it is the deposit which is

shown on the graph. Harris recently contended that both the interfaces and the deposits should be recorded and represented which introduces confusion as to what should be represented in a 3D visualisation system such as *Strat*. Nevertheless in recording terms, it is not always possible to record the sides of a stratigraphic deposit – often the adjacent trench may have already been excavated, and unless careful measures are taken to record both the sides of the trench as well as the new interface then the resulting model will appear similar to Figure 127a. The question then arises, do we attempt to join the sides of the layer with mathematical methods which may be incorrect or leave the deposit side's to be fill-in with the user's imagination.

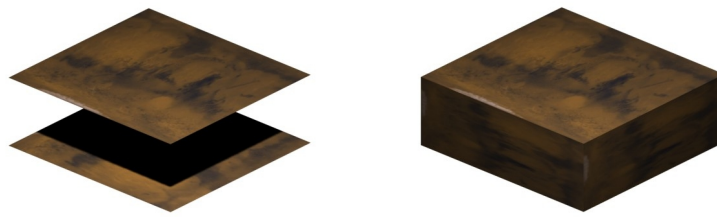


Figure 127. a) Two interfaces of equal width and height.

b) The solid stratum formed from interfaces by the creation of polygonal sides.

### 9.1.8 Integration with Modern and Legacy Archaeological Databases.

It is quite possible that databases currently in use at archaeological sites could be given a new lease of life with systems such as the *Strat* tool. Many archaeologists are recording finds at particular sectors, and it is possible that the software could be rewired to connect to proprietary databases. In this manner, spatial information relating to finds can be visualised in 3D through the use of *Strat* allowing more detailed investigation. More dynamic and less labour intensive ways of connecting the *Strat* tool to various databases can be explored, possibly through the mechanisms of XML. Once again, this course of action needs to be as simple as possible for the user.

## 9.2 Conclusion

The primary objective of this work (under the banner of the 3D-MURALE project) was the development of new software tools to assist archaeologists. The aspect focused upon in this work was the development of techniques to allow for the better recording, reconstruction, visualisation, investigation and hypothesis testing of stratigraphic layering, buildings and artefacts, and the visualisation of the temporal stratigraphic progression of a site.

Software development alone is not considered a strictly scientific endeavour. The new methods made possible for stratigraphic visualisation and hypothesis with database connection to 3D artefact and architecture models by such software are however of scientific merit. Due to the problematic and underdeveloped nature of archaeological recording, the perfectly detailed, comprehensive 3D site reconstruction hoped for was not immediately achievable. The lack of recorded data and the organisation of this data, especially with regard to stratigraphy, vary from site to site and from archaeologist to archaeologist. It is evident from a computer scientist's perspective that the visual results produced fall short of what it is technically possible in terms of modern computer graphics techniques. Developing a tool that can be applied on any site for stratigraphic hypothesis testing was the goal, and as with any research, the end results are unknown. Through time, the focus of this work changed from one of being a stratigraphic visualisation development venture into an endeavour to develop the archaeological recording processes, so that *Strat* and future GISs will be of greater benefit to the community. Suggestions are made in Chapter 8 of such methods.

During this research project, the intention was to develop a tool to fulfil wide-ranging functionality. On studying the recordings of archaeologists, and the state of current photogrammetric techniques it became apparent that achieving this goal would mean solving many challenging sub-problems; each of which are research projects in their own right. As such, a tool was developed that would fulfil the broad requirements of the archaeologist, to gain the best possible results from the types of data that are currently recorded, *without* altering working practice. The developed tool is sufficiently

open-ended such that future research into this area and improvements to stratigraphic recording processes can be used.

Since archaeology is essentially an unrepeatable experiment, mankind may already have lost much vital information about its ancestry. The in-depth development of such tools as the one described in these works makes ever more clear the need, in the field of archaeology, for structured comprehensive recording methods.

Of the reviewed techniques and software investigated in early chapters, the closest to the techniques developed in this work would be that of Bibby's method. This method, however, requires the purchase and use of multiple proprietary softwares. Essentially the method provides a 2D solution for simultaneously analysing profile drawings and Harris matrices, allowing the interchange of this data. It does not fulfil the same capabilities as *Strat* yet provides a different technique for stratigraphic analysis.

The biggest obstacle facing the future success of this work is convincing archaeologists to use new digital technologies. Archaeology as a discipline is in a constant state of flux, and working-practise has continuously changed over the years. Archaeologists have a desire to automate some of the tedious work currently done by hand. What is needed is a way to persuade archaeologists that to accomplish this objective, more methodical and detailed recording methods need to be embraced.

Archaeology is often performed in a hurried manner, especially as is the case with rescue archaeology, where planners place time restrictions upon the archaeologist. Even with non-rescue archaeology sites, there is constant pressure by funding bodies, sponsors and authorities to uncover visually appealing artefacts, since aesthetically these are the most desirable. The time spent by archaeologists using advanced recording methods may be omitted for the pressing urge to uncover artefacts.

Photogrammetric methods of late have become more useful and easier to manage, and as with any new technology these methods will take time to filter down to new archaeologists. A training of archaeologists in computer-based methods at an early stage is necessary. As is shown in the surveys

undertaken in 2002, few practising archaeologists have knowledge of the most powerful software to-date which has been specifically designed for archaeology. These results may not be representative of all practising archaeologists but it does indicate a disparity between those who know what is possible with computers and those who do not. If the capabilities of *Strat* as described in these works are used to their full capacity, the advantages for hypothesis testing are greatly enhanced, as well as providing visually pleasing yet scientific results to demonstrate in presentations to sponsoring bodies. The adoption of new digital based technologies need not cost the archaeologist more time, in fact, as is argued earlier, the time saved from omitting the drawing of stratigraphic profiles can instead be used to record photogrammetrically and in the use of software to gain more information about how the site existed in antiquity.

Colouration in soil profiles was not investigated in great detail as a means to differentiate or correlate stratigraphic layering since this is a large subject currently studied by those in the field of machine-vision. Lighting and weather conditions throughout the day could significantly change the colouration and contrast of such images, possibly producing incorrect results.

It may be the case that *Strat* could have been implemented in a less complex combination of languages. Alternative approaches may be Alias Wavefront's Maya (Alias, 2002) in combination with MEL script or Discreet's 3DSMax in conjunction with MaxScript. Or a web-based system utilising a 3D plug-in and scripting language such as Shout3D (Eyematic, 2002) or the Viewpoint Media Player (Viewpoint, 2002) could have been selected. The C++ programming language was chosen due to its low-level flexibility, power and familiarity. It was not known for certain without extensive development if these languages would be adequate to provide the performance, database connectivity and visualisation functionality that this application requires. The dissemination of this software would then also depend on the licensing of this software and the longevity of the proprietary software. In the case of Maya, it may be possible to obtain a free license for



educational purposes, but by developing the system using open-standards this uncertainty is removed.

The *Strat* system has been designed to be as future-proof as possible. Numerous methods exist for recording 3D models, such as shape-from-video, grid detection and laser scanning (Robson Brown *et al.*, 2001). At present, laser scanners are large and expensive, and although used occasionally are often too bulky to take onto an archaeological site. This situation may change however, and this will not negatively affect the *Strat* tool. *Strat* imports 3D models in a common file format; Open Inventor (IV) - a superset of VRML. VRML is the most commonly used 3D exchange file format, and proprietary software that is bundled with 3D scanners export VRML models. Recording stratigraphic surfaces is already a tricky process using a digital camera, and bulky laser scanners are not particularly suited to such tasks. Laser scanners are more suited to the accurate recording of statues, which once again can be imported into the *Strat* tool.

Due to the data-rich nature of the system, there is a speed issue. Buildings, statues, stratigraphic surfaces and artefacts can all be recorded and visualised in 3D with *Strat*. The visualisation of such large 3D data sets, even with today's high performance 3D graphics card technologies can be a struggle. Fortunately open-source software APIs such as OpenInventor can reduce complex models to bounding-boxes or lower-resolution versions, when the processor fails to cope.

Testing the accuracy of recorded data sets, particularly with a view to finding disparities between photogrammetrically recorded stratigraphic surfaces and the actuality has not been investigated in these works, and is left to the realm of photogrammetrists.

The present situation in archaeology, with a view to computer based recording, is analogous to the chicken-and-egg scenario. Archaeologists will not spend more time using digital recording methods until they can see the immediate benefit. But, until such software is developed and used, archaeologists will not be able to see the results they desire.

The benefits to the archaeologist are numerous, although not yet fully explored. Due to the accurate 3D stratigraphic positioning and texturing of the surfaces, stratigraphic correlations and redundancies can be easily spotted. With methodical stratigraphic recording, slices, plans and profiles can be generated and printed with the press of a button. Accurate 3D renders and animations of entire archaeological sites provide a useful perspective to all abilities of end-user; from an interested member of public to the publishing researcher. The straightforward replay of excavations is a useful tool for those studying archaeology, as well as providing an easy way to see the surfaces replayed through time that were once occupied by our ancestors.

It is anticipated that this software will stand the test of time, and as such has been developed with this in mind. *Strat* is open-source and open-standard and has been entirely developed under the auspices of a EU project. This means that the software and source for *Strat* can be distributed freely and developed further by other researchers if needed, as was the case with ArchEd and Gnet.

These works have described the development of a system, which is designed to fit around the current working practises of archaeology, with added benefits obtainable for those who choose to record in a more detailed fashion.

It is the view of some writers, for example Barker, that non-destructive methods are the future of archaeology. From a purist's perspective, this is the ideal. Until such a time is reached when perfect methods of excavation are developed, it seems more shrewd to leave archaeological sites intact where possible. Non-destructive methods are occasionally used, such as through the use of ground-penetrating radar (GPR). On occasion anomalies are recorded, which when excavated, do not correlate with the expected result. These methods as yet are not perfect and need to be explored more fully. It is possible that *Strat* can be developed further to incorporate the 3D voxel-based output from such devices.

Although it appears to raise many difficult storage questions, the use of digital video cameras (DV) to record the excavation could be a highly

valuable aid. Humans are not perfect, and it is possible that the archaeologist may miss something that a DV camera did not. The ways in which vast quantities of DV data can be stored, indexed and tagged for archaeology is a possible avenue for further research.

Since the database holds 3D temporal models of spatially recorded archaeological sites, it is possible that these datasets can be used in augmented-reality environments.

Archaeology is a pursuit to provide mankind with more information regarding its past. With more detailed recording methods and more tools to manipulate this data, and the ability for other researchers to remotely contribute hypotheses based on raw data shall in the years to come improve our understanding of past lives and improve archaeology as a discipline.

### **9.3 Applying This Work**

Archaeology is a global pursuit, and the *Strat* tool is suited towards the recording, reconstruction, visualisation and analysis of man-made stratigraphic units and surrounding architecture and artefact inclusions. It could be used for geological purposes, but the main investigative powers would not be utilised.

The system might be used to study further the field of tectonic simulation. The situation of recorded collapsed building elements could lead to a more detailed analysis of earthquake activity. The prediction of destruction direction could be theorised statistically based on the spatial position of fallen building elements.

The system developed within this research has been tested on several occasions at Sagalassos in Turkey and requests have been received from archaeologists wishing to use the software on sites in Albania, Greece, England and Egypt amongst others. It is hoped that a follow-on project (currently entitled AMUSE) to the European Union funded 3D-MURALE project (Murale, 2002) will allow for wider testing of this tool and training of archaeologists. By following the methods set out in this thesis in an ordered manner from the start of a campaign, it will be possible to gain a valuable

highly detailed reconstruction of a site that can then be used for dissemination and research purposes.

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# Glossary

|                        |  |
|------------------------|--|
| <b>3D</b>              | Three Dimensional.   |
| <b>AEGIS</b>           | Aegis is a transaction-based software configuration management system. It provides a framework within which a team of developers may work on many changes to a program independently, and Aegis coordinates integrating these changes back into the master source of the program, with as little disruption as possible.   |
| <b>Anastylosis</b>     | The practice of piecing together dismembered remains of buildings.   |
| <b>Anthropogenesis</b> | The scientific study of the origin and development of humans.  |
| <b>Context</b>         | An omnibus term for all the stratigraphic units (layers, features, strata etc) found in an excavation.   |
| <b>Crusta</b>          | A gem engraved, or a plate embossed in low relief, for inlaying a vase or other object.  |
| <b>CSG</b>             | Constructive Solid Geometry.   |
| <b>DOQ</b>             | Digital Orthophoto Quadrangle (DOQ) images are derived from aerial photographs that have been digitised and then rectified to an orthographic projection. This process requires ground control points, camera orientation parameters, and a digital elevation model. The result is a digital image that is free of displacements caused by camera tilt and terrain relief. A DOQ image combines the visual properties of a digital image with the geometric properties of a map. |

|                   |  |
|-------------------|--|
| <b>DTM</b>        | Digital Terrain Map.   |
| <b>EDM</b>        | Electronic Distance Meter  |
| <b>ERD</b>        | Entity Relationship Diagram  |
| <b>Feature</b>    | A feature is an artefact that is too large to move. A feature might be anything from a filled in pit to a foundation wall or floor.  |
| <b>GIS</b>        | A GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations. Practitioners also regard the total GIS as including operating personnel and the data that go into the system.   |
| <b>GPS</b>        | Global Position System   |
| <b>GUI</b>        | Graphical User Interface   |
| <b>HP-GL</b>      | Hewlett-Packard Graphics Language (HPGL) is a vector graphics language, a type of object-oriented language that represents images through the use of geometrical formulas. Vector graphics are more efficient than the alternative, raster graphics: they require less memory space for storage and use input/output (I/O) resources more effectively so that images print more quickly.   |
| <b>NURBS</b>      | Non Uniform Rational B-Spline  |
| <b>OEM</b>        | An OEM (original equipment manufacturer) is a company that uses product components from one or more other companies to build a product that it sells under its own company name and brand. (The term is sometimes mistakenly used to refer to the company that supplies the components.) IBM is an example of a supplier to the OEM market (and IBM is also an OEM itself since it uses other companies' parts in some of its products). |
| <b>Orthophoto</b> | See DOQ in the glossary.   |

|                      |   |
|----------------------|---|
| <b>PSD</b>           | Primary Site Datum, a permanent point on the site from which all measurements are taken.  |
| <b>Sabkha</b>        | An environment of coastal sedimentation characterized by arid or semiarid conditions above the level of high tide and by the absence of vegetation.   |
| <b>Seriation</b>     | The construction of a relative chronology.  |
| <b>Shard / Sherd</b> | A piece of broken pottery, especially one found in an archaeological dig; a potsherd. A fragment of a brittle substance, as of glass or metal.  |
| <b>Stratigraphy</b>  | The study of rock strata, especially the distribution, deposition, and age of sedimentary rocks.  |
| <b>Stratum</b>       | A bed or layer of sedimentary rock having approximately the same composition throughout.  |
| <b>Tachymeter</b>    | A surveying instrument used for the rapid determination of distances, elevations, and bearings.   |
| <b>Temporal</b>      | Of, relating to, or limited by time.  |
| <b>Tessera</b>       | A small piece of marble, glass, earthenware, or the like, having a square, or nearly square, face, used by the ancients for mosaics, for making pavements, for ornamenting walls, and such purposes; also, a similar piece of ivory, bone, wood, etc., used as a ticket of admission to theatres, or as a certificate for successful gladiators, and as a token for various other purposes. |
| <b>Theodolite</b>    | An optical instrument consisting of a small mounted telescope rotatable in horizontal and vertical planes, used to measure angles in surveying, meteorology, and navigation.  |
| <b>Topography</b>    | Detailed, precise description of a place or region. Graphic representation of the surface features of a place or region on a map, indicating their relative positions and elevations. The surface features of a place or region. The surveying of the features of a place or region.  |



# Appendix A

## Stratigraphic Recording Sheets

Every archaeological site adopts different practices for the recording of stratigraphic layering information. This appendix shows actual forms, both blank and completed that have been used on genuine archaeological excavations at both the ancient Greco-Roman city of Sagalassos in Turkey, as well as the site of Butrint in Albania.

**A.1 Completed Stratigraphic Form for Sagalassos Excavation**

**SAGALASSOS**

**SITE:**   L   **RECORDED BY:**   Femke  

**SECTOR:**   LVII     57   **DATE:**   25/07/94  

**LAYER Nr:**   14N   **PLAN:** \_\_\_\_\_

(only integers, no accents) **PHOTO:**   p52  

**SAMPLE:** \_\_\_\_\_

**LAYER DESCRIPTION**

**Compaction:**   quite compact  

**Colour:**   DARK BROWN  

**Composition:**   SILTY SOIL  



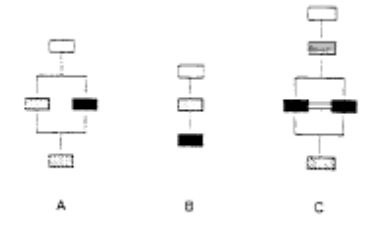
**Inclusions:**   SMALL SIZED AND MEDIUM SIZED STONES  

**Thickness and extent:**   TH: SEE ALTITUDES / EXTENT: 1.50m X 0.5  

**Your interpretation:** \_\_\_\_\_

**STRATIGRAPHICAL RELATIONS:**

| Sector ... | Sector ... | Sector LVII | Sector ... | Sector ... |                      |
|------------|------------|-------------|------------|------------|----------------------|
|            |            | SAG4L 115   |            |            | Layer <u>  13N  </u> |
|            |            | SAG4L 126   |            |            | Layer <u>  14N  </u> |
|            |            | SAG4L 129   |            |            | Layer <u>  16N  </u> |

A
B
C

Figure 128. Stratigraphy Form - Front Side



11

**FINDS: from same sector and layer as mentioned ceramics**

| Number     | Material | Number | Material |
|------------|----------|--------|----------|
| SA 94L 127 | BONE     |        |          |
| SA 94L 128 | METAL    |        |          |
|            |          |        |          |
|            |          |        |          |
|            |          |        |          |
|            |          |        |          |
|            |          |        |          |

**SKETCH:** EASTERN PART OF SECTOR LVII (N) → 14 N

50 cm left unexc. covered for safety reasons

30 m

Figure 129. Stratigraphy Form - Reverse Side

## A.2 Empty Deposit Sheet for Butrint, Albania Excavations

### ALBANIAN RESCUE ARCHAEOLOGY UNIT

|  |                          |                              |                          |                                      |   |                                |             |
|--|--------------------------|------------------------------|--------------------------|--------------------------------------|---|--------------------------------|-------------|
| LOCATION   |                          | YEAR                         | GRID REFERENCE           | SITE SUBDIVISION                     | DEPOSIT   |                                | CONTEXT NO. |
| SITE   |                          |                              |                          |                                      | Natural   | Artificial                     |             |
| LEVELS<br>Highest      Lowest  |                          | DEPTH                        |                          | LENGTH                               | WIDTH   |                                |             |
| PLAN NO.   |                          | SECTION/ELEVATION NO.        |                          | PHOTO<br>B/W<br>COL<br>TRANS         | FINDS RECORD NOS.   |                                |             |
| MATRIX   |                          |                              |                          |                                      | MATRIX LOCATION   |                                |             |
| <div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> </div> <p style="text-align: center;">This context is:</p> <div style="border: 1px solid black; width: 30px; height: 20px; margin: 0 auto;"></div> <div style="display: flex; justify-content: space-around; margin-top: 5px;"> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> <div style="border: 1px solid black; width: 30px; height: 20px;"></div> </div> |                          |                              |                          |                                      |   |                                |             |
| SAME AS  |                          |                              |                          |                                      | DATE  |                                |             |
| FILL OF  |                          |                              |                          |                                      | PERIOD  |                                |             |
| CUT BY   |                          |                              |                          |                                      | PHASE   |                                |             |
| ABOVE  |                          |                              |                          |                                      | DATING EVIDENCE   |                                |             |
| BELOW  |                          |                              |                          |                                      | STRATIGRAPHIC RELIABILITY    very low    low    high    very high |                                |             |
| DESCRIPTION  |                          |                              |                          |                                      |   |                                |             |
| <div style="border: 1px solid black; padding: 5px;"> <ol style="list-style-type: none"> <li>1. Colour/Munsell</li> <li>2. Composition<br/>(particle size greater than 10%)</li> <li>3. Coarse components<br/>(particle size less than 10%:<br/>occasional/common/abundant)</li> <li>4. Compaction/consistency</li> <li>5. Thickness and extent</li> <li>6. Excavation method &amp; conditions</li> <li>7. Other comments</li> </ol> <p>DRAW SKETCH OVERLEAF</p> </div>   |                          |                              |                          |                                      |   |                                |             |
| INTERPRETATION   |                          |                              |                          |                                      |   |                                |             |
| SAMPLE NO.   |                          | FLOTATION                    |                          | DRY SIEVE                            |   | METAL DETECTOR                 |             |
| FINDS  |                          |                              |                          |                                      |   |                                |             |
| Pottery  | Wasters                  | Metalwork                    | Metal waste              | Terracotta                           | Animal bone   |                                |             |
| <input type="checkbox"/>   | <input type="checkbox"/> | <input type="checkbox"/>     | <input type="checkbox"/> | <input type="checkbox"/>             | <input type="checkbox"/>  |                                |             |
| Human bone   | Worked stone             | Architectural fragments      | Glass                    | Flint                                | Other   |                                |             |
| <input type="checkbox"/>   | <input type="checkbox"/> | <input type="checkbox"/>     | <input type="checkbox"/> | <input type="checkbox"/>             | <input type="checkbox"/>  |                                |             |
| SUPERVISOR<br>NAME      DATE   |                          | CHECKED BY<br>NAME      DATE |                          | COMPUTER RECORD BY<br>NAME      DATE |   | COMPLETED BY<br>NAME      DATE |             |

A.3 Completed Deposit Sheet for Butrint, Albania Excavations

ALBANIAN RESCUE ARCHAEOLOGY UNIT

|   |   |  |  |                                     |   |                         |  |   |     |
|---|---|--|--|-------------------------------------|---|-------------------------|--|---|-----|
| LOCATION <u>Butrint</u>   |   | YEAR <u>01</u>                                       | GRID REFERENCE <u>105/405</u>  | SITE SUBDIVISION <u>Trench 4</u>    | DEPOSIT <u>Natural</u> <input type="checkbox"/> <u>Artificial</u> <input checked="" type="checkbox"/> | CONTEXT NO. <u>2092</u> |  |   |     |
| SITE <u>Excavation W</u>  |   |  |  |                                     |   |                         |  |   |     |
| LEVELS<br>Highest <u>10.20</u> Lowest <u>10.18</u>  | DEPTH <u>0.1m</u>   | LENGTH <u>5m</u>                                     | WIDTH <u>5m</u>  |                                     |   |                         |  |   |     |
| PLAN NO.  | SECTION/ELEVATION NO.   | PHOTO<br>BW<br>COL<br>TRANS                          | FINDS RECORD NOS.  |                                     |   |                         |  |   |     |
| MATRIX  |   |  |  |                                     | MATRIX LOCATION   |                         |  |   |     |
| <div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; padding: 2px;">2085</div> <div style="border: 1px solid black; padding: 2px;">2092</div> <div style="border: 1px solid black; padding: 2px;">2098</div> </div> <p>This context is: <u>2092</u></p>   |   |  |  |                                     | <div style="border: 1px solid black; width: 100px; height: 50px; margin: 0 auto;"></div>              |                         |  |   |     |
| SITE NOTEBOOK REFS  |   |  |  |                                     |   |                         |  |   |     |
| SAME AS   |   |  | DATE <u>Med</u>  |                                     |   |                         |  |   |     |
| FILL OF   |   |  | PERIOD   |                                     |   |                         |  |   |     |
| CUT BY  |   |  | PHASE  |                                     |   |                         |  |   |     |
| ABOVE <u>2098</u>   |   |  | DATING EVIDENCE  |                                     |   |                         |  |   |     |
| BELOW <u>2085</u>   |   |  | STRATIGRAPHIC RELIABILITY very low <input checked="" type="radio"/> high very high |                                     |   |                         |  |   |     |
| <p>DESCRIPTION</p> <table border="0"> <tr> <td style="width: 20%; vertical-align: top;">                     1. Colour/Munsell<br/>                     2. Composition (particle size greater than 10%)<br/>                     3. Coarse components (particle size less than 10%; occasional/common/abundant)<br/>                     4. Compaction/consistency<br/>                     5. Thickness and extent<br/>                     6. Excavation method &amp; conditions<br/>                     7. Other comments<br/>                     DRAW SKETCH OVERLEAF                 </td> <td style="vertical-align: top;">                     1. DARK GREY/BROWN<br/>                     2. SANDY CLAY<br/>                     3. MODERATE MASONRY DEBRIS (75% LIMESTONE, 25% TILE)<br/>                     OCCASIONAL MORTAR<br/>                     OCCASIONAL CHARCOAL<br/>                     OCCASIONAL SHELL<br/>                     4. COMPACT<br/>                     5. ✓<br/>                     6. MATLOCKED THEN CAREFULLY TROWELLED. HOT + DRY.<br/>                     7. LOTS OF ROOTS.                 </td> <td style="text-align: right; vertical-align: top;">                     (7)                 </td> </tr> </table> |   |  |  |                                     |   |                         | 1. Colour/Munsell<br>2. Composition (particle size greater than 10%)<br>3. Coarse components (particle size less than 10%; occasional/common/abundant)<br>4. Compaction/consistency<br>5. Thickness and extent<br>6. Excavation method & conditions<br>7. Other comments<br>DRAW SKETCH OVERLEAF | 1. DARK GREY/BROWN<br>2. SANDY CLAY<br>3. MODERATE MASONRY DEBRIS (75% LIMESTONE, 25% TILE)<br>OCCASIONAL MORTAR<br>OCCASIONAL CHARCOAL<br>OCCASIONAL SHELL<br>4. COMPACT<br>5. ✓<br>6. MATLOCKED THEN CAREFULLY TROWELLED. HOT + DRY.<br>7. LOTS OF ROOTS. | (7) |
| 1. Colour/Munsell<br>2. Composition (particle size greater than 10%)<br>3. Coarse components (particle size less than 10%; occasional/common/abundant)<br>4. Compaction/consistency<br>5. Thickness and extent<br>6. Excavation method & conditions<br>7. Other comments<br>DRAW SKETCH OVERLEAF  | 1. DARK GREY/BROWN<br>2. SANDY CLAY<br>3. MODERATE MASONRY DEBRIS (75% LIMESTONE, 25% TILE)<br>OCCASIONAL MORTAR<br>OCCASIONAL CHARCOAL<br>OCCASIONAL SHELL<br>4. COMPACT<br>5. ✓<br>6. MATLOCKED THEN CAREFULLY TROWELLED. HOT + DRY.<br>7. LOTS OF ROOTS. | (7)  |  |                                     |   |                         |  |   |     |
| <p>INTERPRETATION <u>SPIT TAKEN OFF THROUGH MEDIEVAL SOIL BUILD-UP TO TRY TO FIND POST BUILT STRUCTURES. NO FEATURES FOUND.</u></p>   |   |  |  |                                     |   |                         |  |   |     |
| SAMPLE NO.  | FLOTATION   | DRY SIEVE  | METAL DETECTOR   |                                     |   |                         |  |   |     |
| FINDS   |   |  |  |                                     |   |                         |  |   |     |
| Pottery <input checked="" type="checkbox"/>   | Wasters <input type="checkbox"/>  | Metalwork <input type="checkbox"/> <u>Ferrail x1</u> | Metal waste <input type="checkbox"/>   | Terracotta <input type="checkbox"/> | Animal bone <input checked="" type="checkbox"/>   |                         |  |   |     |
| Human bone <input type="checkbox"/>   | Worked stone <input type="checkbox"/>   | Architectural fragments <input type="checkbox"/>     | Glass <input type="checkbox"/>   | Flint <input type="checkbox"/>      | Other <input type="checkbox"/>  |                         |  |   |     |
| SUPERVISOR<br>NAME DATE   | CHECKED BY<br>NAME DATE   | COMPUTER RECORD BY<br>NAME DATE                      | COMPLETED BY<br>NAME DATE  |                                     |   |                         |  |   |     |
|   | <u>AC</u> <u>18.08.01</u>   |  | <u>SAH</u> <u>6/6/07</u>   |                                     |   |                         |  |   |     |



# Appendix B

## The STRAT Tool Survey

This chapter contains the original questionnaire as described in Section 5.4 along with the instructions used by the participants in order to complete the questionnaire. The results and observations derived from these questionnaires are detailed in Section 5.4.

## B.1 Strat Questionnaire



# STRAT

## Questionnaire



This survey is being conducted to evaluate the efficacy of the STRAT tool for archaeological recording, reconstruction, investigation and dissemination. The comments from these questionnaires will affect the future development of the tool. Hence your comments are of great value to future archaeological research. This project is funded by the European Union, Proposal Number IST-1999-20273. Professionals in the field of archaeology are asked to participate. The findings will be published in the thesis of D.Green which should be published later this year, 2002. This document once published, will be available at the following URL: <http://www.brunel.ac.uk/~eepgdag/publications.htm>. Names and personal details as filled in in part A are for statistical purposes only and will be omitted from publication. Thanks for your cooperation.

### PART A.

Name: \_\_\_\_\_

Age: [18->25] [25-30] [30-35] [40+]

Occupation: \_\_\_\_\_

Gender: M F

### PART B. Creating a Project, Site, Excavation Unit and Trench trial.

Please circle the response that most closely corresponds to your view.

| 1. Have you used any archaeological software Before? If YES Answer question 2. | YES   | NO        |           |  |  |
|--|-------|-----------|-----------|--|--|
| 2. Which of these archaeological software do you use?                          | Never | Sometimes | Regularly |  |  |
| Microstation   |       |           |           |  |  |
| ArchEd   |       |           |           |  |  |
| Harris   |       |           |           |  |  |
| BASP   |       |           |           |  |  |
| GNet   |       |           |           |  |  |
| AutoCAD  |       |           |           |  |  |
| 3DSMax   |       |           |           |  |  |

|   |                   |                  |                   |             |                  |
|---|-------------------|------------------|-------------------|-------------|------------------|
|   |                   |                  |                   |             |                  |
|   |                   |                  |                   |             |                  |
|   |                   |                  |                   |             |                  |
| 3. Which software do you use on a regular basis:  | <i>Never</i>      | <i>Sometimes</i> | <i>Regularly</i>  |             |                  |
| <i>None</i>   |                   |                  |                   |             |                  |
| <i>MS Office</i>  |                   |                  |                   |             |                  |
| <i>Windows</i>  |                   |                  |                   |             |                  |
| <i>Linux</i>  |                   |                  |                   |             |                  |
| <i>MS-DOS</i>   |                   |                  |                   |             |                  |
| <i>Internet Explorer</i>  |                   |                  |                   |             |                  |
|   |                   |                  |                   |             |                  |
| 4. Time to learn whole operation  | <i>0-5mins</i>    | <i>5-10mins</i>  | <i>10-15 mins</i> | <i>More</i> |                  |
| 3. How easy was the software to use?  | <i>Difficult</i>  |                  |                   |             | <i>Easy</i>      |
|   | <i>1</i>          | <i>2</i>         | <i>3</i>          | <i>4</i>    | <i>5</i>         |
| 4. How many errors did you make during the processing of function                                 | <i>Many</i>       |                  |                   |             | <i>None</i>      |
|   | <i>1</i>          | <i>2</i>         | <i>3</i>          | <i>4</i>    | <i>5</i>         |
| 5. How satisfied was the user that the function was the most efficient way of completing the task | <i>Frustrated</i> |                  |                   |             | <i>Satisfied</i> |
|   | <i>1</i>          | <i>2</i>         | <i>3</i>          | <i>4</i>    | <i>5</i>         |
| 6. Overall reaction to user interface.  | <i>Difficult</i>  |                  |                   |             | <i>Easy</i>      |
|   | <i>1</i>          | <i>2</i>         | <i>3</i>          | <i>4</i>    | <i>5</i>         |
| 8. Feedback provided by software  | <i>Unhelpful</i>  |                  |                   |             | <i>Helpful</i>   |
|   | <i>1</i>          | <i>2</i>         | <i>3</i>          | <i>4</i>    | <i>5</i>         |

10. Final User's comments / Suggestions for improving the software.

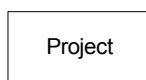
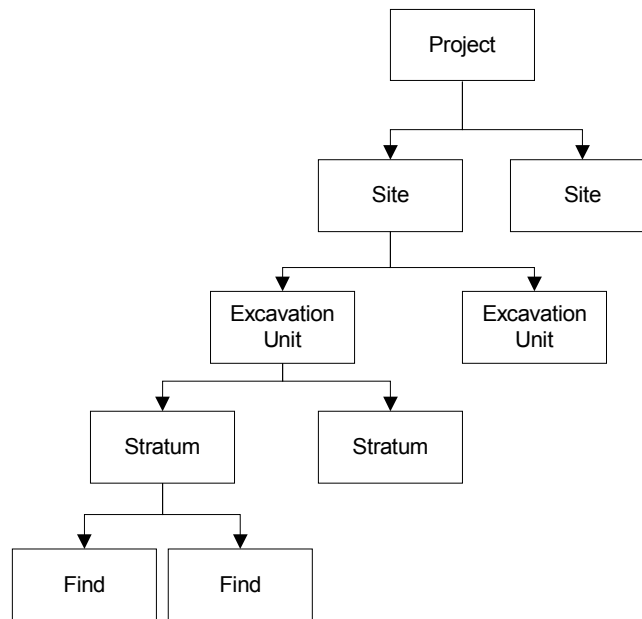
**Thank You!**

[Please Return to Damian Green, Brunel University, Uxbridge, Middx, UB8 3PH]



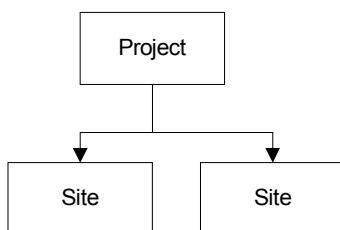
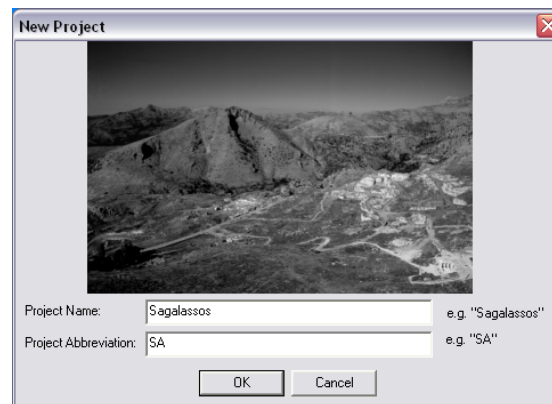
## B.2 *Strat* Tool Instructions – Creating a Project, Site, Trench and Strata.

In this short exercise, you are asked to test a small portion of the *Strat* tool's functionality. You will create a Project, a Site, and Excavation Unit and a Stratum. The relations between these are shown below:



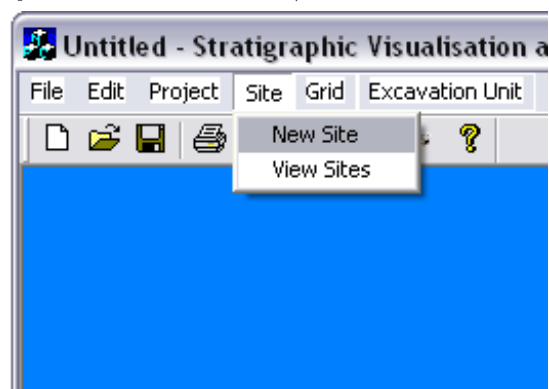
### STEP 1, Creating a Project.

After running the *Strat* tool, the user is presented with a dialog box (see image below) that asks you to enter a new project. This project refers to your campaign, or the entire excavation you are currently working on, for example “Sagalassos” is the name of a large excavation in the Mediterranean which is composed of several sites, even if your campaign contains only one site, please define the name of your campaign. An abbreviation will be generated for you or you can define one. This is used later for generating unique context numbers. Click on the OK button with the mouse once you have typed in the name of your campaign. WELL DONE. You have completed the first step.



**STEP 2)** The second step is to define the sites used. A SITE is a separate excavation that is being carried out as part of the main campaign.

- Using the mouse, select the menu item entitled “Site”
- Click on the entry called “New Site”, as shown in the image below.



You will then be presented with another dialog box like the one shown below.

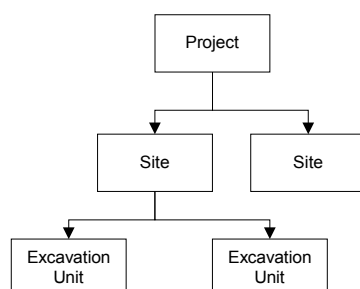
- In the box that says Site Name: Enter the name of the site to create. For example, the “Roman Baths” is a SITE. “Upper Agora North” is a site. As you type, the box which says Abbreviated Site Name will create a word which is formed from the first letter of the site name.

This is the abbreviation, which is used later on to automatically form part of the unique context identification number, if you so wish.

- A grid is defined at the start of an archaeological campaign. It defines how a repetitive grid is laid out and is oriented around a point of origin. This can be defined by click on the New Grid button. Otherwise a default grid will be set for you at 5m intervals.
- Click OK to continue.

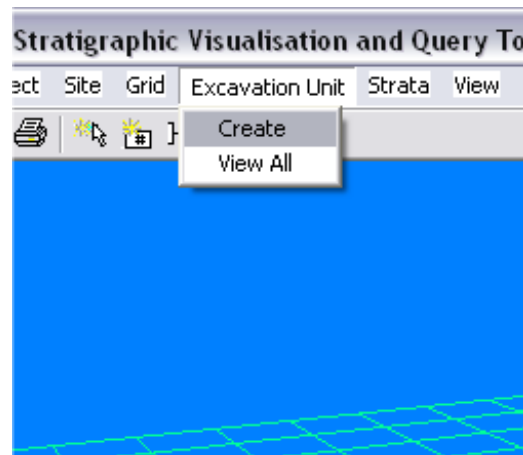


If successful, you will be presented with a dialog like the one shown below and you will then be returned to the interface of *Strat*.



**STEP 3)** You have now defined your Project and a Site. Now we can begin to excavate.

- To create a trench, click on the menu item entitled “Excavation Unit” and select “Create” as shown in the image below.



You will then be presented with a dialog box like the one shown below.



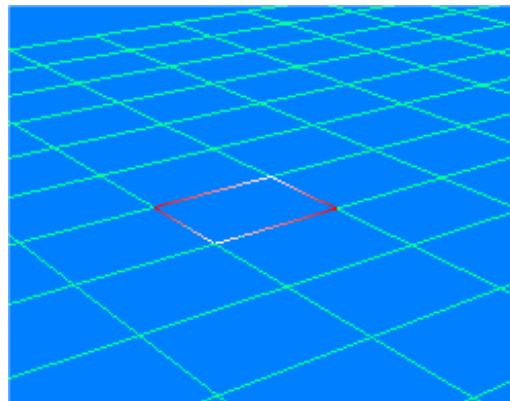
The site you defined earlier should be displayed in the drop down list entitled “Site”. As you create more sites, this dialog box will grow. The next step is to specify the offset the trench is begun being dug from your point of origin

(PSD). On every archaeological campaign, a point, e.g. a nail is set out on a rock, it's coordinates are measured using a GPS receiver and then every trench or find is recorded in 3D in relation to this point.

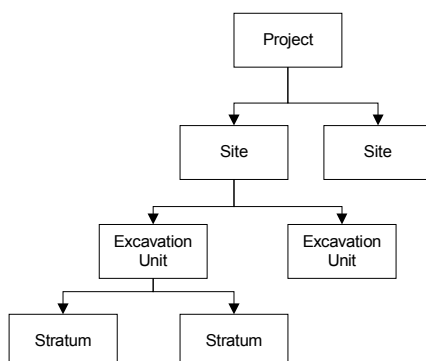
- For example, if you are about to open a trench at location 5 metres East of the PSD, 10 metres south enter “5” in the Offset X box and “10” in the Offset Y box.
- Then enter the dimensions of the trench you are about to open, for example 5m, by 5m. Enter these values in the width and length boxes.
- Click OK To continue.



Congratulations, you have created a trench in the database. If you are viewing a portion of the map which is close to the PSD then you will see your trench outlined in red and white as shown below:



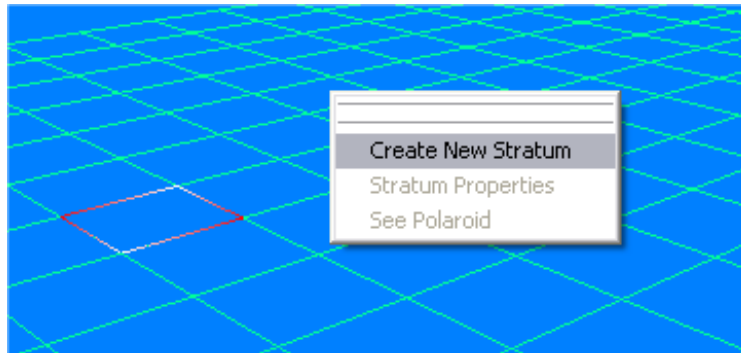
a



**STEP 4)** The final step to creating a 3D layer is to create a stratum. A stratum is soil layer. Usually this is excavated stratigraphically. That is to say, once a

new layer is uncovered and noticeable changes can be seen, a new stratum has been identified.

- With the right mouse button, click anywhere on the grid.
- Select “Create New Stratum”.



The dialog box below will now appear.

DO NOT WORRY; IT IS NOT AS COMPLICATED AS IT LOOKS. ☺

- Where you see Date Excavated, click on the black arrow to select the date when this layer was excavated
- Check that the site you have just created is selected in the Site drop-down box. If not, select your site from the list.
- In the next drop-down box, check that the excavation unit you created is selected, this should be filled in for you automatically, but if not, it can be changed in the same manner as before.
- In the next box enter the number of your layer, for example, layer 1.
- In the four boxes surrounding the picture of the square enter the depths of the layer you have excavated. Enter “100” in each of the four boxes to create a 1m deep trench.

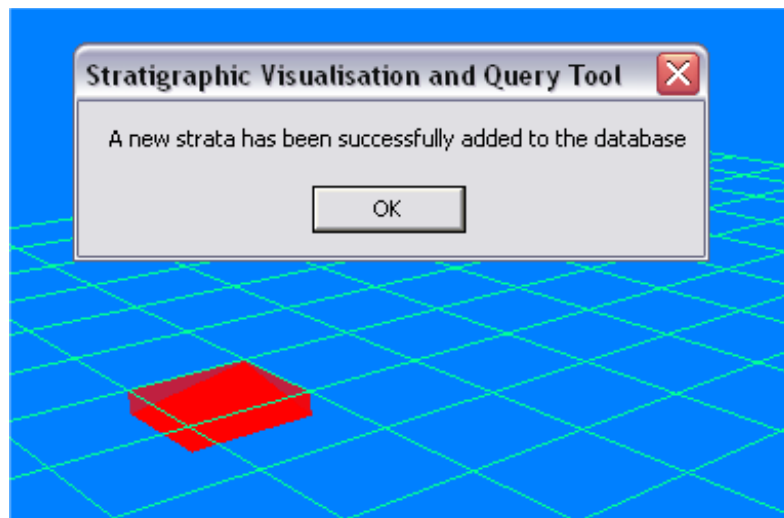
- Click on the colour picker (the red square) and select a colour, preferably not blue.
- Click OK.

Epoch is used to date the layer; this is usually defined post-excavation once artefacts within have been dated.

The Description box is used to enter information about that layer; it's composition, colour and so on.

The Layer photo button is used to add a photograph of the layer, e.g. a Polaroid to that database.

The Import Photogrammetric Model button allows the user to load a 3D model of the layer surface, this allows for a lot more detailed representation of the surface to be defined.



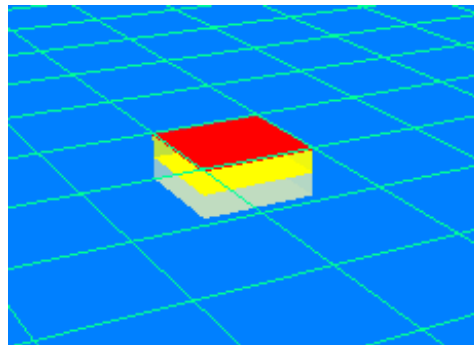
Congratulations. You have now created your first stratum in 3D.

**STEP 5)** Press and hold the 'L' key on the keyboard to rotate the world clockwise

**STEP 6)** Press and hold the 'R' key on the keyboard to rotate the world anti-clockwise

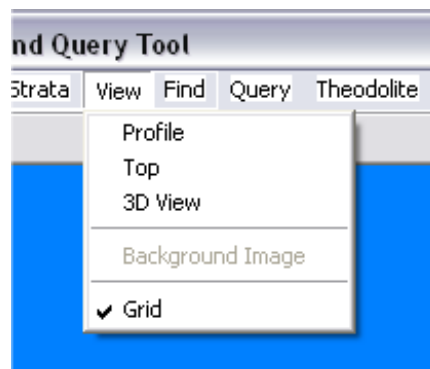
**STEP 7)** Repeat Steps 4-6, this time adding a new stratum with the same depths, but a different colour and different extents. This will then add a stratum to the previous layer resulting in something similar to this:



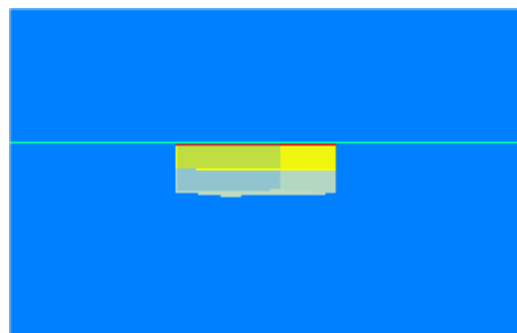


**STEP 8)** The world can be seen from several angles.

Click on **View** menu. Select the **Profile** option

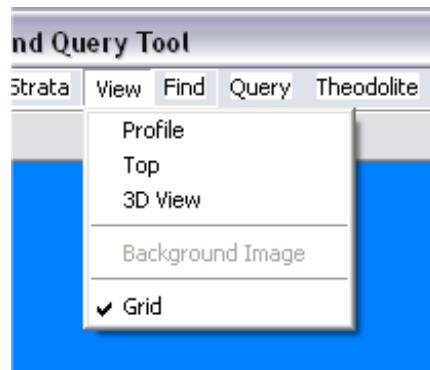


You will then be able to see your stratigraphic layers from the side, as shown below.

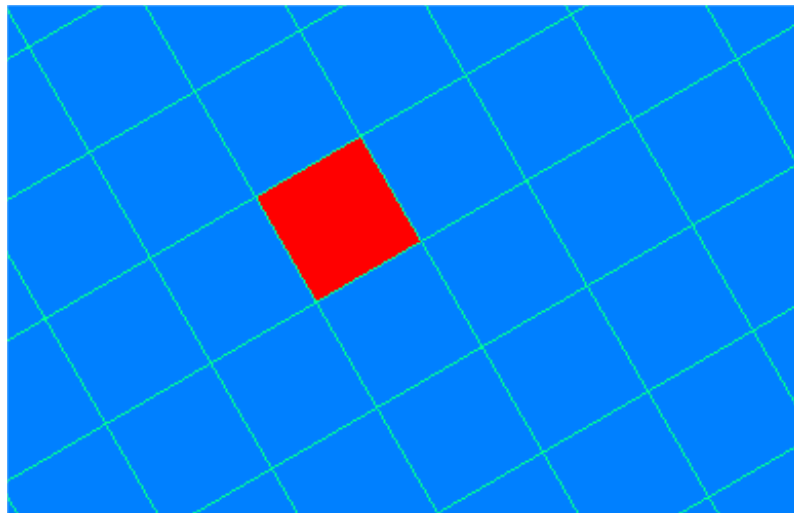


**STEP 9)**

Click on **View** menu. Select the **Top** option



The excavation unit can now be seen from the top.



The *Strat* tool is capable of much more than creating strata. It is a means of entering pottery artefacts, creating relations between stratum, generating Harris matrices, recording 3D and visualising 3D. It is a very good way of disseminating the results of the archaeological site since the visual result is presented before you.

**END.**

### B.3 Results of Pilot Study

1. In the pilot study, during the creation of a grid, the user wondered as to the purpose of the “New Grid” button. Creation of a grid was omitted from the original questionnaire for the purpose of brevity but a decision was made to extend the questionnaire, making further sections more understandable.
2. The questionnaire was printed in black and white, but the coloured outline of an excavation unit was not visible in the black and white print out, so a colour manual was suggested.
3. To gain an indication of the speed in which the user learnt the system it became apparent that the user should iterate through the steps more than once.
4. It was suggested to remove the theodolite point buttons from the Create Stratum dialog. This was a partial implementation and continues to be developed.
5. One user was offended by a question asked aiming to determine their gender. They were of the opinion that their gender should make no difference to the study. This author does not intend to discriminate on sexual grounds, yet in archaeology there is a divide between the occupations of female and male archaeologists (Moser, 1996). The question may not be important in terms of user-trials, however it is a question which can be answered by the interviewer before or after the questionnaire takes place so as to pre-empt arguments.
6. The question of speed-of-task-performance was omitted due to the instant nature of the response by the software. Results would show high in all cases, and therefore not provide any useful statistical information with regard to the future development of *Strat*. Moreover it would have slowed the questionnaire process.
7. The pilot questionnaire was aimed at determining usability on a small part of the system. By keeping the questionnaire short it was hoped to keep time down, so as not to detract future participants or antagonise

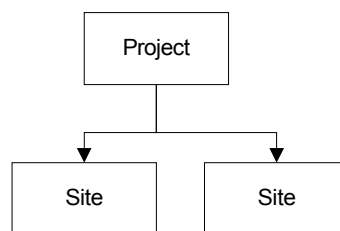
users. The questions asked were familiar to a process that future users would have to carry out on a regular basis.

8. In the user manual, a step was ambiguously defined as: “**STEP 5)** Press and hold the ‘l’ and ‘r’ keys on the keyboard to rotate the world to see your stratum for several angles.” The user tried to hold both keys down at the same time, when what was actually meant was for the user to press the keys separately. Suffice to say that the question was reworded as follows:

“STEP 5) Press and hold the ‘L’ key on the keyboard to rotate the world clockwise

STEP 6) Press and hold the ‘R’ key on the keyboard to rotate the world anti-clockwise”

9. The terminology used in the instructions was a little vague to one user. It was not immediately clear that *Site* referred to a sub-site of the *Project*. The questionnaire was rephrased accordingly, and diagrams were included showing clearly the relations. This notation was extended throughout the questionnaire producing diagrams similar to the one shown below. It is suggested that the ambiguous photographs currently used be replaced by these images in the appropriate dialog-box.



10. To one user, the “stratum” terminology was not understood. The questionnaire was extended such that a short explanation was provided making a definition of a stratum.
11. To keep instructions short and to reduce the users’ time, the test was kept simple. It became apparent that parts of the dialog, which were not part of the original questionnaire, needed to be described so that the user gained a more complete understanding of the tool.

12. On creating a stratum, the colour-picker was omitted from use in the original questionnaire. However, since aesthetically this is one of the simplest and most visually responsive buttons it was decided that the usability of the study would be improved with its inclusion.
13. The user did not have an opportunity to practise what they had learnt in the instructions. A further step was added asking another stratum to be added to the previous one.
14. Users felt that they wanted to interact more with the scene, see it from more views and so on. The questionnaire was extended taking this point into account.
15. Some users were not familiar with terminology “drop-down box” in the instructions.
16. The image explaining certain steps of the operation were on the following page, so most users had completed the task before fully reading the instructions. In the subsequent questionnaires, instructions were left to the end of the step, following any explanation and imagery, and preferably on the same page.

#### **B.4 Results of STRAT User-Trial Study**

1. A suggestion was made to make the site-dialog (Figure 91) editable so that the user can replace it with a real photograph of the site. The generic photograph used was deemed confusing since a photograph from the site of Sagalassos was shown, and not all sites would appear like Sagalassos. This photograph was originally used to make the interface more visually appealing to the user. This comment is a perfectly valid one, however, and an idea which can be easily implemented.
2. One user made an accident when creating the site. Somehow they created the site earlier than intended (the user most probably prematurely clicked on OK). They then questioned how the site could be removed. The user logically clicked on the "Site" menu, the menu they originally clicked on to create the site, searching for a dialog box to delete the site. At this point in development there was not the possibility to delete the site from memory or from the database. There is currently implemented an option for viewing the sites; a dialog with a list of currently created sites is displayed. This is a good place for the user to select and delete the site. An alternative would be to add a new menu item entitled "delete site". An undo button would be invaluable in this case. The delete-site code was then implemented on site during the 2002 season.
3. The same point was made about the images in Figure 90 and Figure 92 as was made in point 1; it should be possible to change the images to those representing the site currently worked upon.
4. The user felt it good that they did not need to retype the name of the site when creating an excavation-unit; they liked the way that they could select a site from the list.
5. After creation of the stratum, the user felt a little disorientated because the grid shown was rotated 45 degrees from north. They suggested the presence of a north arrow or X and Y on the map.
6. In the create-stratum dialog box a date/time control exists that allows the input date of the excavation of a stratum (Figure 85). It was

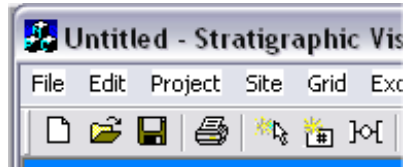
discovered that it was possible to select a date in the future. Obviously it is not possible to excavate a layer in the future. This is not a bug of the system, but the system could have some validation implemented preventing the user entering future dates.

7. On clicking OK on the Create Excavation Unit dialog box, the Excavation Unit box did not appear immediately, that is to say the screen was not refreshed every time. This bug was fixed on site.
8. It was noted that the PSD (origin), was not indicated anywhere on the visual grid. This could be marked somehow on the grid, perhaps with an arrow, annotation or 3D object.
9. The combo-box identifying the excavation unit displays the offset. It was noted by one user that it might be useful to also display the excavation unit extents. Since excavation units do not have clear identifying names, this coupling of attributes may provide more clarification.
10. On the create-stratum dialog, the user would like to see the picture of the stratum change as the user changes the depths of the corners or opens a 3D model. This functionality the author already had in mind, but had not yet implemented due to OpenGL / OpenInventor design decisions. This can be implemented in the next development stage.
11. Bug: pressing return in the offset text-box in the create-excavation-unit dialog-box caused the new-site dialog to be launched.
12. Bug: the tab-order was incorrect in the create-excavation-unit dialog.
13. One Unix-experienced user preferred the “enter” key to go to the next text box instead of the usual “Tab” key which is standard in Windows.
14. One user felt the new-site button could cause confusion in the new-excavation-unit dialog-box. The intention was to help users who had forgotten to create sites. The dialog could instead generate an error if no sites exist. If sites do exist, but not the one that the user originally intended, the user can always click cancel. This is a design decision to which the answer is not straightforward.

15. One user wanted the menu-bar to be dockable. This functionality is already possible in applications such as Word and Outlook, so could possibly be implemented in *Strat*.
16. On testing the software in Sagalassos, the Belgian archaeologists had problems using the UK keyboard on the Sony Vaio laptop. This should not present a problem when the software is installed on non-UK computers.
17. It may be helpful to display confirmation of a site's creation visually in the system.
18. One user created an excavation unit at sector 2560, but the system does not yet navigate to that part of the grid so the user was unable to see the unit they had created.
19. One (perhaps more computer literate) user, clicked on create-stratum from the menu, instead of from the context menu as is described in the instructions. This demonstrates the different manner in which users tend to interact with software based on previous experience.
20. The *epoch* combo-boxes in the create-stratum dialog box only allow the user to enter modern dates. The software needs to be altered such that these are text boxes.
21. Bug: on clicking the *average* text-box in the create-stratum dialog box and entering an average depth, the user then clicked on a text field for one of the depths and found that it could not be edited. This is because the controls were set to read-only. The spinner controls could change the number but not through editing.
22. One user entered "DA1" (the abbreviated site name) in the site-name text-field accidentally. After making this mistake once the user would learn the correct procedure.
23. In the site dialog-box, the grid combo-box showed "no grid" so one user instinctively attempted to create one although this was not part of the original instructions. Since a default grid was already present this part of the system did not affect the results.



24. A user entered an “!” instead of a “1” in the Site-name. Currently, there is no way of modifying the site name. This needs to be implemented.
25. For some reason, possibly due to a facet of MS Windows XP, menu items were surrounded with a white box instead of the background colour. The reason for this must be discovered and fixed.



26. At Sagalassos, it came to light that the height of the first PSD is unknown, i.e. x and y are known but z is not. However, points are taken relative to a second PSD, for example, 2500,2500,Z. So it turns out that the x and y are measured from the first PSD and the z is measured from the second PSD. This issue needs to be investigated to see if it affects the system.
27. On entering a layer, one user clicked on the previous layer combo-box and tried to type in a ‘1’. But since this layer had not yet been created it was not shown. This issue needs to be investigated to determine whether the user should be allowed to enter subsequent layers or whether they should begin entering from the top.
28. Typo: “A new Strata” should be labelled “A new Stratum”.
29. One user was confused of the purpose of creating a new excavation unit. She thought she was locating a sector, and due to the grid being present felt constrained to create an excavation unit within the regimented bounds.
30. One user prematurely created a stratum and was unable to undo their actions. A confirmation box may be useful.
31. Zooming was deemed important due to the thinness of some layers.
32. Bug: The excavation date for the layer was wrongly recorded as 01/01/1970 10:24:08 when a date was not selected. This was fixed on site.
33. One user mistakenly clicked on the “view site” menu option instead of “new site”. Imagery could be used, or more dissimilar names could be used differentiating the options.

34. Several users clicked on the “New Grid” button confusedly when creating a New Site. It may be better to simply omit this button, since this is not an operation that will happen frequently. In fact, it is an operation that in most cases will only be used once by one user in the entire life cycle of the campaign. This numbering system is crucial for the spatial positioning of all contexts.
35. The user base for this system became more apparent during testing. Archaeology as a field has diverged into many separate sub-occupations; dendochronologist, statue specialist, database developer, excavator, surveyor and so on. The end-user of this system will most likely be a surveyor or one of the people who normally records pottery information in a computerised database, or perhaps simply the most computer literate archaeologist on site. It seems sensible that future publications and collaborations in this area should involve the surveying community. The study shows that the software is easy enough to be learnt quickly by inexperienced archaeologists.
36. Previous dialogs should be removed when the confirmation dialog box appears. One attempt was made to click the “OK” button on the dialog *behind* the confirmation dialog.
37. It may be sensible to remove the new-site button from the create-stratum-dialog, since in most cases of stratum creation it will not be used (a site is not often created). The question can be asked automatically on clicking OK if no site currently exists.
38. One adventurous user wanted to know what *average* and *middle* stood for. This could be made clear by appending the word “depth”.
39. The *average* text-box is empty after the user has completed the four height fields. This is a little misleading; this text box should be automatically completed with the mean average of the four heights by the software, if only for purposes of clarity.
40. One user did not know what “extents” meant. This was not explained in the questionnaire but was also not asked for.

41. One user was also unsure where to enter finds in the stratum dialog box. They appeared a little confused as to whether they were entering the dimensions of a layer or an excavation unit; this might need to be rethought to represent it in the clearest manner.
42. One user wanted to know if the “colour” button in the create-stratum dialog represented the colour of the layer. It is true that the purpose of this colour box is not made clear to the user, but several archaeologists suggested that the Munzel colouration method could be used for this.
43. On creating a duplicate site, one user skipped past the dialog informing them that the site already exists, incorrectly thinking that this had been done. The user should be redirected to the new-site dialog box to fulfil their original goal.
44. One more advanced user, after following the original instructions to create a new stratum by using the right mouse button, then went on to create a new stratum later from the menu. This appeared quite bizarre but indicates the behaviour of certain users.
45. One user who was familiar with using a database called Filemaker for recording statues had some interesting comments about the epoch section to the Create Stratum dialog. On the system she uses, the user enters the century, e.g. 14<sup>th</sup>, 15<sup>th</sup>, 1<sup>st</sup>, and selects a greater level of detail from a selection of radio buttons. These are broken down into the following order: All (century), Middle, End, First Half, Second Half, 1<sup>st</sup> Quarter, and then to the ten decades of that year. A variation of this method could be implemented instead of the specific year numbers that are currently entered, since layers cannot be dated to a precise year. An alternative would be having a time slider of which the units snap to quarters of century. This possibility is expressed in Figure 130.

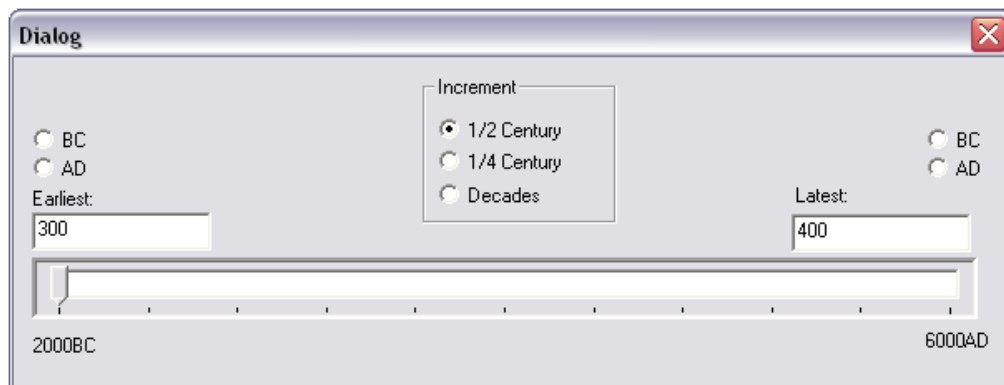


Figure 130. Dating stratigraphy, a new suggested interface.

46. Two users instinctively attempted to click on a grid sector trying to create an excavation unit. This makes logical sense and could be implemented.
47. One user attempted to double-click on the stratum in order to view the finds in that layer. The layer details can be displayed perhaps with a drop-list or combo-box displaying the finds.
48. One user trying to create a new trench but instead clicked on create-new-stratum. Logically this makes sense; the user wants to excavate without first defining an excavation unit. The exact workflow is not clear-cut.
49. Error checking is currently not implemented to ensure that trenches do not intersect one another.
50. Some users were left feeling confused because the short instructions did not explain all buttons on the toolbars.
51. One user was confused as to whether the layer they were creating was being added beneath the previous layer. Perhaps this needs to be clarified in some manner in the software. This can be illustrated through the use of 3D graphics.
52. Most users reported that the software was “well made” and “not difficult at all to use”.
53. On the create-stratum dialog-box, one user reported that the line drawing of a layer was too abstract and a photograph would have been preferred.

# Appendix C

## Publications

### C.1 Publications List

#### C.1.1 Conference Papers

1. Green, D. 2001. "Moving Towards the 3D Visualisation and Automatic Correlation of Stratigraphic layering". Proceedings of conference 6 of Archaeologie und Computer, Vienna, Austria.
  2. Green, D., Cosmas, J., Itagaki T. et al. 2001. "A Real Time 3D Stratigraphic Visual Simulation System for Archaeological Analysis and Hypothesis Testing". Proceedings of ACM Virtual Reality, Archaeology and Cultural Heritage (VAST 2001), Glyfada, Greece.
  3. Green, D. 2002, "Visualizing Legacy Stratigraphic Data from Archaeological Handbooks". Proceedings of the Computer Applications and Quantitative Methods in Archaeology Conference (CAA 2002) "The Digital Heritage of Archaeology", Heraklion, Crete.
  4. Cosmas, J, Itagaki, T, Green, D *et al.* 2001, "3D MURALE: A Multimedia System for Archaeology". Proceedings of the ACM Virtual Reality, Archaeology and Cultural Heritage (VAST 2001), Glyfada, Greece.
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1. Grabczewski, E, Cosmas J, Van Santen, P, Green, D, Itagaki, T *et al.* 2001, "3D MURALE: Multimedia Database System Architecture". Proceedings of the ACM Virtual Reality, Archaeology and Cultural Heritage (VAST 2001), Glyfada, Greece.

2. Green, D. 2002, "The Heritage Of Stratigraphy - Visualizing Legacy Data". First International Symposium on 3D Data Processing Visualisation Transmission. (3DPVT'2002), Padova, Italy.
3. Cosmas, J., Itagaki, T., Green, D. *et al.* 2002. "A Novel Multimedia System for Archaeology". Proceedings of Forum International de Musees. Museum National d'Histoire Naturelle, Paris, 3rd 4th April 2002.
8. Green, D. 2002. "A Novel Stratigraphic Reconstruction System Using Theodolite Points". Interpreting Stratigraphy Conference, London, September 7<sup>th</sup>, 2002.
9. Green, D. 2002. "3D and Visualization in Archaeological Surveys". Preserving Cultures: Documenting Non Material Heritage (CIDOC 2002) Conference, Porte Alegre, Brazil, Sep 17-21 2002.
1. Green, D. 2002. "STRAT: A Novel way of temporally visualising the progression of archaeological sites". Amman Cultural Heritage 2002 Conference (CH2002), Amman, Jordan, Sep 29 – Oct 2, 2002.

## C.2 Invited Talks

Green, D. Oct 2001. "Real Time Visualisation of Stratigraphy for Archaeological Investigation". *Institute of Computer Graphics and Algorithms, Vienna University of Technology, Austria.*

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