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A 3D Model of an Archaeological Excavation

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Abstract. We think that archaeological fieldwork can be enhanced by using Virtual Reality techniques and 3D graphical models. In this paper, we present how to acquire 3D data from the field, and the process of computer representation in order to build a visually understandable model of the excavated reality. The paper explains the process of data capture (both coordinates and shapes), and how images are mathematically rectified. The next step is based on building a Digital Elevation Model of the archaeological layer. Once a model of the excavation has been obtained, we can use the computer model to understand stratigraphic sequence in such a way that gives much more information than standard approaches based on bidimensional or unidimensional matrices. The method also allows volume calculation, and the simulation of archaeological formation and deformation processes.

Keywords. Virtual Reality, Archaeological fieldwork, Photogrammetry, 3D modelling.

1 Elements of Archaeological Space

An archaeological site is the place where social action "was" performed. As a result of human action, physical space is being modified. Therefore, it is only when physical space (ground surface) has been modified as a result of human agency, we can speak about an archaeological site. In that sense, archaeological sites should be considered as an *event* and not as an object, or a series of objects.

We can define archaeological space as a sequence of finite states of a temporal trajectory, where an entity (ground surface) is modified successively. Between two successive modification states, we define observable *discontinuities*. Natural and human process modify physical space, and as a result we are able to distinguish *components*, which can be used as *analytical units* (Estevez 2000, Mameli et al. 2001).

We decompose the archaeological space into physical modifications (structures) and differential accumulations (deposits) to be able to understand how the archaeological space was formed and transformed by human action and natural processes. Decomposition means here a *model* of the site formation process in terms of the spatial variability of ground surface physical modifications and differential accumulation of items.

We need to distinguish where observed discontinuities begin and end. The purpose is to characterize observed discontinuities in terms of distinct components or relevant units with uniform value of shape, size, texture, composition. In the same way, sediment characteristics and strata properties such as degree of consolidation, density, porosity, cohesion, strength, and elasticity may be associated with discrete archaeological volumes with distinct boundaries.

Observed discontinuities can also be expressed in terms of quantitative variables. Quantitative variables exhibit a variation in value throughout an indeterminate region. Variables such as geomechanical properties, mineral grades, material accumulations, soil morphological features, or any other property of sedimentary/depositional units and archaeological contexts, can be sampled or measured in terms of real, numerical values.

We can use geometric primitives (point, line, area, surface, volume), to represent site components, and standard geometric functions for analysing spatial relationships between components. In other words, variation of the archaeological space physical properties such as sediment hardness, porosity, fracture density, archaeological concentrations, topology of components, etc. may change abruptly between adjacent archaeological units or strata. The existence of such discontinuities implies that any consideration of the formation process must take into account the relevant dominant characteristics of the host strata.

2 Shamakush VIII. A case study

Our 2002 field season in Tierra del Fuego (Argentina) was designed in order to build a model of site formation process. To be able to decompose the archaeological site in relevant components, we have made observations in the field, we have processed those data to extract relevant information, and finally we have built a geometric representation of measured spatial variables.

Shamakush VIII is a shell midden generated by hunter-gatherer populations living on the shores of Beagle Channel in America's extreme South (54º degrees south). It can be described in terms of an accumulation of refuse material, which has adopted a specific shape and volume according to deposition, and microtopography of ground surface over which refuse material accumulates. That means that garbage accumulates over previous garbage accumulations. Between non consecutive deposition phases, there is natural soil formation (grass and bushes). New deposition episodes bury those occasional natural soils and integrates them into the accumulation/deformation history of the site.

4 Data Acquisition: Shape measuring

In this kind of shell middens, site components are *contact surfaces*. That is, places where two physical modifications or accumulation deposits join or differentiate (Groshong 1999). It is the consequence of a change in the formation process acting on a specific location. For this excavation, our analytical unit is always the upper stratification plane of a deposition (human, biological or geological). The bottom plane or basis is, by definition, the upper part of another deposition formed before.

We use observational criteria to determine the proper limits of each surface, and the precise topological relationships between overlapping contact surfaces. When possible we have distinguished stratification plans for its mechanical properties (cohesion, density, continuity).

To be able to translate observed discontinuities into a mapping of spatial components, we require a vector based data structure that translates the empirical into the virtual. The idea is to take digital pictures on the field, and through a careful processing, to extract all relevant information about the shape, size, texture and composition for each depositional episode.

Rectification is the process of removing scale variations from any image. We use the Manifold System 5.0 software to rectify the photos took at the site.

The observed discontinuity or contact surface is divided using a precise grid, with nodes at 1 meter. Each square meter is photographed separately, and the resulting image is corrected using 5 control points (grid nodes). Once corrected, pictures are joined in a mosaic, to obtain a precise image of the observed discontinuity (Fig. 1). The border in the final image is now correctly scaled and can be transformed into a vector, and the discontinuity or sedimentary area, described as a polygon.

However, we have only obtained a 2 Dimensional representation, and archaeological components are always three-dimensional. Archaeological information is intrinsically 3 Dimensional. We need a volume data structure that accommodates complex, irregular 3D volumes associated with specific characteristic values. We need additional data to transform a polygon into a *volume.*

5 Data Acquisition: Extension measuring

Usually the archaeologist uses the system of Cartesian coordinates; x,y,z, to locate in space the observed archaeological elements. In many cases, this methodology has imposed a qualitative partition of the archaeological space which delimits the space in a "non natural way". Our goal is to measure the extension of contacting surfaces, and it can only be done if we have properly described the *complete* shape of the site component.

To transcend this problem actually we dispose of measurement instruments that allow us to evade the classic systems of reticules during the excavation. We use spatial coordinates information at two levels: 1) Grid Nodes: we have measured *z* values at fixed points, using a 50 cm. Grid. This nodes act as a column schema, where different z values can be compared at the same location. 2) Additional z values can be measured within the delimited area.

X	**y**	**B2**	**B5**	**C10**	**C15**
46	3.0	12.43	12.41	12.40	12.38
47	3.5	12.43	12.37	12.36	12.34
48	4.0	12.46	12.45	12.42	12.40
49	4.5	12.31	12.29	12.28	12.27
50	5.0	12.25	12.20	12.19	12.15

Table 1. *Surface coordinates.*

These additional *z* values integrate shape coordinates (local coordinates of vertex defining the boundaries), and what we call *surface points*, that is, local coordinates of the surfaces, which close the geometric representation of the site component.

In this table, *x* and *y* are standard Cartesian coordinates in a plane, and *B2, B5 and C10*, are the *z* coordinates of different surface contacts. In this way, the upper part of each deposit can be correlated with the upper part of deposits placed under them, and having an older formation history.

In both cases, a 3D view of each surface contact is easily computed interpolating measured z values. Preliminary examples have been obtained using the inverse distance algorithm. (Fig. 2).

Furthermore, we can insert vector information on the surface, and then recalculate the interpolation. This is a very important step if we want to represent the proper extension of the component. Most interpolation algorithms deal badly with irregular borders. In this case we have used standard triangulation mesh building methods for integrating vectorial borders and surface points.

The requirement for interactive interpretation is satisfied by allowing sedimentary contacts to be defined from whatever sectional orientation is most appropriate to subsurface conditions.

5 Visualizing Site Structure

To adequately represent site components on a computer we must consider a semi-infinite continuum made up of discrete, irregular discontinuous volumes defined by characteristics which in turn influence the spatial variation of the site component. The subsurface distribution of components' values is represented by discrete, contiguous, irregular volumes, with uniform value throughout each volume. Where relevant, the structure of the site, in terms of stratification planes, contacts and other discontinuities are represented by the boundaries of these volumes.

Therefore, to build a spatial model of an archaeological site means much more than a simple correlation between surfaces. The geometry of a site component is not configured by only one surface, but it should be defined in terms of three closed polygonal boundaries; a mid-plane boundary coincident with its reference plane, and a parallel for-plane and back-plane boundaries at specified thickness either side of the reference plane. The spatial data acquisition constitutes a fundamental part of the project. There are different scales of analysis, defined as macro, semi micro and micro, they are all necessary (Barceló 2002).

Site components or sedimentary units are represented as volumes between two contact surfaces. They are, in fact *thickness* representations of accumulated material between contacts. We put special attention into the objects found in the contact surfaces, because this kind of material could allow us to precise the relation between different depositional moments (Fig. 3).

The subsurface distribution of site components is represented by discrete, contiguous, irregular surfaces, with uniform value throughout each volume. We should remember that we are not looking for *stratigraphic unis* as containers for archaeological material, but we pretend to define those regions in a three dimensional archaeological space characterized by some observable discontinuities in shape, size, contents, texture or location. Archaeological site components can be visualized then as *volumes* where the probability of a sedimentary, erosive, deposition or post-deposition process are the highest.

An *isopach* model is a representation of this kind of probabilistic information, that is, those locations were the probability of a formation process (defined by a quantitative or qualitative variable) is higher.

To create an *isopach* or thickness geometry model, we have to compute the difference between the upper and the surface component, that means, the difference between elevation at the top of the first component and the elevation at the top of second component for each surface point. The results are stored in a new *z* value (for instance, SC1-SC2 is SC1thickness; SC2-SC3 is SC2thickness). We can then calculate a 3D model of the thickness.

Now that we have created a geometric model that represents the thickness of the different site components computed from a data base of thickness values, we can compute some basic statistics for the model, including grid area and volume. We can use filter variables to exclude from volume and area calculations any particular structure or element. For instance, we can exclude those areas of a site component where there are no traces of fire (burning=0), or areas with an "great number" of shells (shell>35). If we were computing sand volumes, you could filter based on grain size and sand percentage. This model of site formation process can be expanded using additional information about structural elements (wall, pits, occupation floor, etc.) and material concentrations.

6 Conclusions

Site components are not "photographs" of archaeological buildings, but visual models of the geometry of three dimensional data. Because they are not single pictures, geometric properties (curvature, length, thickness, height, volume, etc.) can now be measured on these models.

The primary objective of decomposing the archaeological 3D space is concerned with the analysis of the spatial variation of one or more variables. In this context, a variable is a property of the archaeological record that exhibits spatial variation, and can be measured or sampled, in terms of real numeric variables.

The spatial variation of archaeological variables appears to be complicated by structural discontinuities introduced by human action (built space) and /or natural process influences.

Consequently, archaeological spatial analysis is a two step process:

- creating a 3D map of observable discontinuities
- analyzing archaeological variables within the volumetric sequence of discontinuities

The principal objective of the volume data structure is to provide a means of qualifying subsurface space in terms of contacting surfaces, which represent different site components, and the spatial variability of formation processes.

Software

Analysis and calculations have done using the Rockworks 2002 software for geological analysis (www.rockware.com), and the Manifold 5.00 GIS software (www.manifold.net)

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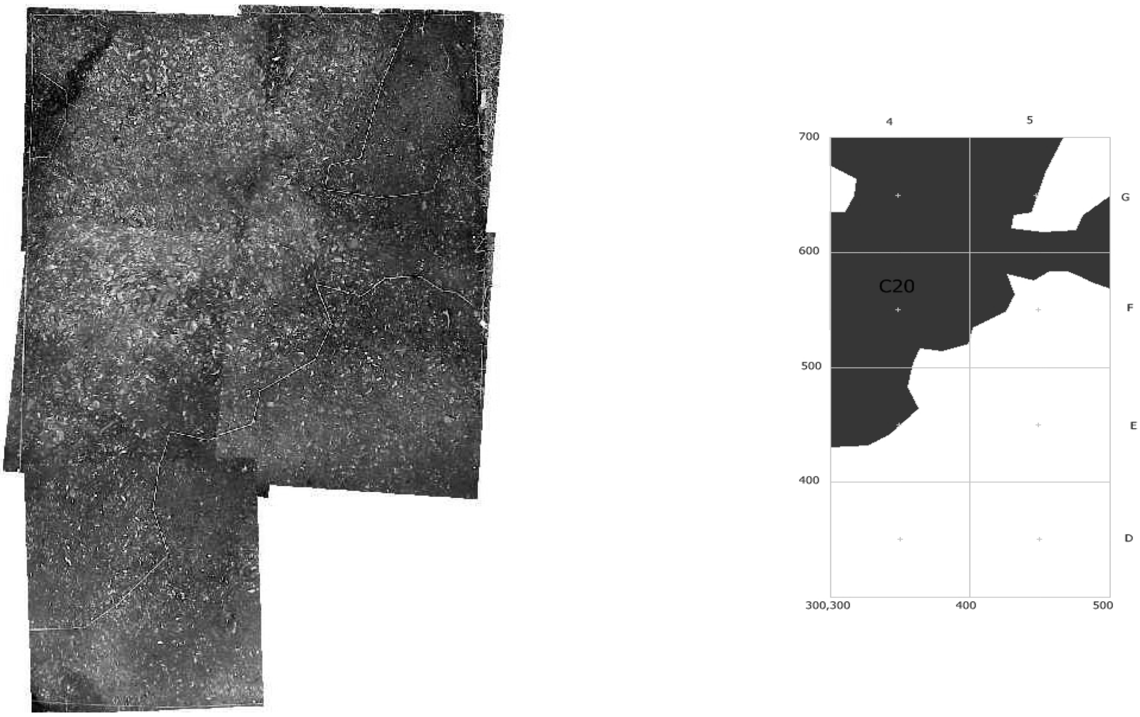

Fig. 1. *Corrected Photographic Mosaic, and vectorial representation of the surface contact.*

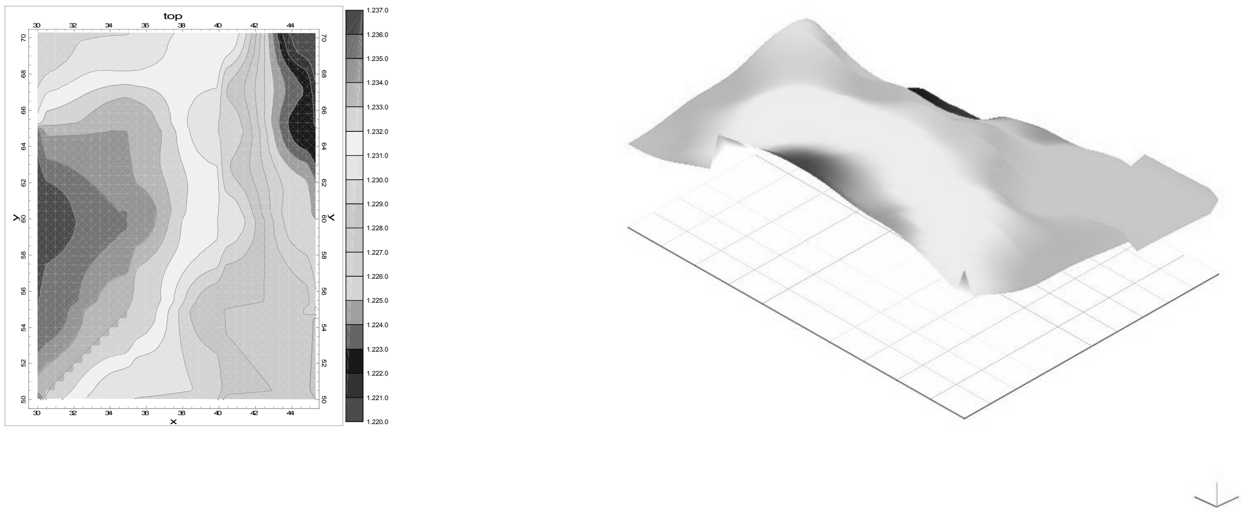

Fig. 2. *Contour map and 3D visualization of the C25 surface contact in the Shamakush VIII site. Calculated using the Rockworks 2002 software.*

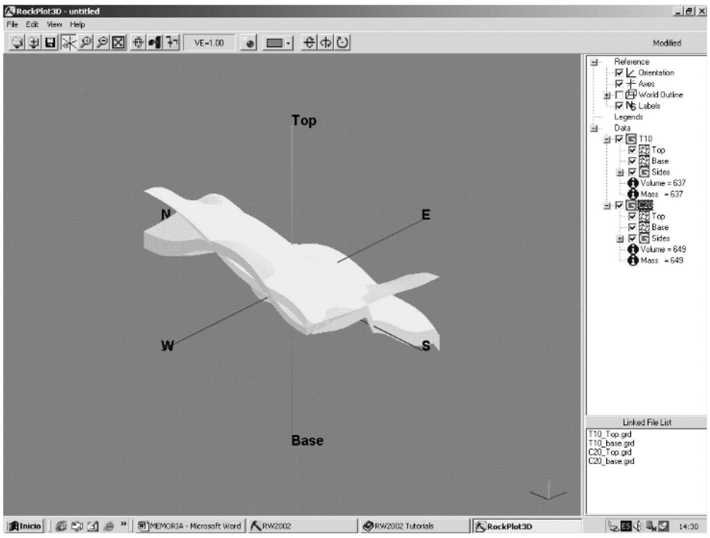

Fig. 3 *Surface Correlation using the software RockPlot 3D.*

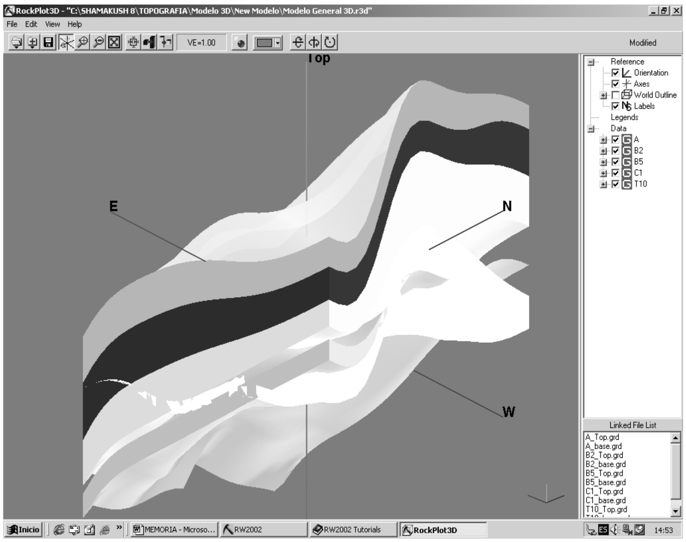

Fig. 4 *Volumetric representation of Shamakush VIII site components using the Rockworks 2002 software.*