Computer applications for a reconstruction of archaeological stratigraphy as a predictive model in urban and territorial contexts

M. Cattani, A. Fiorini, B. Rondelli
Department of Archaeology, University of Bologna

The developments of new software suggest new trends in computer applications supporting the organization of the archaeological record. Archaeological stratigraphy is one of the best frames for the knowledge of the past and many attempts have been made to control each value recognized on the field (excavations, geognostic research) both in urban sites and in the landscape.

With the help of software used in geology it is possible now to relate stratigraphical data to build predictive maps for the management and preservation of archaeological heritage. Other software used for a three-dimensional visualization can add information of architectural elements to integrate the reconstruction of stratigraphy. With the support of GIS and statistical software we can complete the path toward the analysis of archaeological content.

This paper is based on three main assumptions:

1) The archaeological deposit is a complex stratigraphy with layers, features and interfaces that have surfaces and volumes information. Main deal and duty of each archaeologist is to find, describe and record in the best way each of this information (fig. 1).

Figure 1. Montale (MO, Italy). Stratigraphic section of Bronze Age settlement

2) To proceed in this direction it has been more and more evident that the 3d data are significant and can add results in the interpretive step. It is necessary therefore to support stratigraphic documentation with three dimensional single information (survey points) and drawings or CAD interpolations (DEM, DTM, solids)

3) GIS is the best tool for archaeological data management, especially if supported by techniques of survey (Total Station or 3d laser scanner) and digital image photomosaics (fig. 2).
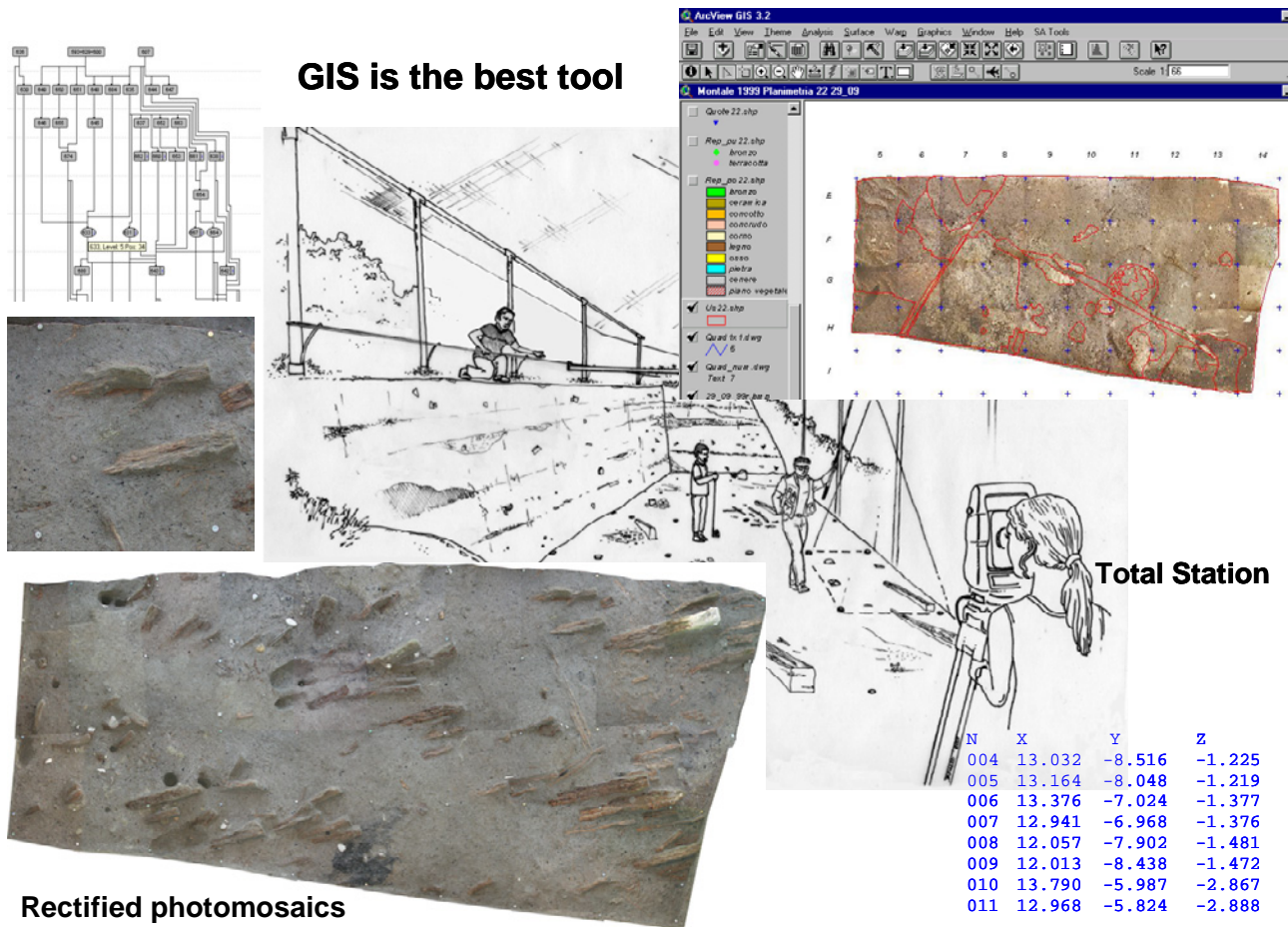

Figure 2. Montale (MO, Italy) Geographic information system applied to excavated site.

The following step of this paper is to present the results of different trial methods and techniques able to acquire a specific documentation of archaeological deposit in order to reproduce in any moment the original stratigraphy destroyed by the excavation. This procedure, far from a simple virtual didactic reconstruction, is intended as a reasoning tool useful to understand what information we need for a more sophisticated stratigraphic analysis. In this condition we need to be aware of our scientific limits and to present interpretive or predictive models about all the elements that took part to the formation or transformation of the archaeological deposit.

Attempts of reconstruction of archaeological stratigraphy become fundamental for predictive model in urban and territorial contexts, where they are used for town-planning development (fig. 3), scientific research and archaeological evaluation (Berger and Verhagen 2001). At the base of these predictive models is the quality of each information and the capability in managing and interrelating different types of data (Cardarelli et al. 2001). Since each value and description of 3d graphic entity is not sufficient for a proper evaluation of archaeological

record it is necessary to obtain and build 3d features inside a more sophisticated system. To control spatial and volumetric information is the best solution for a true management of stratigraphy.
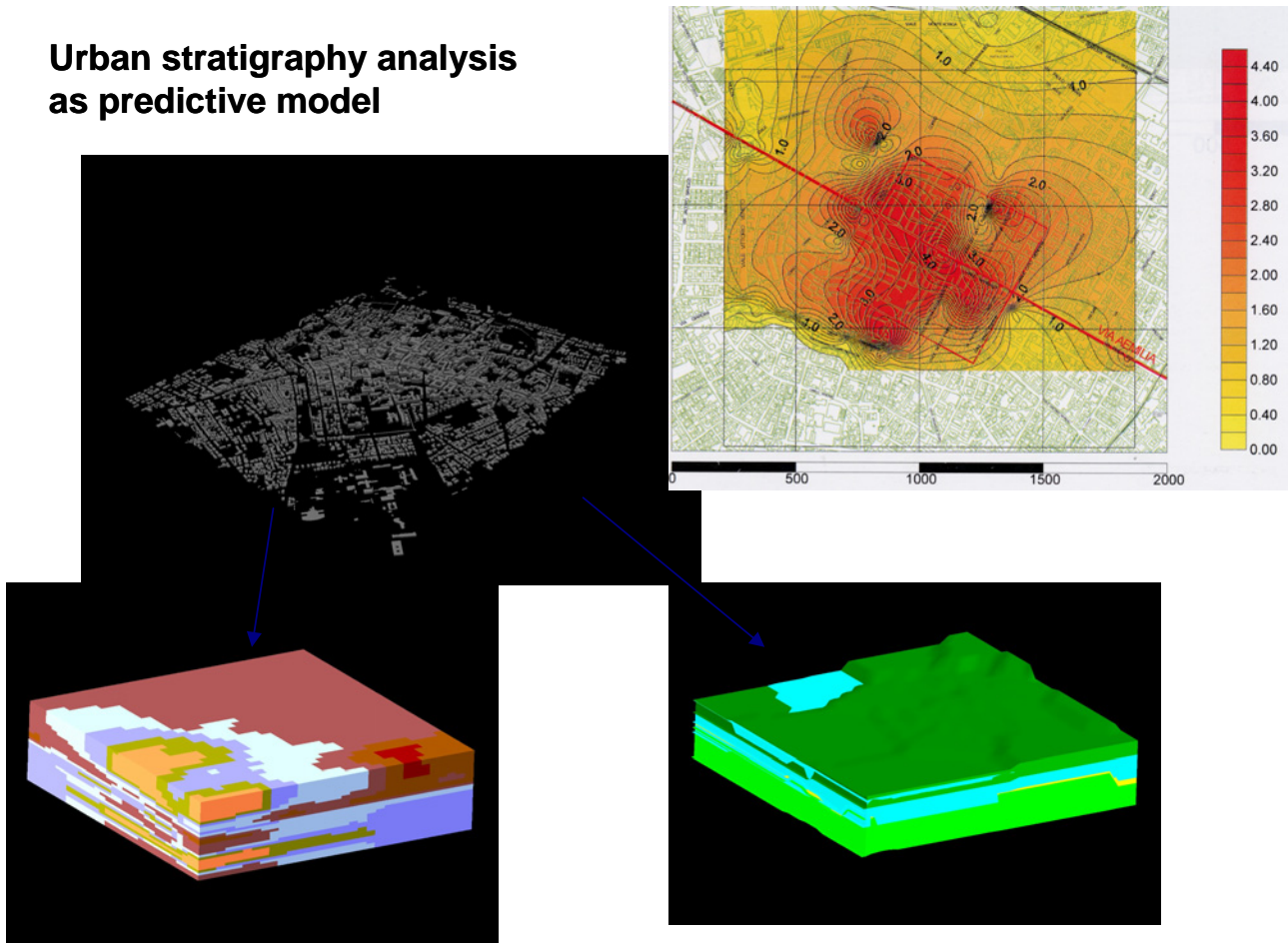
Urban stratigraphy analysis as predictive model

Figure 3. Examples of urban stratigraphy analysis for predictive models: Ravenna (left) and Modena (right).

When we apply models to analyse stratigraphy we need accurateness of field information, facility in 3d data management, capability of 3d analysis through the use of a Geographic Information System that allow us to link and join several kinds of data.

Since the data management of excavations or archaeological maps has been well experienced with ArcView and now with ArcGIS (Esri), we try to test the software respecting fixed requirements. We are aware yet that ArcGIS software does not allow to model correctly 3d volumes and it is not a complete 3d analyst tool:

1) A TIN is an object to represent a surface with a set of contiguous non-overlapping triangles (ArcGIS 3D Analyst 2002). It means the interpolation methods manage only a bi-dimensional plan.[1]

2) ArcGIS software does not include as entity the *solid*; therefore it does not include analyst tools for solids.

Waiting for an upgrading of software in this direction we propose some examples to stress 3d data management and relative problems applied to the excavation context. The data used for

this application belong to an excavated site of Bronze Age (Montale, MO), where the whole documentation has been recorded since 1996 within a GIS through digital equipment supported by Electronic Total Station and a digital camera with zenithal photographs[2] (Candelato et al. 2001). A latter example regards an architectural feature to emphasize problems with 3d management. It has been chosen a part of a ruined wall from Middle Age context.

For each of these archaeological contexts we tested two different ways to manage 3d data surveyed with the Total Station: a voxel modelling and a vector modelling (fig. 4).

Voxel modelling: © RockWare, Inc.- RockWorks 2002
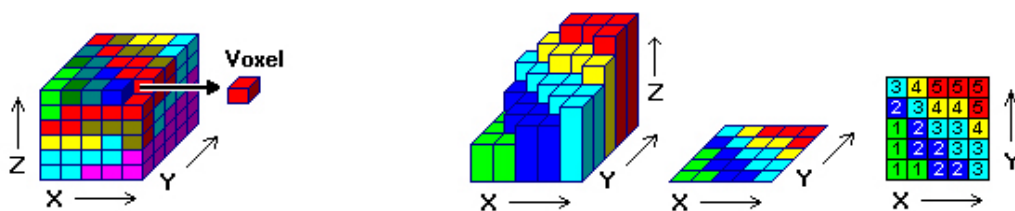
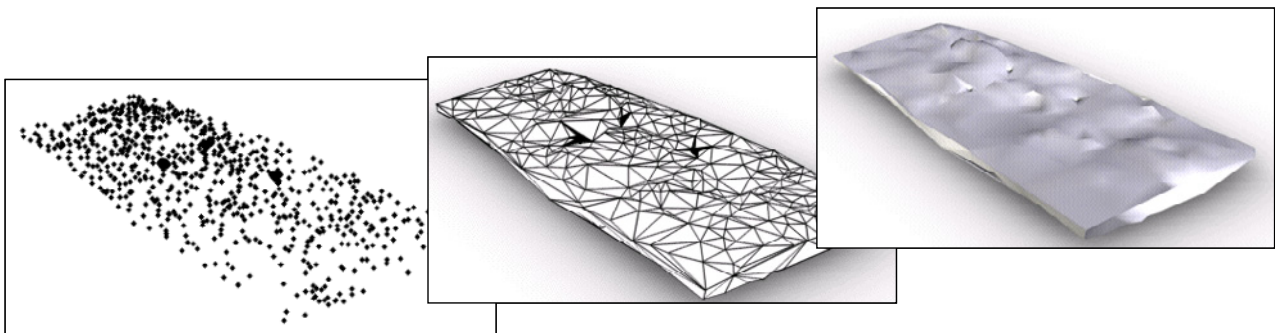# Vector modelling: SDRC ® Surfacer

Figure 4: Softwares for voxel or vector modelling

First evidence to stress regards the acquisition of data. For a reconstruction of any stratigraphic layer we tried to respect the following requirements:

- To get available a high amount of surveyed points (usually from 500 up to 3,500 points in 40 m square).
- To respect a regularity in data acquisition for flat surfaces and more density in morphological variability.
- To avoid excessive loss of time and resources on the field research (experimentation is often tolerated but not always accepted).
- To repeat the same methodology for all the recognized stratigraphic units.

To satisfy these requirements it was applied systematically a Total Station with a strong use. The future will stand in a 3d laser scanner, but since the high price of available sets, we are far

from a their regular use on the field, especially if applied to all the excavations usually open at the same time. The Department of Archaeology is involved contemporaneously at least from five to ten excavation field projects and it can dispose of seven Total Station. It is too early to think about the use on the field for same amount of laser scanner. Besides we still have no idea about a fast and coherent arrangement of data coming from a laser scanner survey.

One result is to determine the regularity of data acquisition and control the media of distance between the needed points. The results here presented regard only some of the best-surveyed layers recognized in the excavation, but they have been sufficient for an analysis and discussion toward a three-dimensional reconstruction (fig. 5).
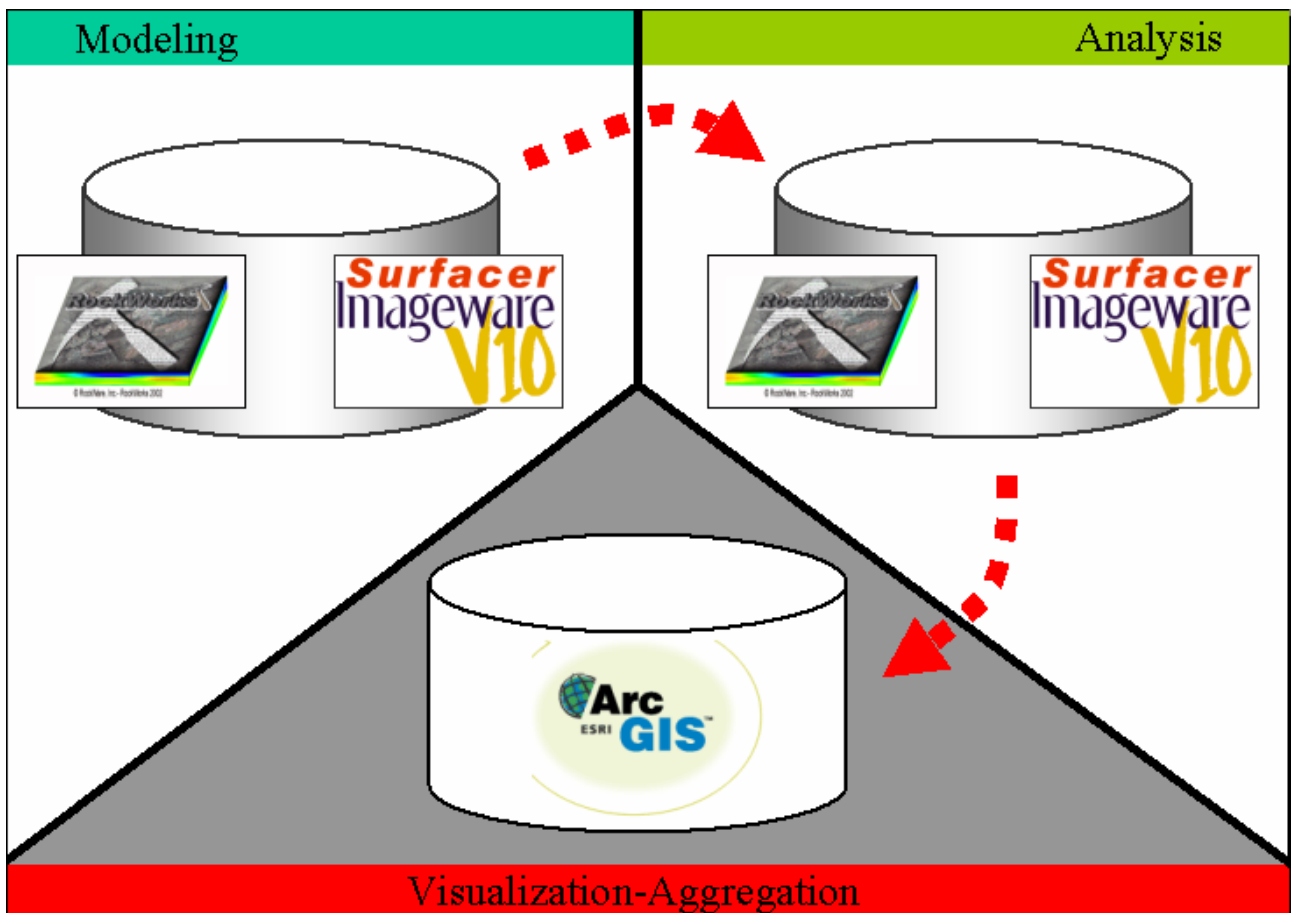

Figure 5: System architecture

The first attempt concerns the *voxel modelling*. Creation of raster structure through algebraic and geostatistical algorithms is widely used solution to discrete the real world, including both digital image representation and numerical values modelling. The advantage of raster matrix lies in the easier use of filters or Boolean operators applied to single pixel or groups of pixels through sophisticated image processing or modelling. With voxel dimension (a cube pixel with three dimension) the filter capability support volumetric and informative added value (usually colour).

Voxel methodology has been largely applied on Physics, Tomography and Geology. In this last environment several software have been developed for the management of stratigraphic boreholes and slices and for these software we tried to find a similar application in the archaeological context.

In particular we have tested RockWorks2002 (© RockWare, Inc.), largely used software for geological applications. With Rockworks we can visualize and manage data from boreholes to obtain stratigraphic sections, profiles, models and interpolated reconstruction combining stratigraphic points with litologies. It allows to build solid models made by voxel starting from points with x, y, z values, characterized by an added numeric value qualifying properties of volumes (colour, type or US number) (fig. 6).

Figure 6. List of surveyed points with x, y, z coordinates and US value

Good examples have been tested for geophysics or geochemistry models, where the use of filters of image processing allows producing sophisticated analysis and variations. Barcelo showed in a paper in the previous meeting of CAA 2002 an example of application in archaeological context (site of Shamakush VIII, Argentina) (Barcelo 2003). The modellization proposed is based on the interpolation of overlapping points with different z value belonging to different layers, following the method largely applied in Rockworks of boreholes. From these points they have obtained interpolated surfaces (GRID Upper and Down) closed by each side.

This method is strongly limited by the choice of fixed surveyed points, in contrast with the complexity of the archaeological stratigraphy and it appears not to exploit the full capability of the software with the interpolation of voxel solids.

Rockworks is based on a main difference between stratigraphy model and solid model: it can obtain thickness geometry model from boreholes, but also it can build solids from whole excavated deposit. We applied the use of filtering Two Bounding Grids to obtain a model shaped by two surfaces Upper and Lower. Rockworks import the text files with coordinates from a Total Station survey and it has two possibilities to create a TIN or a GRID with points related to the top surface of a solid, filtered by the polygon that is defining the limits of the stratigraphic unit. The same can be done with the lower surface (fig. 7).
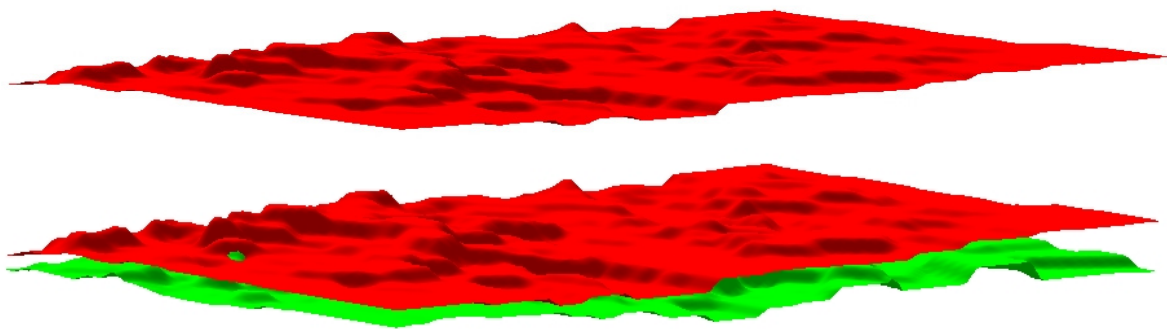

Figure 7: Modelling of upper surface and lower surface

If we use the datasheet with all the surveyed points characterized by US number as Grade value Rockworks creates a solid model of each stratigraphic unit with t*he Closest Point option, under the Create New Solid Model / Algorithm settings.* This is the most basic solid modelling method, in which the value of a voxel node is set to be equal to the value of the nearest data point, regardless of its distance from the point or the value of its other neighbours. Between the advantages we recognised that the model's value range will be equal to the data point range, with maximum and minimum model node and data point values corresponding exactly. Solid model nodes will honour the control points. This method is useful when generating models in which the values are not gradational. Between the disadvantages, this algorithm produces a grid model with abrupt changes between grid nodes. For us it was not successful because of the poor quantity of coordinates.

Figure 8: Single solid model (single stratigraphic unit)

In our test we tried to use two different voxel modellization of the same set of selected points:

- a unique model with joined together all the information of several layers (fig. 8)
- a single model for each layer (fig. 9)

The total voxel model is a result of interpolation of all the points in tabular shape with coordinates x, y, z and a numeric value (*value G*) added for the identification of stratigraphic unit (US). To avoid interpolation faults created inevitably by the algorithm, it is necessary to create an offset at the limit of each US. For all the points that belong to the bottom surface or to the side surface have been reduplicated to a specific distance (1 cm) and ascribed to the neighbouring US.
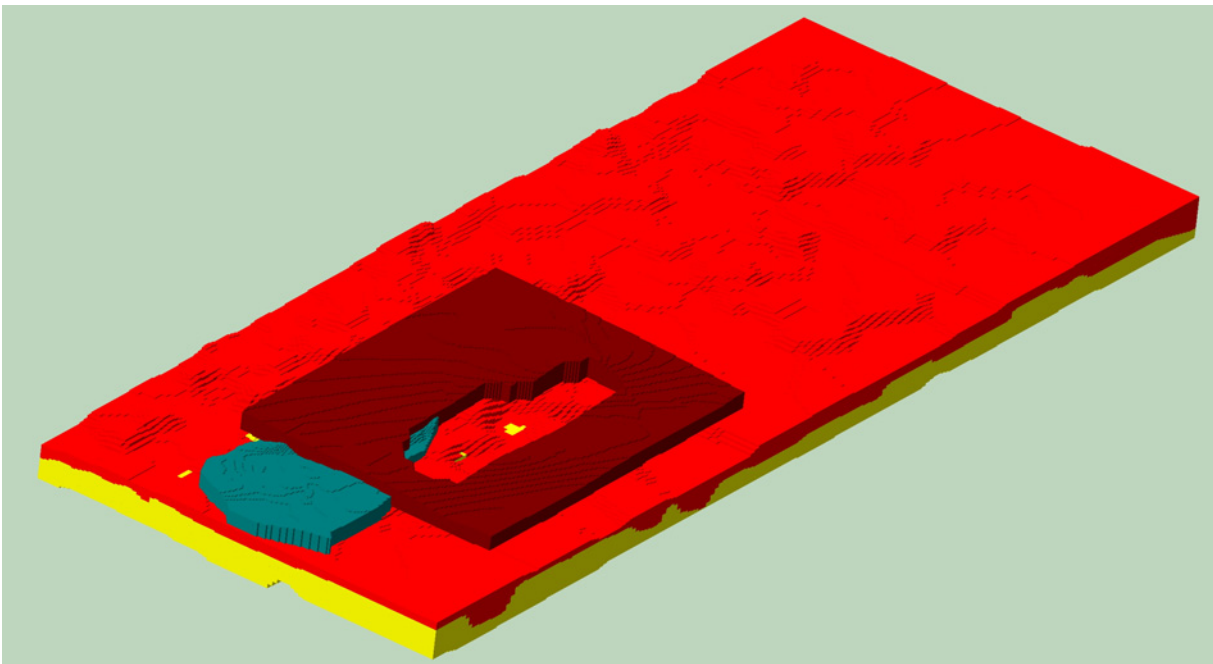
Figure 9: Multiple solid models (several stratigraphic units)

In this type of modellization we can obtain a good result through the algorithm "*Closest Point*" (largely used in raster 3D model) or through the algorithm *Inverse Distance Anisotropic*. For the top surface or the side surface we can apply filters for polygons or surfaces that allow isolating and removing from the "camera-voxel" the "air" parts, particularly important to obtain a good result in the voxel modellization (Nigro et al. 2002). This first type of modellization offers the advantage of a total model, that is possible to filter (by selection) or to analyse in a cumulative system obtaining slices, profiles in every direction beside the capability to select or exclude desired stratigraphic units.

The modellization through voxel does not solve some problems: if the number of points is limited there are serious errors of interpolation, especially if we want to build a cumulative solid model; the resolution of models and management of models depend strongly from hardware and graphic cards. Nevertheless the wide aptitude of this model type is limited by the high amount of memory required, necessary to maintain the high resolution. The number of nodes of the volume determines Voxel resolution. Quite as larger is the volume of the stratigraphic units as higher will be the needed resolution in order to maintain the reliability in

the stratigraphical analysis. The high resolution will imply long time for the computation and regeneration of the model. With an ordinary personal computer it has not been possible to exceed the voxel resolution of 5 cm. This measure is anyway lower or equal to the density of points surveyed by the Total Station.

The second type of modellization has been applied especially to overcome these problems. For each US it has been created a model filtering the top and bottom surface (UPPER and DOWN GRID FILTER) through the algorithm Kriging. With this system it has been possible to achieve the resolution of 1 cm. The entire visualization of all the stratigraphic units is possible with the command APPEND.

Once created the solid we can proceed to realize profiles, slices, regularly spaced sections, isolate volumes and layers, apply filters or Boolean operations, density analysis satisfying a large part of the requirements of the archaeological research and enhancing the three dimensional informative capability. More relevant and useful for the archaeological analysis is the peculiarity of voxel model to create three-dimensional density buffers. Rockworks allows to visualize colour-scaled three-dimensional volumes pertinent to single points. We tested this procedure to the distribution of metallurgical slag found in the excavation and recorded with each coordinate. This visualization is largely more representative and explicative respect to the traditional two-dimensional density analysis.

At the end of the voxel modellization we can affirm that it represent a powerful tool for a three dimensional analysis of stratigraphy. The reliability is based to the high number of surveyed points and this is contrary to the disadvantage of the already mentioned high cost computation (Nigro et al. 2002). Moreover important and meaningful are the export possibilities of Rockworks2002 both compatible with CAD and GIS software: fences, vertical or horizontal slices can be exported raster to vector as two-dimensional GRID (x,y; x,z; y,z), sections and profiles as dxf or shapefile, besides to format Voxel Analyst for Intergraph. The export of voxel models in shapefile format still needs an intermediate step that transforms the model as isosurfaces. Then we can import in ArcGIS models of isosurfaces (fig. 10).
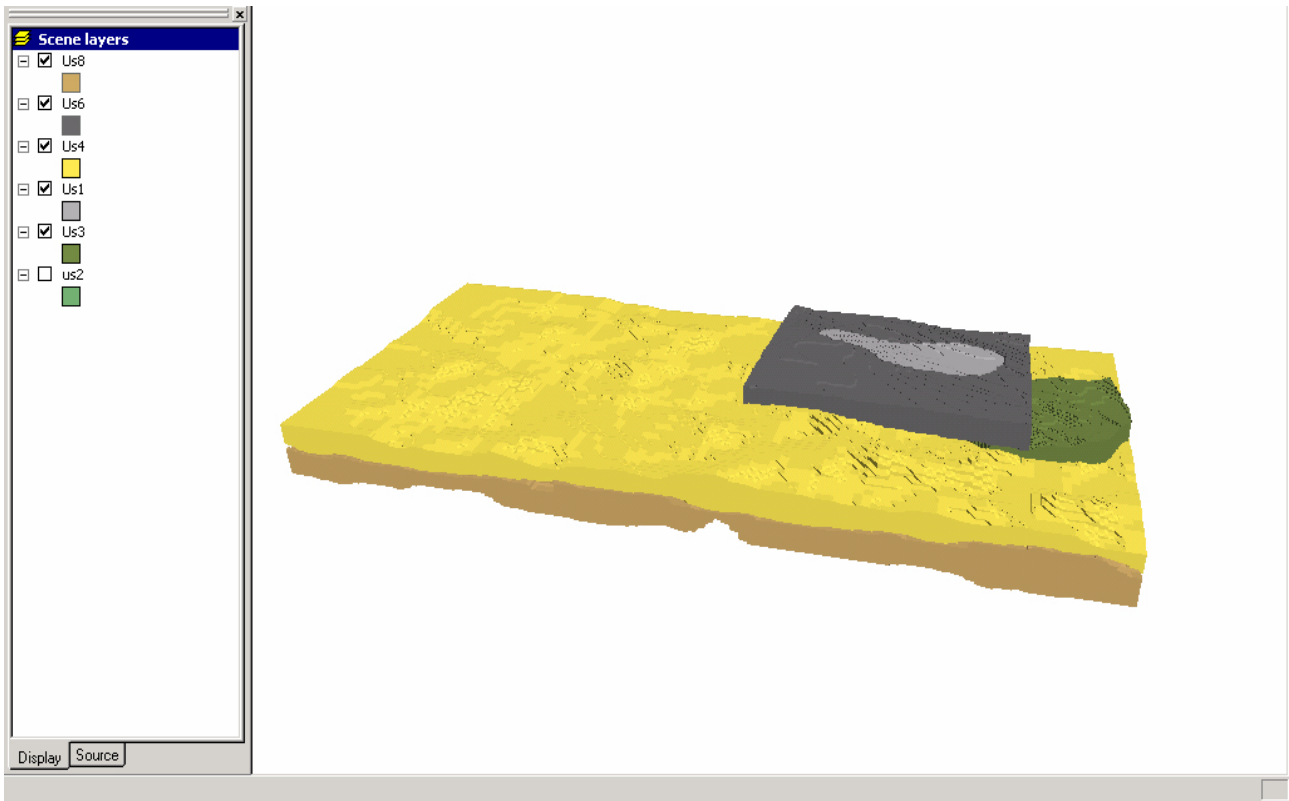
Figure 10: Models of isosurfaces imported in ArcGIS

In the GIS environment we can proceed with exploded display or create sections of each isosurface (fig. 11).
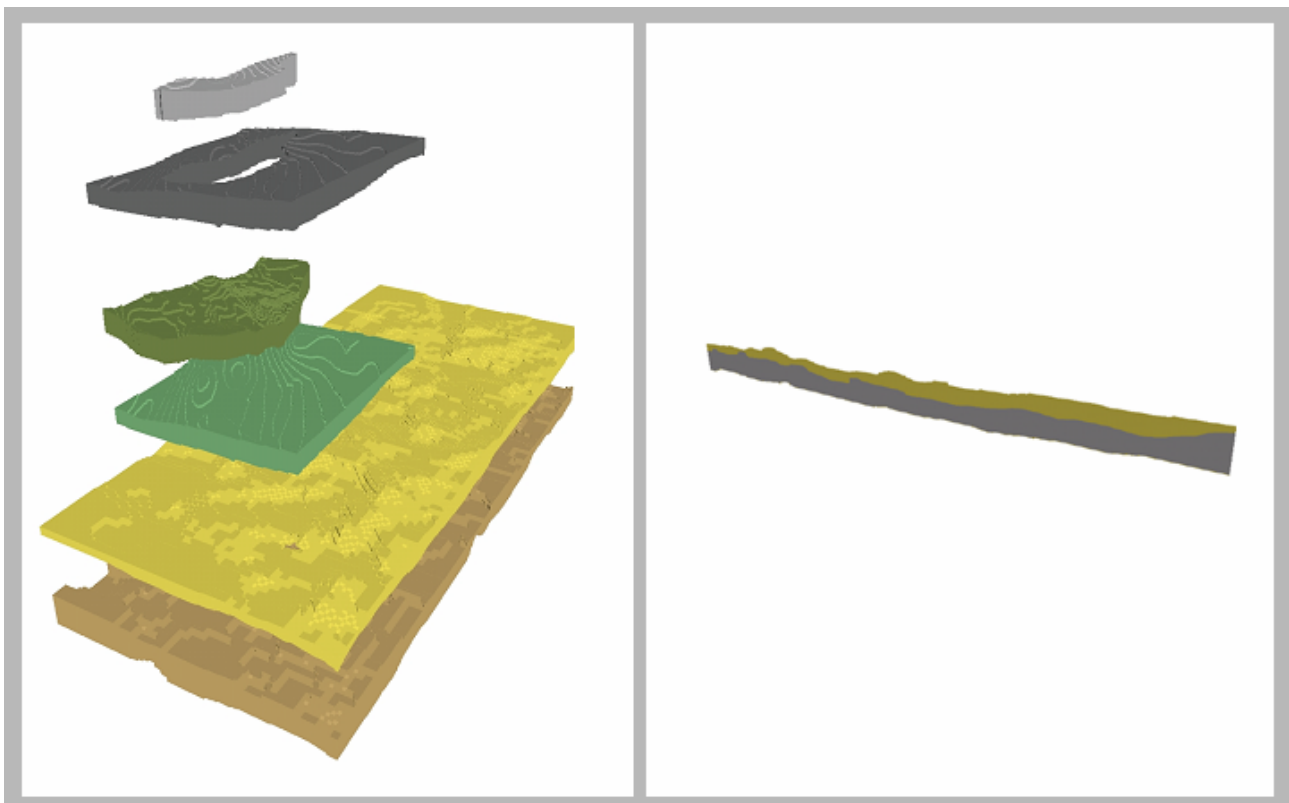

Figure 11: Models of isosurfaces with exploded representation and sections imported in ArcGIS

In spite of this capability, since ArcGIS does not include solid primitive, the exported models from Rockworks as isosurfaces become a set of contiguous polygons. A single US can contain thousands of records and the capability of GIS of topological analysis is reduced if not invalidated. A solution of this problem is to merge the contiguous polygons in one entity.

We exploited the main feature of Rockworks to determine geochemical models to control postdepositional effects in archaeological stratigraphy or to display density analysis through the occurrence of some finds. As example we show a 3d density as evaluation of an archaeological process with metallurgical slag (green points) (fig. 12).
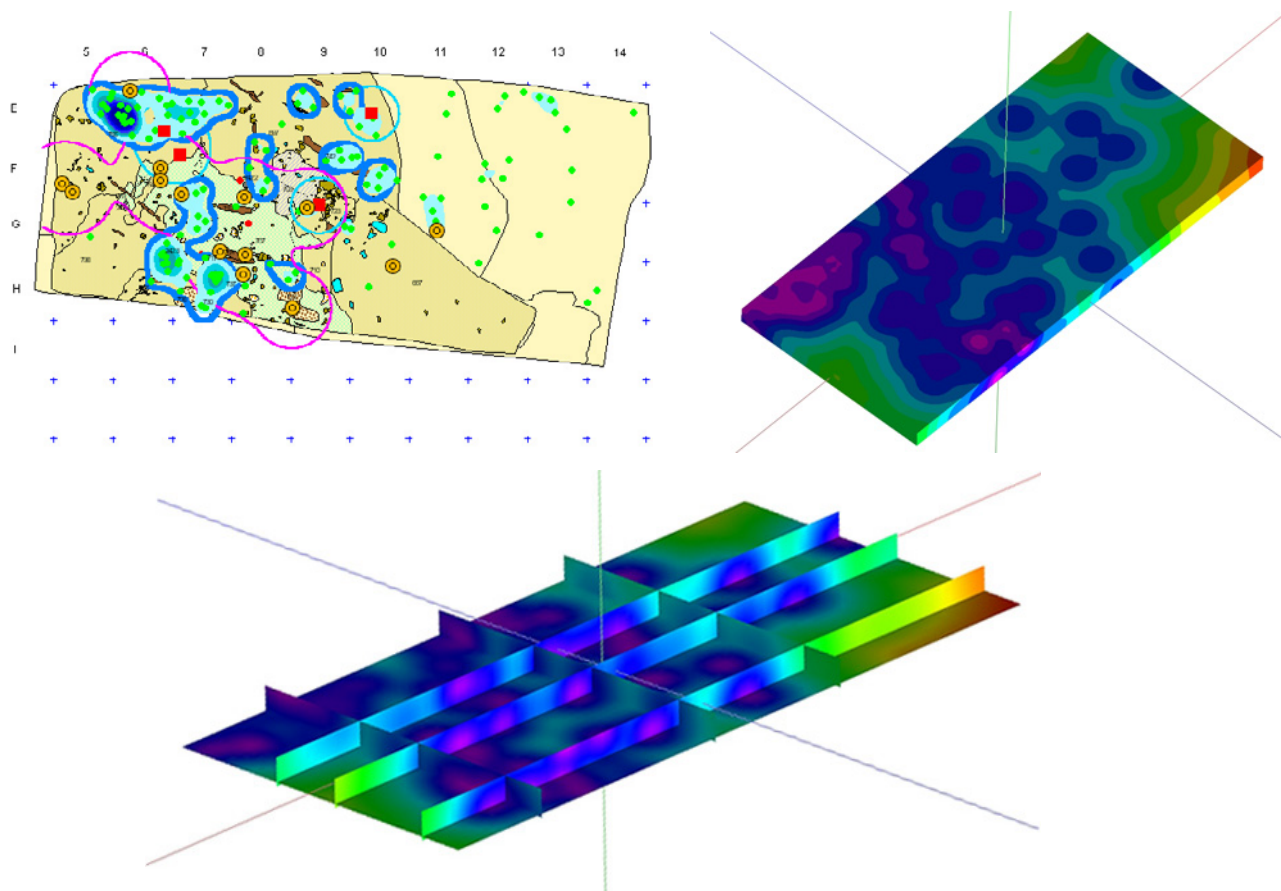

Figure 12: 3d density as evaluation of archaeological process: voxel as gradient model

We met with difficulties using voxel modelling applied to architectural features, but we did not yet test completely the management of 3d points. Besides it seems impossible as explained by software house to import and insert solid models created with different methods. The test to solve the so-called "cave effect" has been almost satisfying (fig. 18).

The second attempt of identifying a modellization system of stratigraphic data concerns the use of a *vector modeller*.

SDRC ® *Imageware Surfacer* is a specific software for three-dimensional modellization, for systems of rapid prototyping and therefore appropriate to create, verify, and analyse solid models. A three dimensional model satisfies the required features for a material reproduction

when it is verified the continuity of the surface both mathematical and visual. The vector modeller allows to create a closed surface with double zed value and therefore obtain a solid able to calculate volume, surface, curvature analysis or to obtain profiles or sections along any line of representation, even cumulative, to subtract, merge or to extract the contact surface with other solids. The model considers topology but we need to develop controlling and culling systems, not yet available in all GIS software.

Starting from the same stratigraphical context used for voxel model, we import as text files the coordinates of a layer divided in upper surface and lower surface. Then we can create a TIN for each surface through a Polygonization. The software creates a triangular mesh by connecting points to neighbouring points of a selected cloud. After that we merge together the two surfaces and obtain a single object that can consequently closed as a solid. The final process is to export this object in ArcGIS.

The current archaeological research employs the three dimensional survey of US by top and bottom surfaces, but we propose as more correct, the use of tools of modellization able to describe the shape as regions of volume explicated by a closed surface. A *Triangulated Irregular Network*, based on criteria of triangulation proposed by Delaunay and available in most of GIS software, cannot generate this kind of models[1] (fig. 13) and therefore does not provide elaborations of solid modellization, like Booleans operations and cumulative slices.
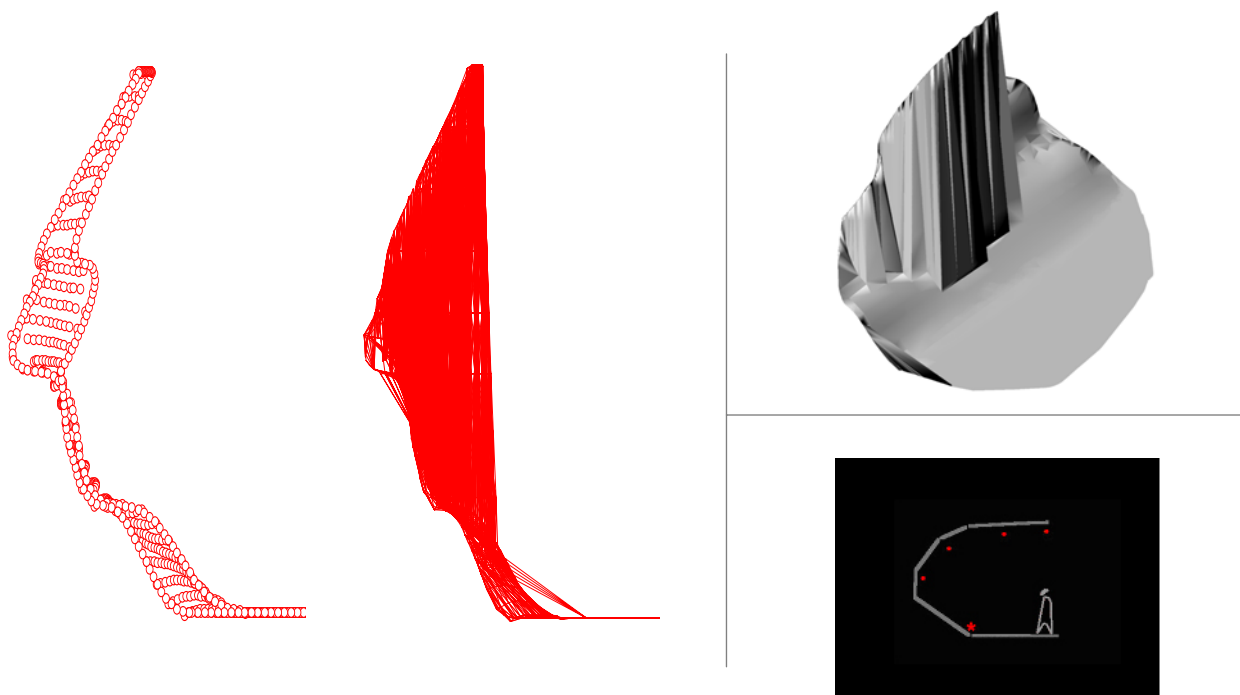

Figure 13: A Triangulated Irregular Network store a single z value for any given x,y location ("cave effect")

Imageware Surfacer has a data model for geometric vector entity (*Closed Polygonized Point Cloud*) able to describe the shape of objects as a closed collection of bi-dimensional triangles, oriented in the three-dimensional space.

We propose a process of modellization with three steps: optimisation and polygonization of points, evaluation and repairing of surfaces, analysis and final output of the model. The data-entry of two main stratigraphic units is represented by four lists of coordinates of the spatial location of points of surfaces top and bottom. These points are organised on different layers and submitted to the process of polygonization (fig. 14).
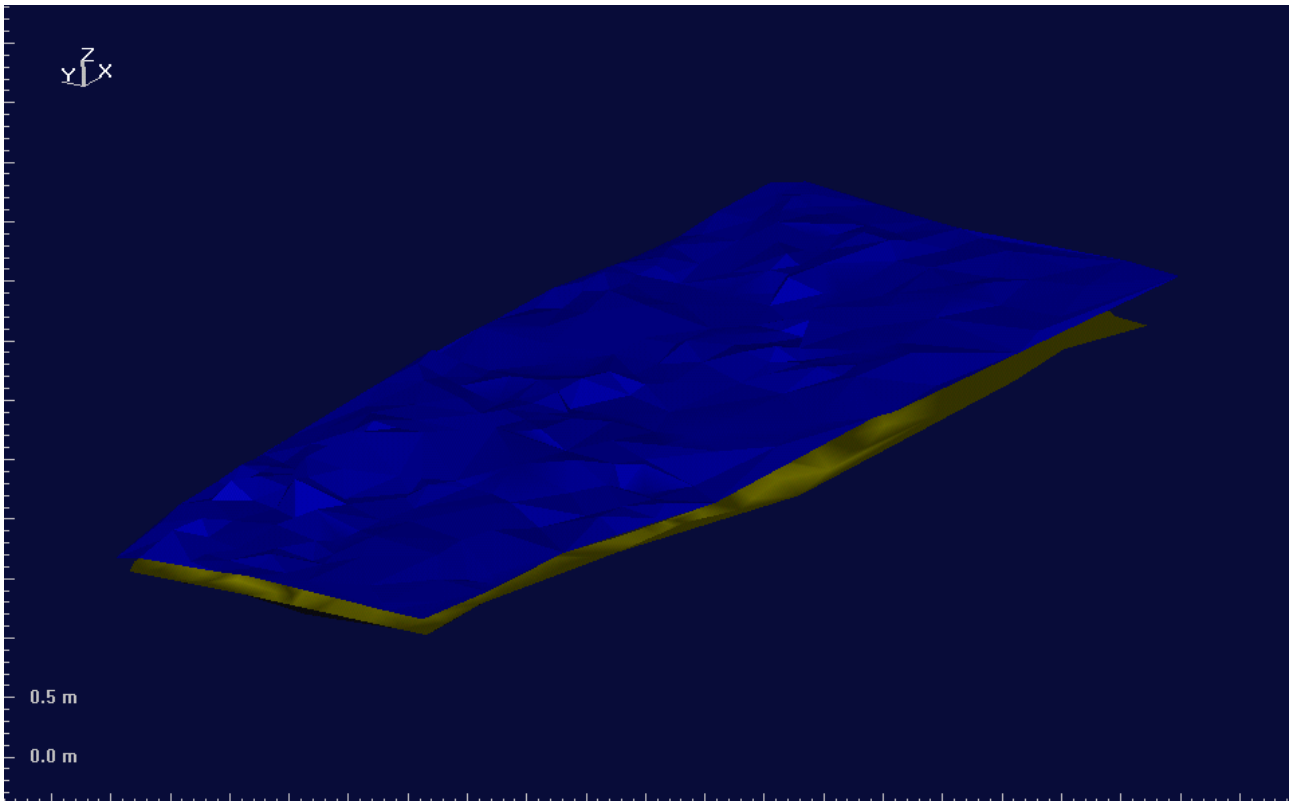

Figure 14: Point|Polygon Operation|Polygonize

One of the best features of modelling software is the possibility of Verifying models. It has tools to control the congruence of the model to the entry points with the possibility to avoid anomalous points or to address us to repeat measurements in some areas (fig. 15).
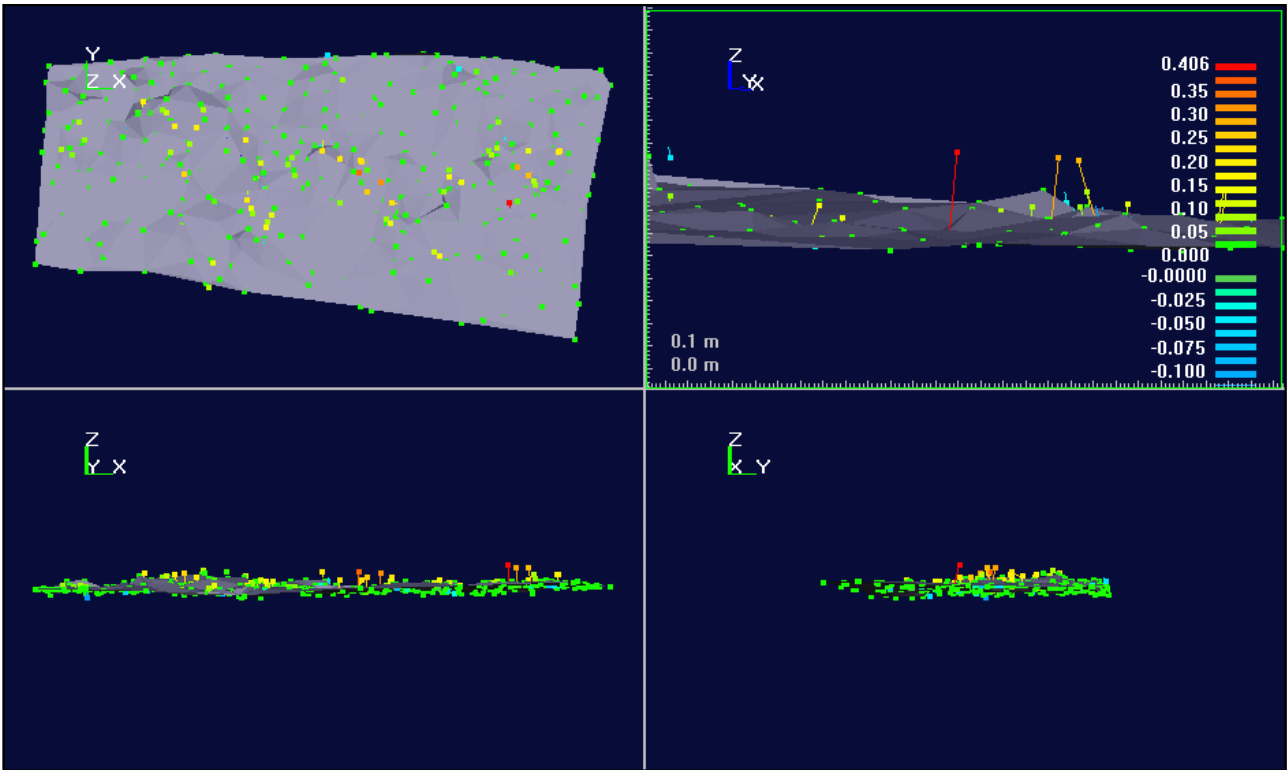
Figure 15: Surface-Cloud Difference: computes and reports the difference between one surface and one point cloud

The algorithm creates a triangular mesh by connecting points to neighbouring points of a selected cloud[3] with the result that volume of each US is completely described by a process of automathised lofting of edges of the top and bottom surfaces (fig. 16).
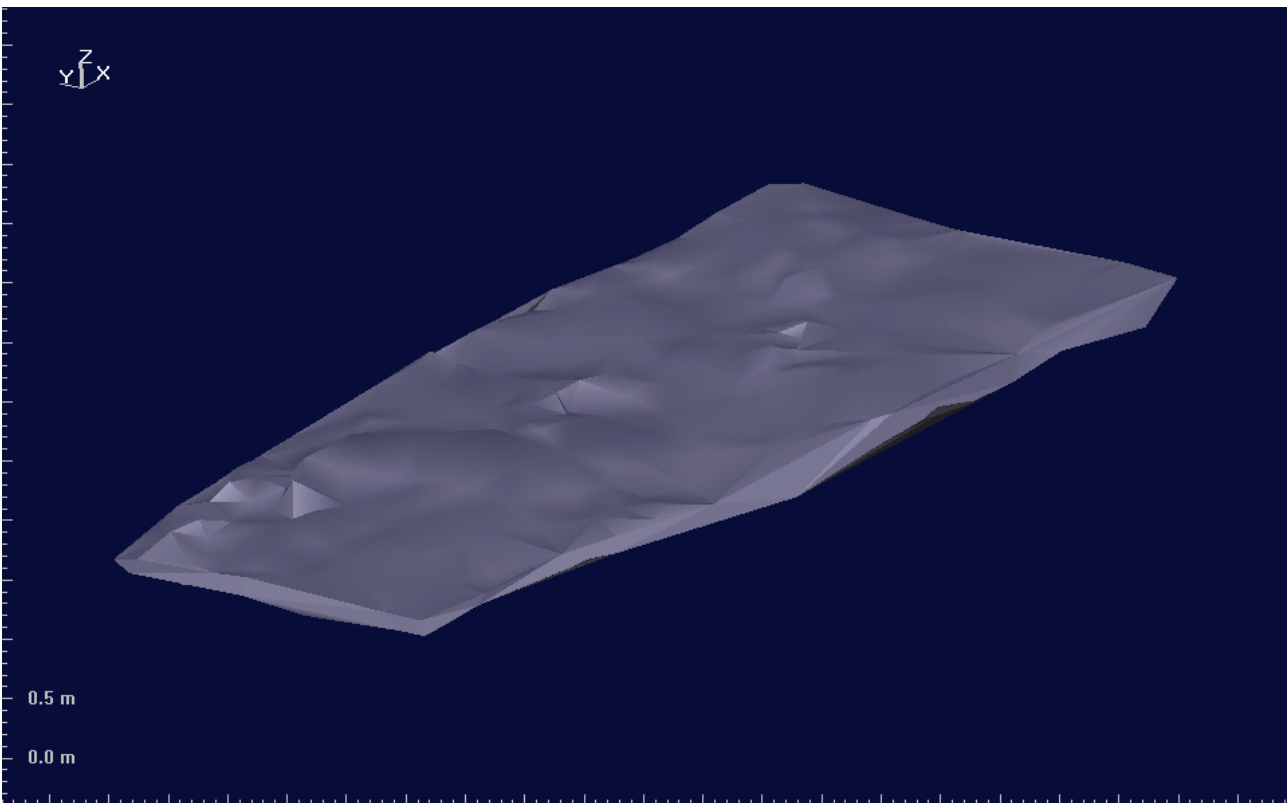

Figure 16: Close|Ring

This method as the advantage to create a mesh of triangles directly from original data but it can produce errors of mathematical continuity of the surface, especially in zones of high disorder of points (holes or imperfections in the connection between polygons). More the original surveyed points are organized more efficient will be the software ability. This phenomenon has been remarked processing points in a pseudo-regular grid with increment more or less high respecting the complexity of the shape. In the process of modellization we have tools to verify and correct the mathematical continuity of surfaces so to check the accurateness of all the information and eventually to reproduce many times the modelization. The software can display the volume, can obtain sections and profiles, union, add or subtract different features and propose other geometrical analysis (e.g. curvature). The result will be saved in output format with coherent geometry to be imported in the GIS. Since ArcView 8.2 does not include the closed polygonal entity, it is necessary to export in DXF format, and then explode the geometrical continuity. The final output will be readable in ArcScene as collection of single bi-dimensional polygons oriented in three-dimensional space (fig. 17-18).
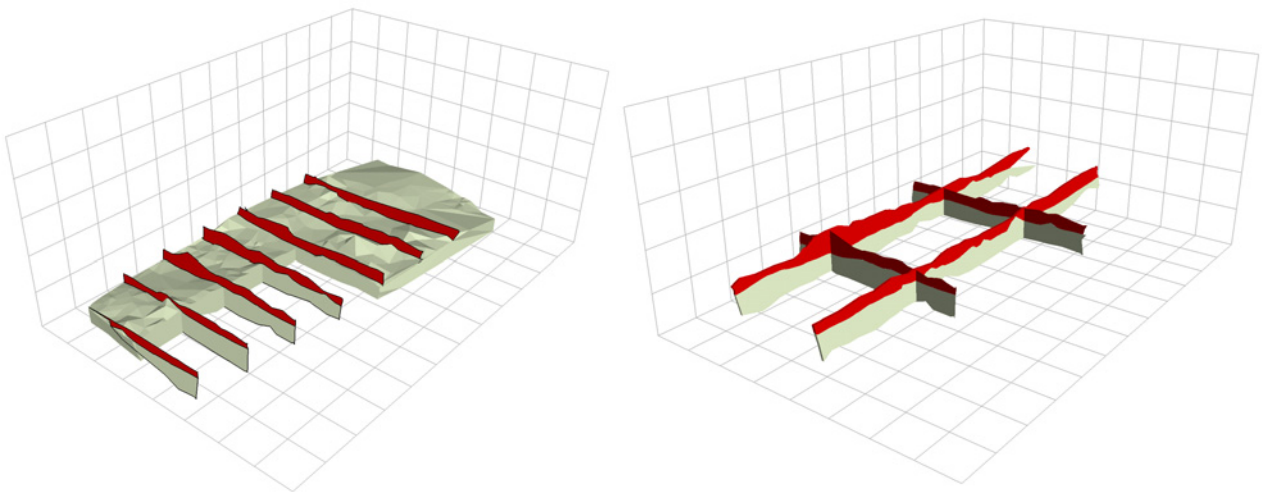
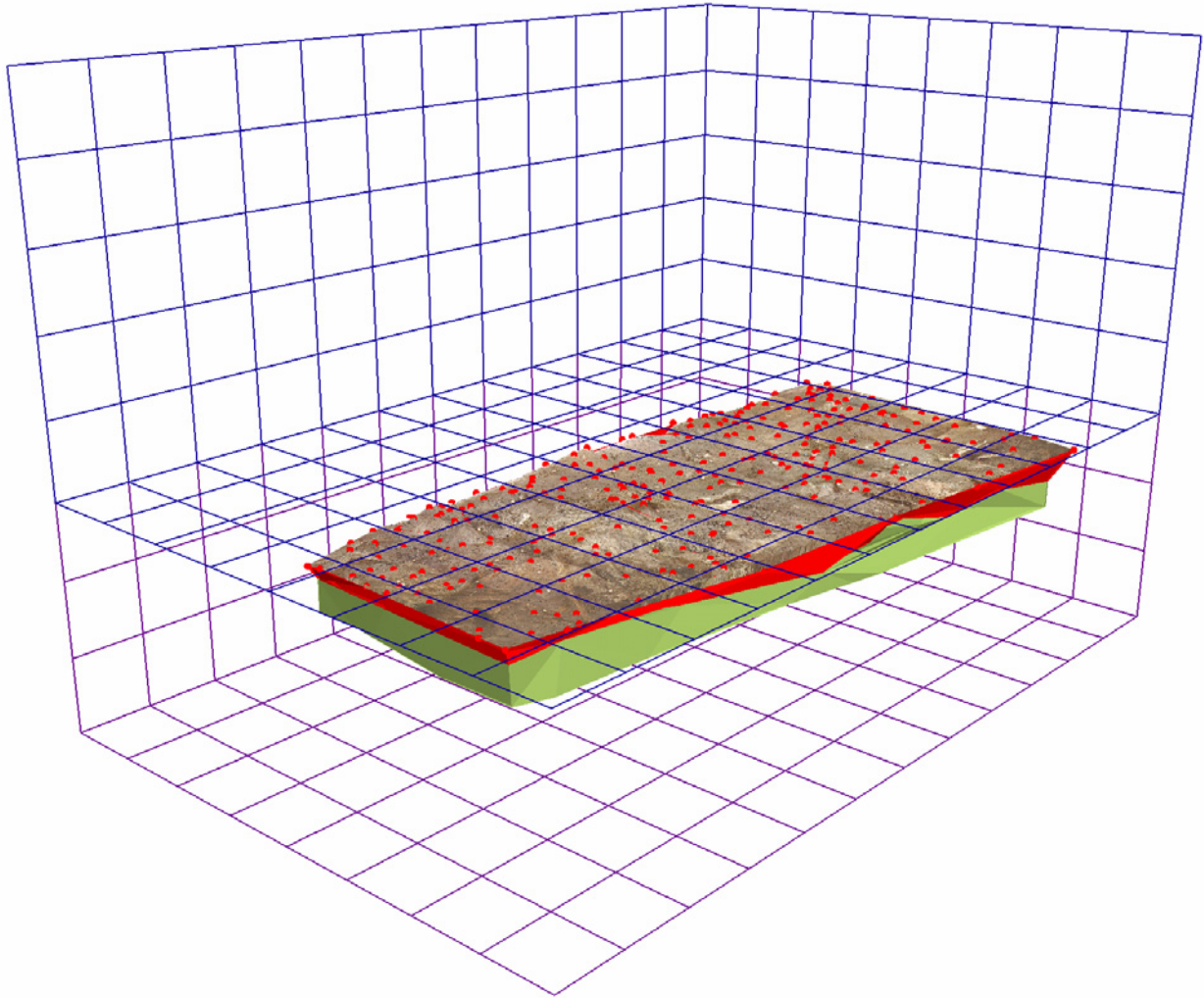

Figure 17: Vector model imported in ArcGIS: sections

Figure 18: Vector model imported in ArcGIS

The software ArcGIS can transform two TIN surfaces in a single graphic entity called MultiPatch through the lofting process. This multipatch can not be considered as real solid entity since there is no direct method to take a collection of individual 3D polygons and construct a single multipatch geometry out of it. The alternative is to import from different software and it has been released that the forthcoming ArcGIS 9.0 has some advanced functionality for importing as a form of "multipatch", 3D Objects from 3D modelling software such as 3D Studio Max.

One of the best results we obtained with vector modeller is the application of this software to architectural features (fig. 19).
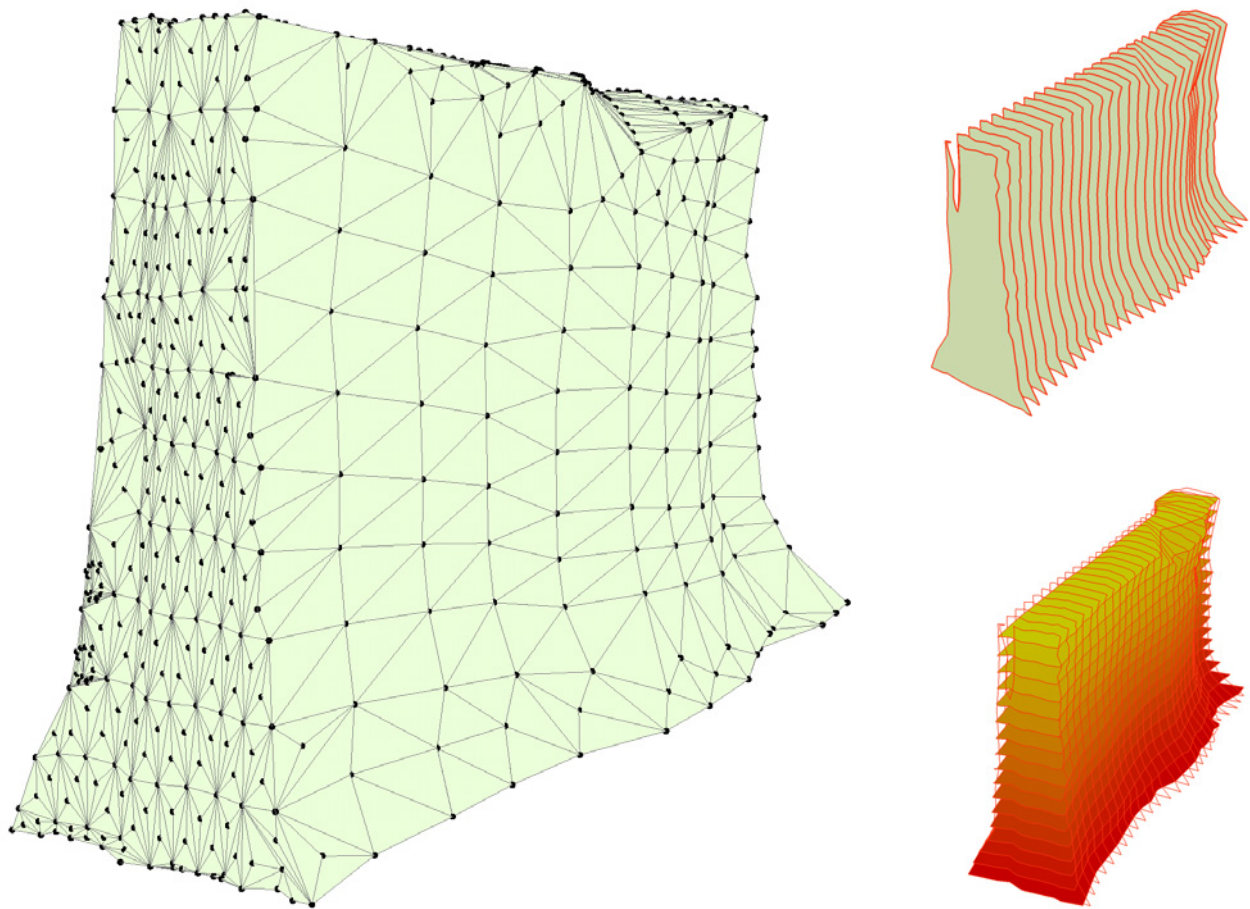
Figure 19: Vector model imported in ArcGIS: architectural features

To put to test a formal description more symbolic and more immediately understandable we can apply algorithms for automatic triangles decimation through the reduction of vertex with same approximate value. The removal of vertex is based on the combination of three parameters with different weight to assign in the process of compression of the shape. First parameter guarantees that all removed vertex leave a surface of polygons with same size. Second parameter assures that surface will be maintained, as it was where the curvature is higher. Third parameter minimizes the error between original and newer surface through the analysis of vectorial difference. Through the command *Reduce Polygons to Count* the software will remove points from flat surfaces, avoiding changing edges or other basic points of the geometry of model (fig. 20).
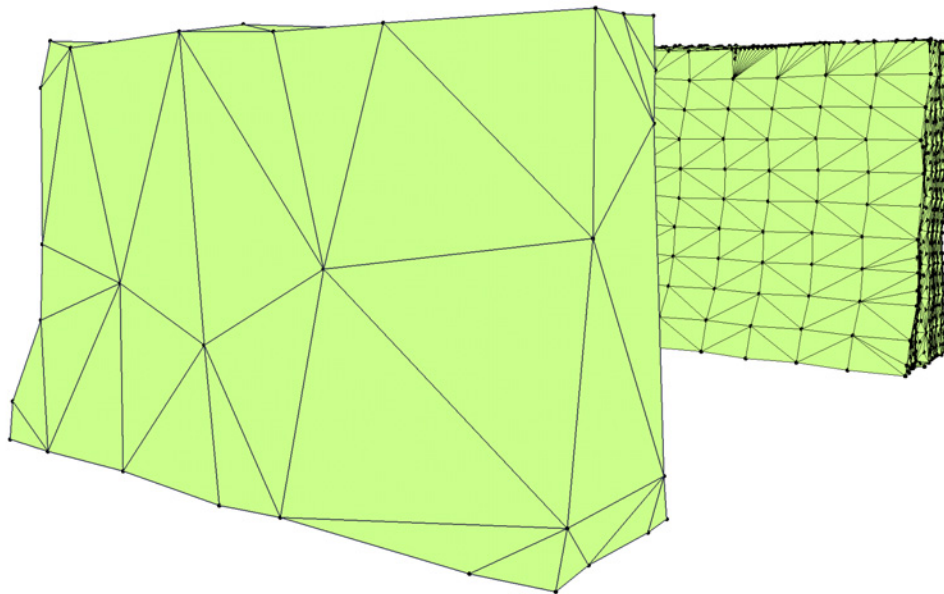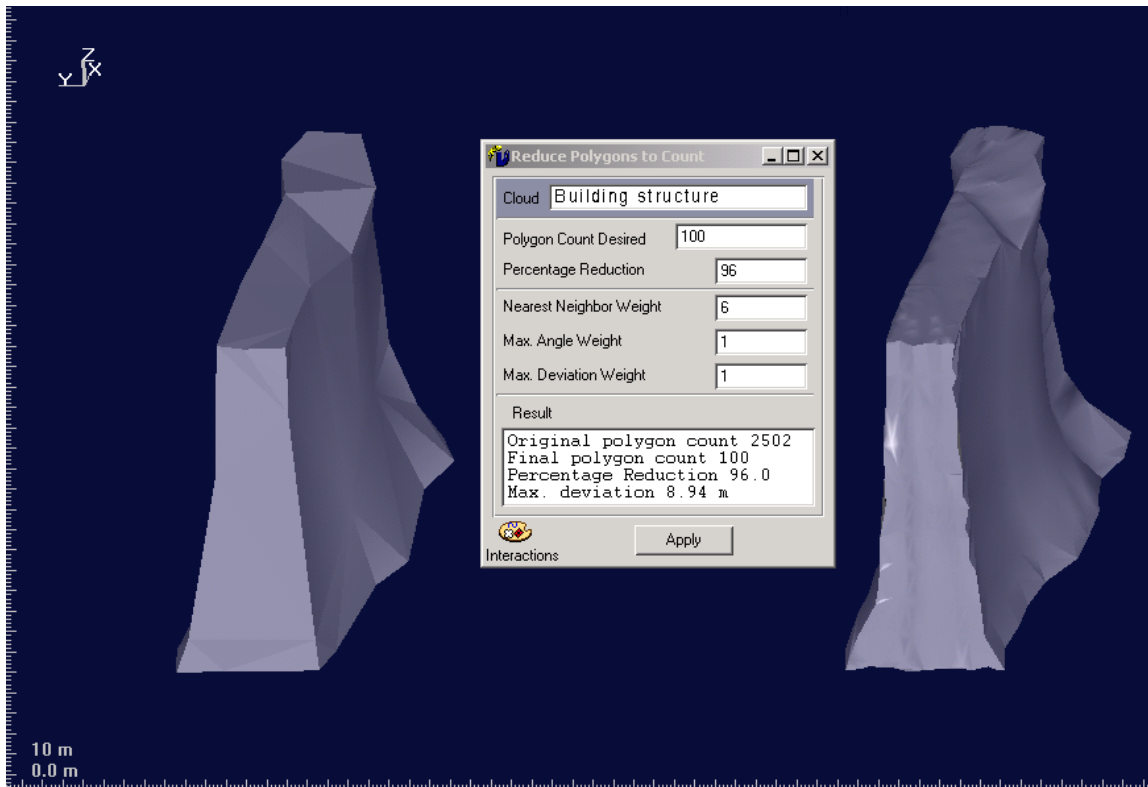
Figure 20: Reduce Polygons To Count

The application to architectural features has been applied both with voxel and vector modelling (fig. 21). The result in managing data located with the so-called "cave effect" is both satisfying.
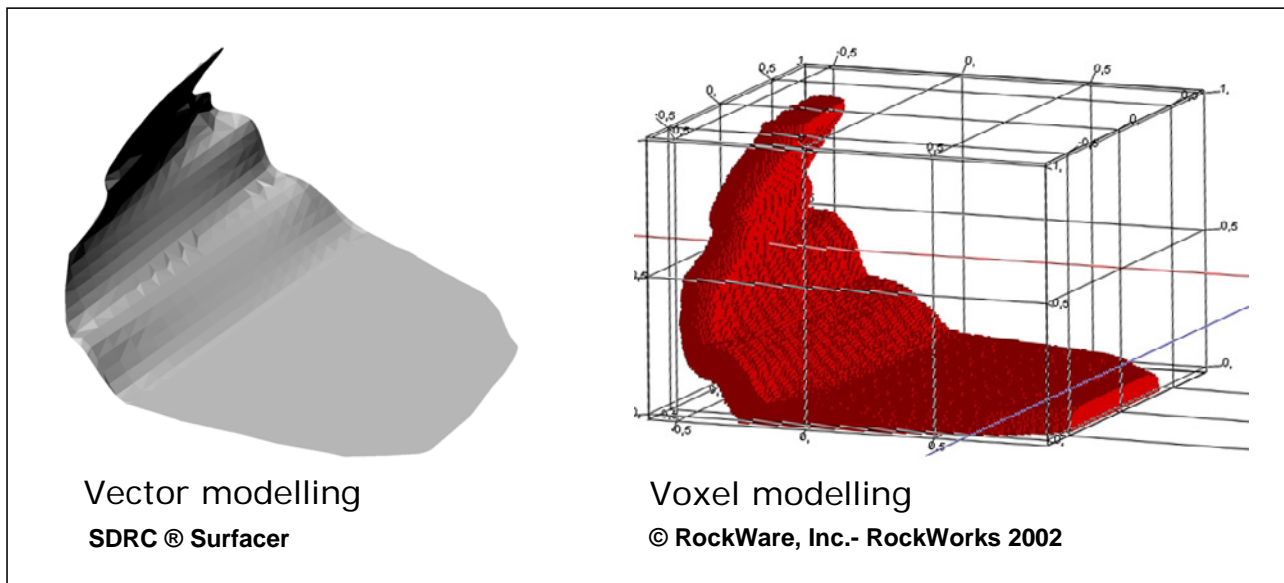
Figure 21: Models capable of storing multiple z values for any given x,y location

Our experimentation finds more confirmation about the path to follow from several examples of 3d GIS applied by urbanist scholars in collaboration with main software houses. In such cases new trends are directing to the explication of spatial relations between three-dimensional object (Arens 2003, Arens, Stoter and van Oosterom 2003).

References

ARCGIS 3D Analyst, 2002. Three-Dimensional visualization, Topographic Analysis, and Surface Creation. An ESRI White Paper, January 2002.

ARENS, C.A., 2003. Maintaining reality: modelling 3d spatial objects in a Geo-DBMS using a 3d primitive. MSc thesis, March 2003.

ARENS, C.A., STOTER, J. and VAN OOSTEROM, P.J.M., 2003. Modelling 3d spatial objects in a Geo-DBMS using a 3d primitive. *AGILE conference*, Lyon, April 2003.

BARCELO, J.A., DE CASTRO, O., TRAVET, D. and VICENTE, O., 2003. A 3D Model of an Archaeological Excavation. In Doerr M. and Sarris A. (eds.), *Computer Applications and Quantitative Methods in Archaeology, CAA 2002*: 85-87.

BERGER, F. and VERHAGEN, Ph., 2001. Predictive modelling of buried archaeological sites in the Tricastin-Valdaine region (Middle Rhone Valley, France*). In CAA 2000: Computing archaeology for understanding the past*, Ljubljana, 18-21 April 2000.

BERGSTROM, A. Techniques for Implementing Three-dimensional Computer Modeling in Archaeological Research and Education (http://atl.ndsu.edu/resources/scanning/).

NIGRO, J., LIMP, F., KVAMME, K., DE RUITER, D. and BERGER, L., 2002. The Creation and Potential Applications of a 3-Dimensional GIS for the Early Homin Site of Swartkrans, South Africa. In *Computer Applications and Quantitative Methods in Archaeology, CAA 2001*: 113-123.

BERGER, F. and VERHAGEN, Ph., 2000. Predictive modelling of buried archaeological sites in the Tricastin-Valdaine region (Middle Rhone Valley, France). In *CAA 2000: Computing archaeology for understanding the past*», Ljubljana, 18-21 April 2000.

CANDELATO, F., CARDARELLI, A., CATTANI, M., LABATE, D. and PELLACANI, G., 2001. Il sistema informativo dello scavo di Montale. In *Preatti del workshop Soluzioni GIS nell'informatizzazione dello scavo archeologico,* Siena, 9 June 2001 (http://192.167.112.135/NewPages/TESTIWORK/06.rtf).

CANDELATO, F., CARDARELLI, A., CATTANI, M., LABATE, D. and PELLACANI, G., 2003. Il sistema informativo dello scavo della terramara di Montale (Castelnuovo Rangone - MO). In

Analisi informatizzata e trattamento dati delle strutture di età preistorica e protostorica, Ferrara, Italia, 26-27 November 2001, Firenze c.s.

CARDARELLI, A., CATTANI, M., GIORDANI, N., LABATE, D. and PELLEGRINI, S., 2001. Valutazione del rischio archeologico e programmazione degli interventi di trasformazione urbana e territoriale: l'esperienza di Modena. In Gelichi, S. (ed.), *Dalla carta del rischio archeologico di Cesena alla tutela preventiva in Europa*, *Atti della giornata di studio*, Cesena 1999, Firenze:31-40.

STOTER, J. and ZLATANOVA, S., 2002. Visualisation and editing of 3D objects organised in a DBMS. *Proceedings of the EuroSDR Com V Workshop of Visualisation and rendering*, 22-24 January, Enschede, The Netherlands.

ZLATANOVA, S., RAHMAN, A. and PILOUK, M., 2002. 3D GIS: current status and perspectives. In *Proceedings of ISPRS*, 8-12 July, Ottawa, Canada, CD-ROM:8p.

---

[1] "TIN represents surfaces as functional surfaces. Functional surfaces have the characteristic that they store a single z value, as opposed to multiple z values, for any given x,y location."…"Functional surface models can be contrasted with solid models which are true 3D models capable of storing multiple z values for any given x,y location." (Surface Modeling with TIN. ArcInfo Users Guide; Version 7.0, ArcDoc, 1994. Environmental Systems Research Institute, Inc., 380 New York Street, Redlands, CA 92373).

[2] Thanks to the courtesy of Prof. A. Cardarelli, director of the excavation carried out by the Archaeological Museum of Modena.

[3] Imageware V10, 2000. Command Reference.