# From Stratigraphic Unit to the mouse: a GIS based system for the excavation of historical complex. The case study of Pompeii

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*Abstract: The needs of archaeologists are the recording, the management and the elaboration of a huge quantity of data and information linked to different monuments which put us daily in front of difficult questions. The systematic proceedings of research increasis the quantity of information to be recorded and managed. The archaeologists need a quick and correct elaboration of collected data, in order to understand and analyse the investigated contexts.*

*In this framework, we developed our application, born under a MURST 1998 Project (Ministry of University and of Scientific and Technological Research). The project, started in May-June 1999 at the University "La Sapienza" of Rome, under the Scientific Direction of Prof Andrea Carandini, focused on two case studies: Pompeii and Palatino, having as its main aim the realization of a methodology and of a GIS based system for the recording and analysis of an archaeological excavation.*

*Briefly, the system consists in the elaboration of a desktop GIS based system helpful for the archaeologists during the excavation phases of recording and management and able to support SU forms with as much information as possible. It is mainly a system for the management and for the analysis of the stratigraphic sequence, both graphic and alpha-numeric. Moreover, a final 3-D visualisation of the excavation is displayed, broken down into its elements, Stratigraphic Units, in order also to link the information and the data coming out during the excavation to 3D SU. In this way, we hope to complete the usual graphical documentation (plans and prospects) with 3D display format, showing surfaces and volumes of excavated SU.*

*Key words: Stratigraphic Units, Dbase, GIS, 3D modelling, TIN.*

## Introduction

Archaeology is the study of the human past through material remains and traces. Archaeological remains range from complex urban sites and monumental architecture through individual dwellings to small "portable" objects such as broken tools. Archaeology is, by its nature, fieldwork based and interdisciplinary. Its scope ranges from the sciences of C14 dating and chemical analyses, through environmental and behavioural sciences, to historical and literary research and even art history. Along the way phenomenal, and ever increasing, quantities of data are collected. Far from being concerned with the individual spectacular object, out of its cultural and physical context, archaeologists attempt to piece together evidence and extract information from a myriad small details: the interrelationships between objects, the soil from which they were unearthed, the position of archaeological sites in the landscape and their relationship with the environment. The work is painstaking. To archaeologists with bigger datasets, computers have become essentials for their work.

Archaeology is a *spatial* discipline, and this is why today desktop mapping software is so important. On a Micro-scale, we use the distribution of artefacts in sites to understand the organisation of daily life. On a Macro-scale, the position of sites in the landscape and relative to one-another informs us about social organisation and economic strategies.

Archaeology uses stratigraphic methodologies, which allow us to manage wide and multistratified excavation areas and to reconstruct scientifically histories generated by the analysis of monumental complexes. The needs we have are the recording, the management and the elaboration of a huge quantity of data and information linked to different monuments which push us daily in front of difficult questions. The systematic proceedings of the research increases the quantity of information to be recorded and managed. Archaeologists need a quick and correct elaboration of collected data, in order to understand and analyse the investigated contexts.

Everyone who has directed or managed a large scale excavation project, knows how difficult it is to remain informed about daily progress by comparing the excavation diary and reports, plans, Stratigraphic Units (SU) cards, maps and sections, photos and electronic forms.

For decades directors of excavation projects have tried to put order in the wide data-set of different information, using database archives and CAD system.

In the last ten years, in Italy, we have witnessed the spread of GIS in order to record, manage and display interactively huge archaeological data-sets, with priority on spatial and geographical information.

Between 1985 and 2000, under the scientific direction of Prof A. Carandini, research on the northern edges of Palatino and on Pompeii Insulae VIII,2 and VII,9-11 carried out.

Using funding from the Italian government (Ministero per l'Università e la Ricerca Scientifica e Tecnologica, MURST) from 1999 we started planning for the realisation of a GIS-based system able to manage the entire archaeological data-set, making self operating information recording and elaboration, in order to facilitate the reconstruction of phase to phase image sets for historical interpretation.

## Excavation data, archives and the GIS engine

The first target of our project was to have at our disposal, at the end of each fieldwork season, all the archives updated for all the data recorded in the field (graphic and texts) from which to extract automatically thematic diachronic plans (phase plans).

Considering that usual systems of recording archaeological excavations allow the recording of information and limited graphic elaboration, and as we want to elaborate the stratigraphic sequence for separate phases creating thematic images, as the result of the combining of graphic, spatial and written information, we decided to choose to adapt the capacity of the GIS system to our needs.

The system realised is based on a simple structure, mirroring the procedure of scientific elaboration of data collected in the field (Fig. 1). Starting from this point of view an option not to be set aside is that the system realised, based on inter-exchangeable and common file formats, which allows easy exchange with colleagues, giving us a warranty of an opening for future solutions and an insurance for the data. Looking at the future, we decided to use from the beginning the *. mdb* format for data-entry, and to use Visual Basic release 6.0 for all the scripts, programming operations and also for the realisation of the database forms. It could seem too pretentious to say that almost all software houses, after a period of transition, are waiting for a more fixed and stable release of the Win '98 operating system, to make some changes in their product, at least for the script language. It is, as everyone now knows, also the case for ESRI, which in the new release of ArcView 8.1 and of ArcInfo 8.1 changed the script language from Avenue to Visual Basic, and also with OLE/COM languages.

Considering the difficulties represented by the quantity and the diversity of data, an important step was the analysis of the existing data, both on paper (SU cards) and graphic/ topographic data (plans, maps, diagrams). So we decided to integrate the paper cards of the different samples chosen, by realising a specific *thesaurus* for each category of data, in order to realise an archive, with combo-boxes checked vocabularies that will help the user which must input data and avoiding redundancy o data and lexical problems. The same kind of analysis has been developed for the graphic documentation, analysing the existing stratum plans and beginning the vector acquisition of these.

Once shared, managed and overlapped the information on the GIS base, we could observe differences and coincidences of recorded data, and so decide when, where and how to make a more accurate and detailed level of lecture and interpretation. The main function of our GIS based system will consist on the reconstruction of the existing relationship between archaeological layers and their spatial intra site distribution. In fact, the GIS as a representation of information dropped by the physical reality, must stand out for its own capacities to collect all the objects existing in the physical world, making them suitable to the mixes that really occur in the reality.

During the vector analyses the archaeological record is known to the operator since from the first phase of the project, in such a case the computing application asks, by the beginning phase, the accurate definition of an operative route able to normalize on distinctive levels the different existing information and the final goals to reach: the reconstruction of a topographic base, the overlapping of the Stratigraphic Units in a unique file, the recording of data linked then to the spatial information.

Beginning with such methodological remarks, we planned a research route marked by the following working steps :

- Coding of the information and structuring of the field excavation data by realising of one database;
- Elaboration of *thesaurus* lexicon and of scripts of control routines in order to guide the data-entry phase;
- Digitise and transformation in vector of the cadastral and/or photogrametric plans and of all the stratum plans, each with different layers and SU;
- Geo-coding and assignment of a numeric identification key to the graphic objects which define the single SU;
- Integration of graphic and numeric/textual data, with spatial and not spatial attributes, by using a vector GIS as engine;
- Realisation of a graphical user-friendly interface (GUI) able to simplify the operations of recording and visualisation of the data in the database.

So, the work has been necessarily divided in different steps; the first one is the planning of the archives, and it took away a long time for the analysis, also to evaluate the problems connected to the data coding and to define the logical and physical structure of the system (fig. 2). Considering also that information must be organised in a way to satisfy different users at different layers, it seems to us obvious to choose a relational architecture, mirroring the elaboration of more archives connected between them by a primary key, here identified with the SU numbers.

First archive contains all the data of SU, following the form of Italian Ministry of Cultural Heritage; the second one is assigned to the recording of graphic documentation (photos and drawings), by keeping always the relational link with the primary key, the SU number; the third one, contains each object found in the context and it is also linked to the primary key. In order to make easier the data-entry for the students, we realised a database system which manages in a hierarchical mode the different tables, and that using graphic user friendly interfaces (GUI), drives the user during the choice of alternative values remotely controlled between them during the programming phase (figs 3–5).

The next steps of our project were represented by the vector transformation of the 1:20 excavation plans and by the realisation of the final GIS engine.

The vector transformation of all the excavation plans was necessary to allow an exact collocation of the excavated strata and of some finds, and for the entire visualization of the existing graphic information, without compromising the overall readability of the data. So we proceed to transform in vector the different papery *overlays*, or better defined as *stratum* plans, beginning in this way the construction of the cartographic basic system, with a basic level of plans of *stratum* at 1:20 scale.

After this step, the GIS engine realisation starts, by linking together the data-entry and the graphic overlays of each SU, giving us already the possibility to extract phase plans directly by writing a simple SQL query (figs 6-7).

At this point, once having done some joining and linking operations directly in the ESRI ArcView release 3.2a GIS, we try to extract some charts and analyses on the SU data, for example, the diagram of pottery by different periods, or queries about SSUU with some special finds (figs 8-10).

### 3D SSUU modelling

Established that the GIS engine works well for the management of 2D SSUU, we decided to try to accomplish 3D models of some SSUU in room VII of "Domus della Pescatrice" in order to arrive to calculate the volume of each SU and to directly reconstruct, by the computer, the excavation phases.

Thanks to our methodological approach, that appears to be soon he right one and also thanks to the module 3D Analyst release 1.0 of the ESRI ArcView release 3.2a, it has been possible to follow the excavation phases directly on the field and than to reconstruct the excavation on a Desktop Personal Computer.

The main goal of the last fieldwork campaign in Pompeii was therefore to test a new standard of documentation, consisting in a research tool.

Hardly the traditional documentation of an archaeological excavation recorded all the three dimensions of the space, in the best cases restricted to 2,5 D! The few elevations marked on the excavation plans and sections are in fact never satisfactory, because they can not represent the precise depth of the entire SU surface. Starting from this need, we elaborated a qualified strategy for 3D fieldwork data acquisition.
We used an electronic total station and a Nikon digital photo camera for the data recording, considering that the documentation strategy included the survey of control points, of borderlines and of internal surface points and the photos of each SU.

The post-processing phase is based on two data formats: the .DXF coming out from the total station and the *.tiff* digital images.

At this point, our problem was to optimise the survey proceedings and times; we didn't need a long and complex recording methodology.

If we consider the SU volumetric value as the space between its surface and the surfaces of the SU covered by it, our system to record the complete three dimension of SU could be limited to the survey of the surface of each SU. We decided in this way to document the excavation of the room using an ETS, for the recording of the contours and of the surfaces of each SU. The SU were surveyed with an average of 100 points per square meter. Other interesting problem was the borderline: in fact, the surface of SU, which we will call *upper surfa*ce from this moment, touches the underlying SU surfaces, called *SU bottom*, in a portion of space limited to it. At this moment we realised that the orthorectification of the digital images of SU was necessary; once orthorectified, thanks to the four control points surveyed by the ETS, the photo was georeferred and linkable to the topographic data of SU, following the same co-ordinate system. We decided to use an ArcView extension, 3D Analyst, to build the TIN of upper surface and of bottom of each SU; as those TIN overlap on the borderline, we could see the SU as an unique solid. On the *upper surface* TIN we overlaid as texture the georeferred and orthorectified photo. In this way we obtained a jpeg photo, including the values of the elevations and two different TIN with inside the volumetric value.

Finally, the volumetric count was made by calculating the space between a before surface and an after surface, using the *cut fill* function of ARCVIEW, where with before surface we mean the until now called upper surface and with after surface we mean the bottom.

We must underline also that importing in a CAD the orthorectified and georeferred photo and points we could anyway produce a traditional plan, avoiding errors usual during the manual survey.

Because of the absence of findings and remains in the stratigraphic deposit, we couldn't make distribution analyses in this room; in fact surveying the location position of the remains in the SU deposit, we could easily visualise and analyse the primary contexts.

At the end, we want underline that often plans and sections are not enough to represent the precise and entire aspect of the investigated deposit, and they add only the physical bi-dimensional data of the SU to the Harris matrix and to the SU recorded cards.

We think that this recording methodology could provide the archaeologists a set of 3D data, including the advanced possibilities of volumetric counting (figs 11-14).

## Some final considerations and future approaches

In this paper we follow almost the same pattern of some our previous papers, about the Pompeii Excavation GIS, where we presented our system as a *work in progress*, with some results already obtained but capable of many implementations.

In the present paper we tried briefly to summarise some of the results:

- The GIS database engine provides a solid archive for the thousands of US cards and the other papery documentation.
- Once in the database, it is easy to query (and to obtain answers if the queries are appropriate) this previously not nimble Leviathan.
- The digitising and geo-coding of the numerous overlays is not only a good procedure of archiving but allows the user to better visualise the relationships between the surveyed structures.
- From its beginning (i.e. without any GIS based operation but simply after the data entry of US cards) the system can fill automatically the Ministerial form for US documentation.
- After a simple query the system can provide the user with phase or period maps.
- 3D reconstructed SU with draped images give the possibility to calculate volumetric values and to visualise in a more realistic way the aspect of the excavated (i.e. destroyed) deposit.
- Even if still *in progress* our GIS already allows simple and crossed SQL queries both from the tables of the database and from the graphic representations of the structures.

But we would like to illustrate briefly the main implementations we are working for:

1. We want to extend the 3D modelling to the walls and mainly to the study of the structures, as for the reconstructed SU, making possible queries directly from the graphic interface of our GIS.
2. We are trying to realise automatically the Harris Matrix and to keep it visible and editable directly from the GIS engine.

The problems to solve for those two points are still many, even though we have already reached some good results from the research point of view.

## 3D managing of the Wall Stratigraphic Units[1]

Due to the scarcity of resources available this year for the entire project, we can here present only the preliminary stages of our work that, in our intentions, will push the quality of USM data managing at the same level reached for SU.

It is important here to remember that our GIS is entirely developed in ESRI ArcView[2] because we think that the winning choice for this kind of systems could be the complete intercommunication between each module[3]; that being stated 3 D Analyst 1.0 extension is, at the moment, the only available option.

If one thinks of this system as a two-faced Janus, where each object is at the same time a database record and a graphic entity, one can easily understand that the major problems come from the graphic aspect.

The planning and creation of the new database for Wall SU data-entry was made easier by the experiences gained with the previous SU one.

This doesn't mean that we duplicate the database we already have and use it for Wall SU but that now we know exactly how to plot the diagram of the relations between the tables, how to prepare the appropriate user-friendly layouts, how to control input data errors, just because we made some errors and wasted time creating the SU data-entry!

At the beginning, we hoped the same for the graphic aspect : *utinam id sit, quod spero* ! (Terentius).

But we realised immediately that ArcView 3D Analyst 1.0 doesn't allow in any *x-z* or *y-z* plane the same data processing it uses for *x-y* plane.

In fact, TINs creating method builds up a surface joining each point with the ones contiguous: stricter is the net of points, more accurate is the surface obtained.

The other factor involved in TINs creating is the *boundary*, a line that circumscribes the area where the new surface will be created. In the case of SU, the boundary lays in the x-y plane and the software have no problems in TINs creating; but working with Wall SU, the points and the boundary of the surface belong to a *x-z / y-z* plane polygon.

3D Analyst manages that data as if they lays in the *x-y* plane; it seems to us that the software processes only surface points with x and y coordinates that fall inside the boundary line projection on the *x-y* plane.

In fact, in our tests, we can see that there are some points involved in the process of TIN creating and others (often close to the former ones) totally ignored.

It seems at the same time that even the neighbourhood between surface points is calculated in the *x-y* plane (i.e. ignoring the elevation of each point) so that often the triangles of the surface are created from points that in reality are not so close! (figs 15-17)

Now it's important to keep in mind what we want from our system: we don't want to bring out one of the thousands of *3D Virtual Trip of Pompeii* and we don't want to digitally rebuild our *domus* case study; we just want to manage the huge mass of data coming from the excavation and gain new knowledge analysing them.
This is not a secondary aspect: if we already have Wall SU data from the database and, at the moment[4], our GIS software architecture doesn't allow a photo realistic 3D reconstruction of the walls, we can consider satisfied with the simple Wall SU

extrusion.

This solution was tested and provides a valid graphic interface for Wall SU database in the GIS 3D scene.

With the extrusion of our bi-dimensional plan of Room VII we were able to extend our GIS analyses to the structures in elevation, making queries directly on 3D structures as on the 2D views. Anyway, we must recognise that in our case of study, the stratigraphic sequence of the walls is quite easy, with each Wall SU one beside the others, and that in case of a more complex sequence (with Wall SU one above the other) could be hardly visualised by a simple extrusion process (fig. 18).

## The Harris Matrix

As usually said, the work of the archaeologist seems to be quite a strange activity; in fact, during a first step of his work on field he must excavate and so to remove the stratigraphy, that, in a second phase of his work he will be obliged to rebuild during the elaboration and the interpretation of data. Such a model has a its own graphic representation, the so called " Harris Matrix" or also the "stratigraphic diagram". It is necessary to resume all the existing relations, that in case of monumental complexes excavations can be also thousands, between the SU or the Actions in them identified. The layers are the most little unit of an archaeological identification and they have besides their spatial dimensions also a time (chronological) dimension. As a result Harris developed the so called " Harris Matrix" able to describe and to represent graphically the time relationships between different layers. We could imagine that the layers in a Harris Matrix are presented as a rectangle containing the layer name (or number). The relations draft as lines and the position of linked rectangles describe the type of relation. Such a graphic representation corresponds well to the common image of archaeological excavations, where it is usually expected that the most recent layer is above to the oldest one. As there are several exceptions, the relations must always be confirmed by some other observations.

From the mathematic point of view, the relation " After than" could be defined as a set partially ordered. So, we could easily define some additional rules for the relations: Relations are thoughtless, asymmetric, transitive and anti-cyclic.

For the relation "Contemporaneous to" we have different rules: These relations are reflexives, symmetric, transitive, and they are called "relations of equivalence".

We don't want here to resume the concepts of Harris Matrix but just we would like to underline that anyone which could realise a software or an application for the matrix diagram must be very careful to observe these basic rules. In order to increase the readability of the Harris matrix it will be useful to clean it from all the so called "redundant relationships". These are relations already formed by other relations.
The stratigraphic diagrams or matrix allow therefore to represent in a very schematic way on a bi-dimensional plain the 3D reality of the stratification of an archaeological deposit, and the single SU will contribute to define the phases of an historical period.

Keeping in mind all these rules and laws, we are trying from this year to realise an application able to reproduce directly on computer the Harris matrix; as all our programming language of our database is entirely made in Visual Basic release 6.0, we prefer to continue to use it also for the reproduction of SU diagram. We decided to realise an OCX applet, able to be connected directly to different database formats, i.e. dbf, mdb, etc., and that mainly will be able to read directly the data from the interesting fields and to reproduce the diagram.

Until now we have developed the OCX applet that works well for the main stratigraphic rules; we are now working in order to update and to extend the package, making possible automatically the calculation of all the redundancies (fig. 19).
Moreover, as already told before in the text, with the new version of ArcView release 8.1, we would like to make a porting of all the programming scripts made in Visual Basic directly in the GIS system, and to allow the user to have also the possibility to open the matrix during the vie of the excavation and to edit it directly by inside the system. It is hard work but we can say that is more and more possible, especially by the fact that with new Geodatabase structure of Arc View, we could establish some fixed relationships between graphical objects, in our case the SU.

Anyway, we hope to finish this application for the next CAA 2002 in order to present the full operative system applied also on other excavations ( i.e. a protohistoric site).

## Conclusion

At the beginning of the III millennium we can say that the Information Technologies are inside all the aspects of our work. The need to show to the others and to check ourselves directly in field the data and the information collected during an excavation is nowadays possible, thanks to the IT. Archaeologists are using the modern computer systems in the field since from the beginning of 1980, receiving a grateful help for the management and the recording of the information. Since from the '90s the diffusion on wide scale of the GIS systems give the possibility to manage not only the textual information but also the graphic aspects of it, linked directly each others and mainly to push the intra-site analyses during the same excavation phases.

The use of GIS for excavation is today a reality, also because the specialization of some archaeologists in GIS use is increasing.

Starting from this consideration we can affirm that during the realization of an excavation GIS is better to think to the archaeologist's questions than to the problems of IT experts, making to himself the most usual questions : *What is an excavation GIS for? How will it be made? Which benefits could I get from it? Could it be a tool used for analytical queries and for the making of historical and interpretative models?*

When we started, our main aim was to create a system useful for the management and for the analysis of the excavation archaeological record; after two years, we could say that not only have we accomplished the system but also that today at the University Laboratory there is a team able to manage computers and to use it for its own needs.

Our work is based on three main and important assumptions :

- The computer is only a tool in the hands of the archaeologist;
- We don't have to approach the computer assisted systems with fear of them;
- We must be able to programming scripts, in order to create specific applications.

Our final system is not the ultimate one, but at the beginning of the new millennium we must consider that the winning philosophy of computer systems is represented by personalised solutions. We can say that our system is functional and useful for the management of different excavations, even if it would be not the absolute one.

The real problem today in Italian Universities is to decide what could be the computer knowledge degree of archaeologists. Archaeologists must know directly the recording and management processes; the computers used today give us the possibility to do it. However, it requires the diffusion in the Italian University Departments of basic computer know-how and the realisation of a theoretical and practical school. Archaeology could not survive without the use of computers, but would risk being kept out of new communication systems, which always demand complete and transparent documentation, high and fast transfer protocols, and different reading keys.

The specialists and also common people must have the possibility to access to publication and visualisation of the researches to which they are interested. If we are not able to adapt ourselves to modern communication systems and to transfer our data to different subjects, we will be out of the game and we will work only for ourselves. Archaeology is perfect for digital technology; it finds in this branch several spectacular applications, which will help us to follow modern dynamics and language based essentially on the images. The problem of image language is to keep the distance between "*false true*" and "*true false*". No reconstruction will give us the exact image of the past. This gap between virtual reality and hypotheses on the past is a constant in a inexact science as archaeology, with which the researchers use to play. The final image must increase the value of the scientific reflection and it must exist as a step of the archaeological research process.

IT therefore represents one of the new tools for archaeology and it must be used, as such, with care and attention, exactly as the trowel.

The ambitious purpose of this project, if such exists, is not to open new frontiers for the recording and the management of archaeological record, but to suggest some guidelines and methodological approaches to the excavation data management. At the end, we hope that the development and future extensions of this system could be a suggest for the institutions to begin to consider seriously those new and powerful tools for the archaeological research and for didactical purposes.


## Acknowledgements

Special thanks to Prof P. Carafa for the Scientific coordination of the project. The authors would like to thanks all the students who participated to the data-entry and to the vector transformation of the SU plans.


## End notes

[1] In Italy abbreviated as USM (Unità Stratigrafica Muraria, i.e. Wall Stratigraphical Unit).

[2] We developed the database with MS Access and Visual Basic and we digitised the overlays with AutoCAD R. 14 in order to provide the system with tabular and graphical data but, once created the system, we tried to exploit ArcView resources as, for example, the 3D UUSS reconstruction realised in ArcView 3D Analyst.

[3] The latest release of ESRI ArcView 8.1 seems to confirm this philosophy with implemented graphic and database (geodatabase) capabilities and the choice of Visual Basic instead of Avenue as internal programming language.

[4] We are waiting for the new 3 D extension of ESRI ArcGIS 8.1 that has been distributed in Europe only since last month.

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## Figures

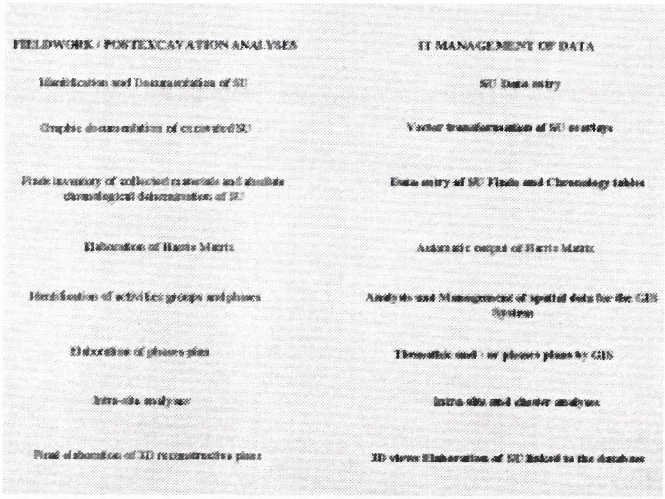

*Figure 1. Fieldwork vs IT proceedings*

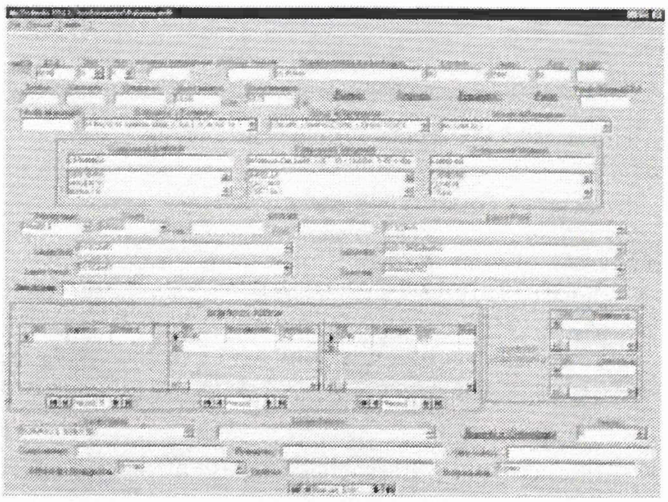

*Figure 4. SU data-entry form*

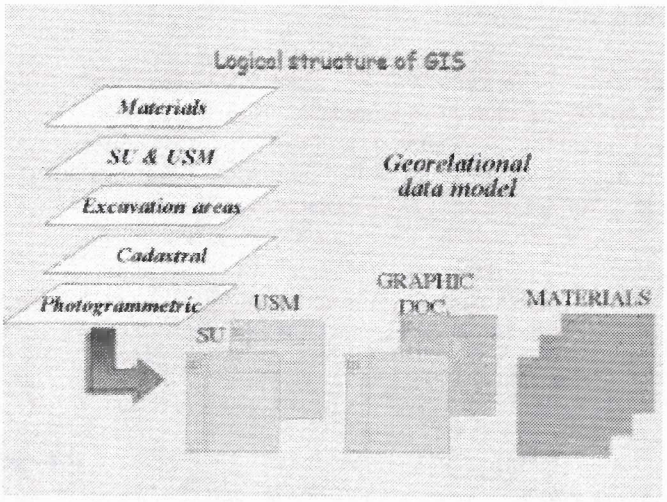


*Figure 2. Logical structure of the realised GIS engine*

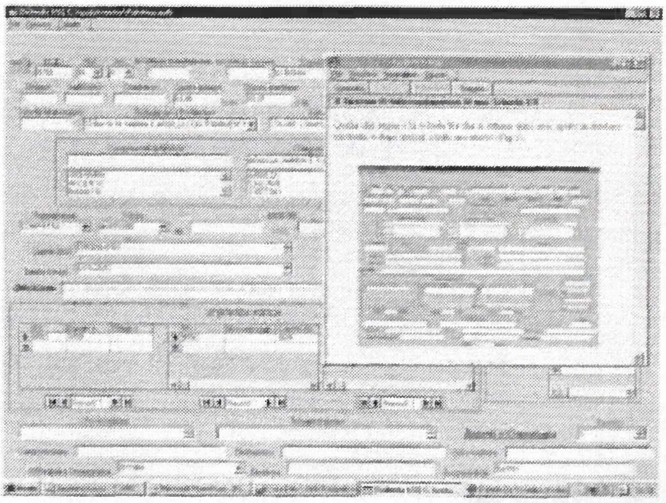

*Figure 5. Help online for the dataentry system*

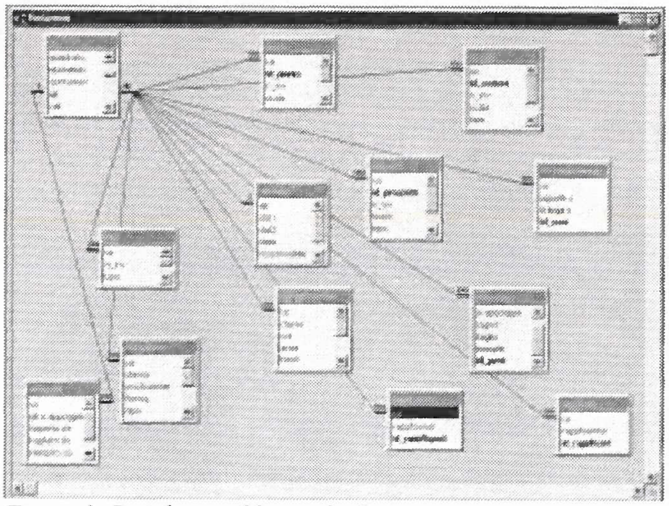

*Figure 3. Database tables and relation*

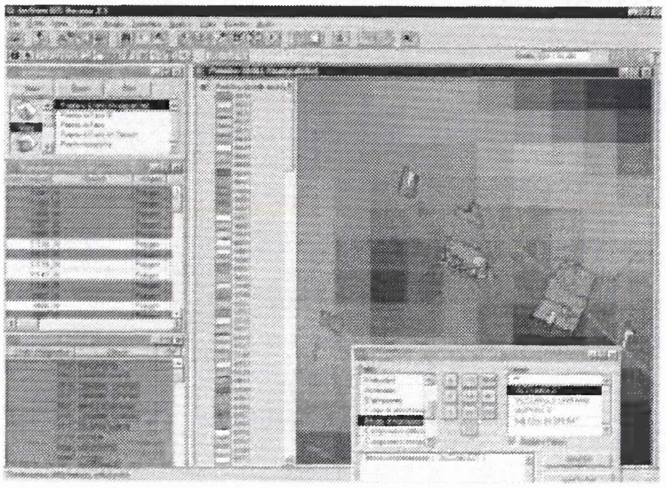

*Figure 6. SQL query on formation mode of SU*

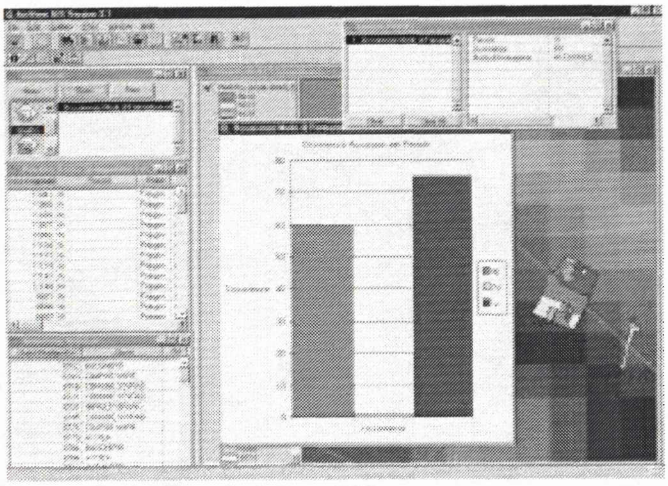

*Figure 7. Graphic chart from SQL query*

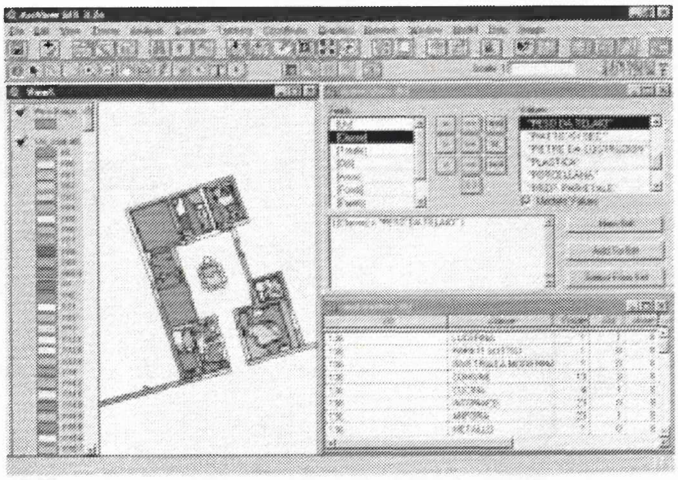

*Figure 10. SQL query for the handloom weights distribution*

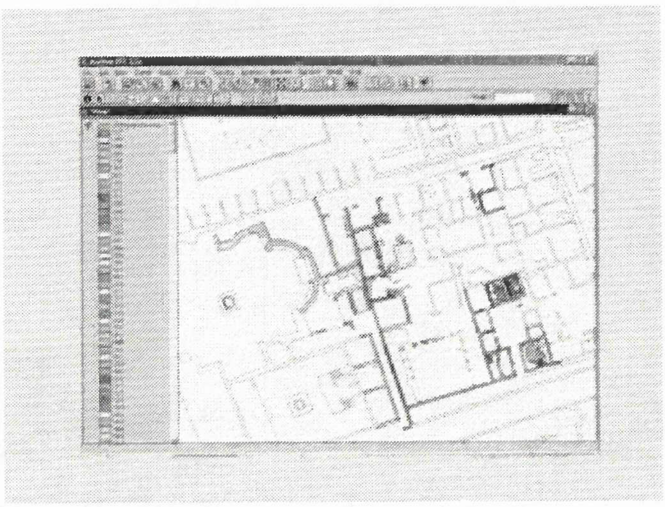

*Figure 8. SU view of Pompei insula with excavated SU*

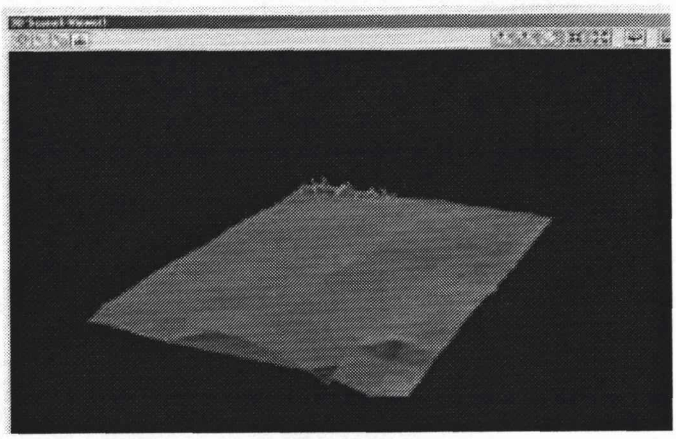

*Figure 11. Surveyed points and computed TIN*

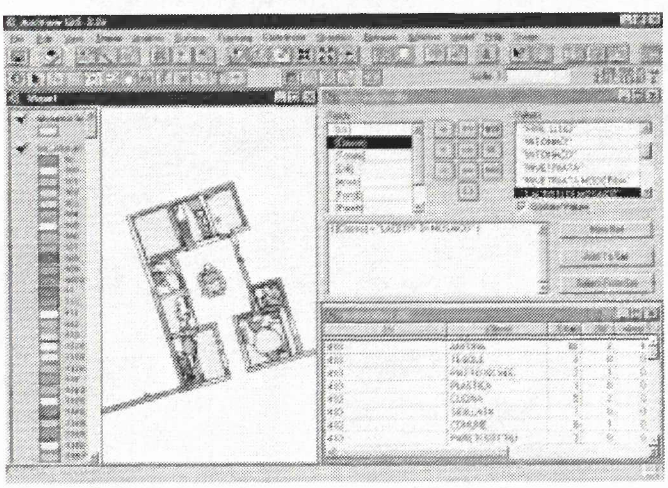

*Figure 9. SQL query for mosaic tassel dispersion*

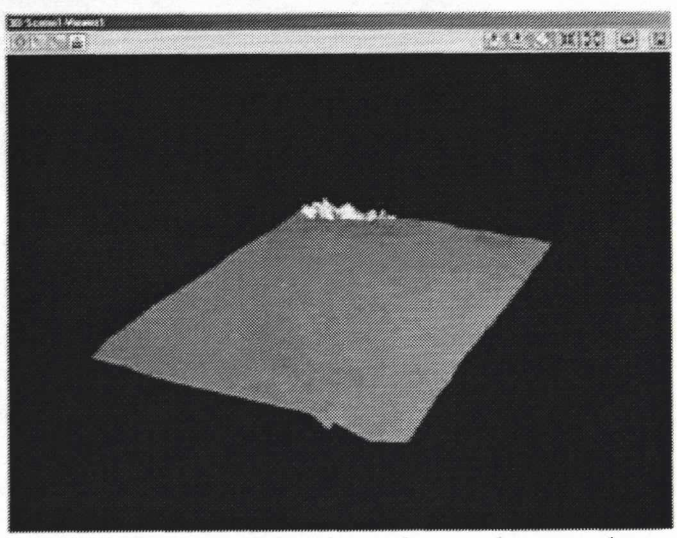

*Figure 12. SU TIN based models with merged texture photos*

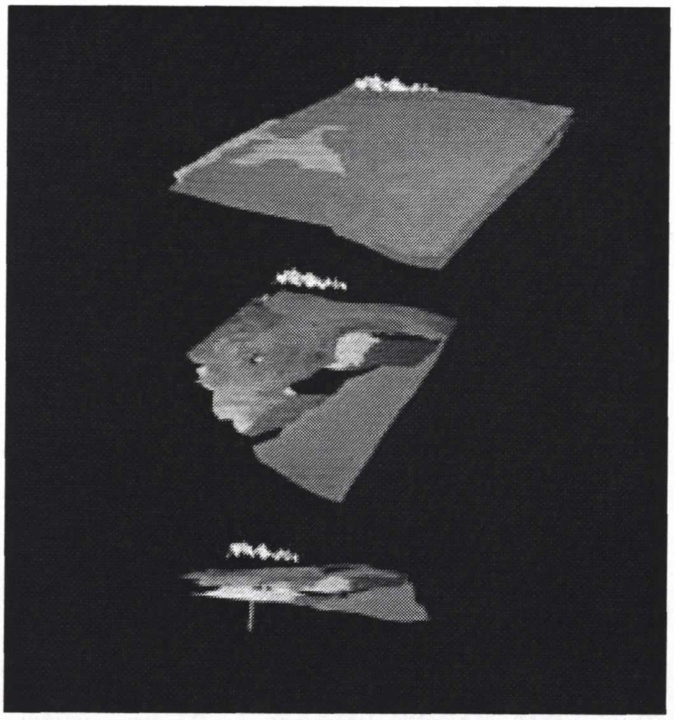

*Figure 13. 3D View of archaeological deposit extruded*

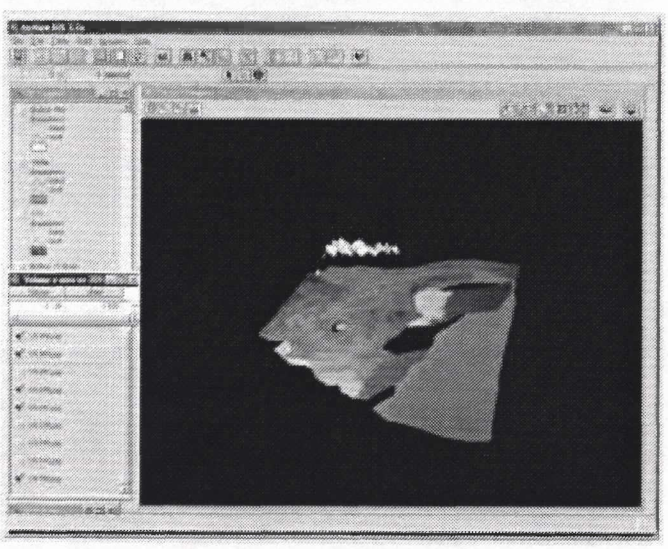

*Figure 14. SU volumes count*

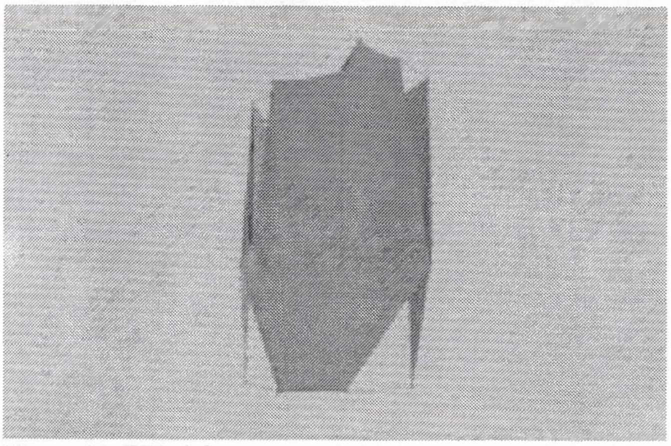

*Figure 15. TIN elaboration with SU boundary points*

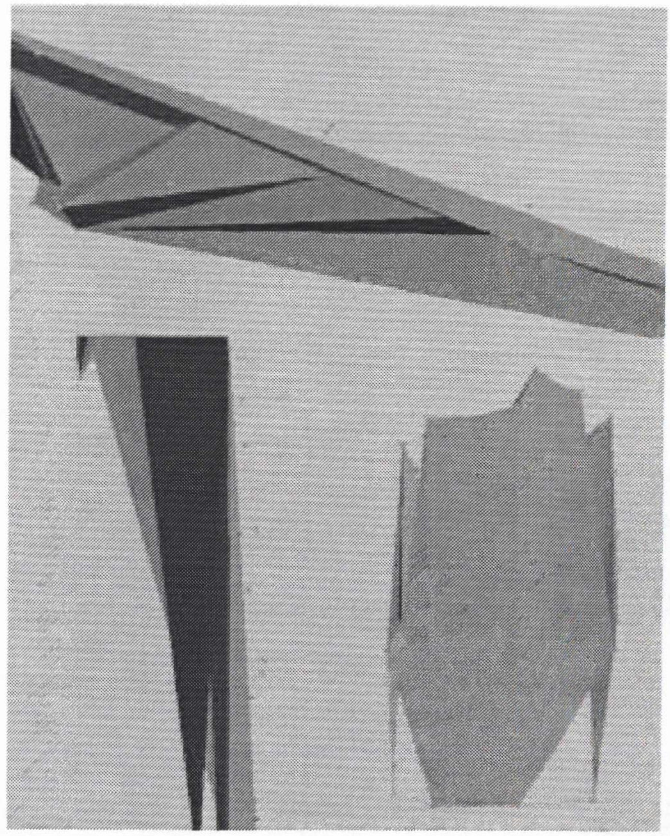

*Figure 16. TIN of SU boundary points showing points remaining outside of it*

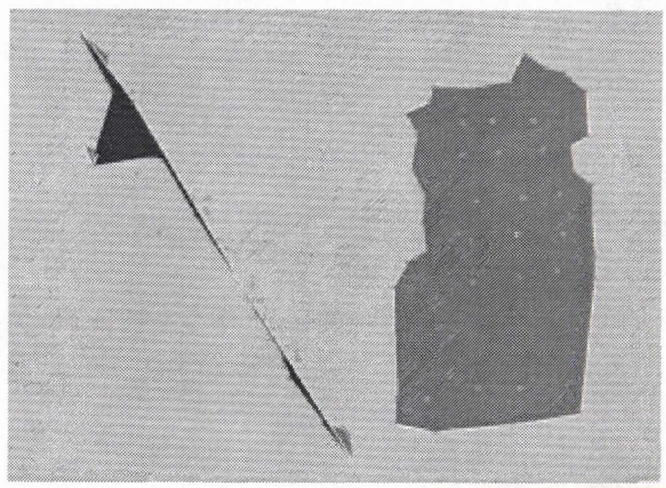

*Figure 17. TIN processed as a polygon*

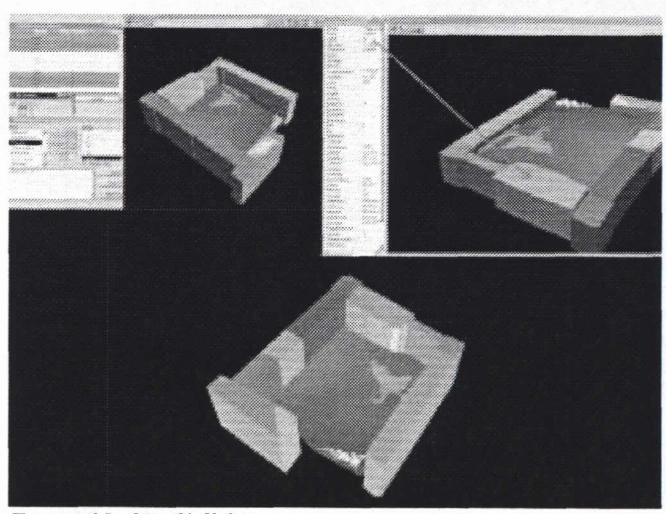

*Figure 18. 3D Wall SU reconstruction and queries*

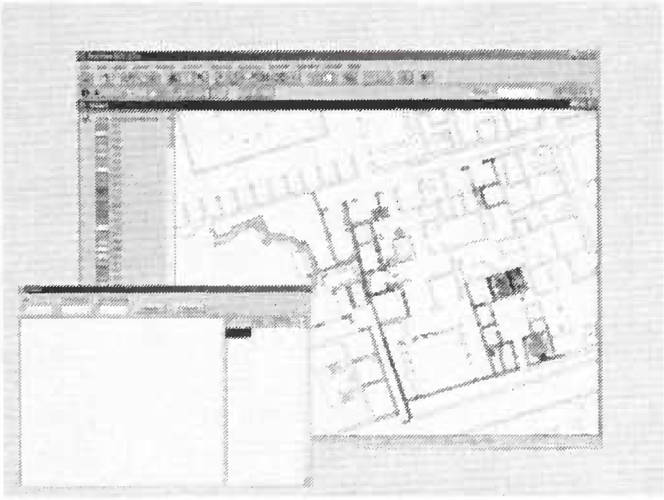

*Figure 19. View of the Matrix OCX applet*