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RECONSTRUCTING A FOSSIL LANDSCAPE BY REMOTE SENSING AND GIS APPLICATIONS: SITES, VIRTUAL MODELS AND TERRITORY DURING THE MIDDLE BRONZE AGE IN THE PO PLAIN (NORTHERN ITALY)

1. Introduction

This paper presents preliminary results of the research project "An inventory of the Terramare in the central Po Plain: physiographic context, stratigraphic and structural characteristics, state of preservation", included in the Cultural Heritage Finalized Project, promoted by Italian National Research Council (CNR).

The project involves GIS and Remote Sensing applications in order to reconstruct a digital thematic cartography of the central Po Plain during the Middle and Late Bronze Age and to integrate different 2D-3D georeferenced data (sites, excavations, surveys, landscape and territorial data), such as:

- raster data (aerial photographs of different periods starting from 1950, regional cartography, DEM, digital elevation models);
- vector data (cartography, thematic layers, archaeological sites, etc.);
- DEM created by cartographic contour lines and using total laser station on the ground;
- alphanumeric data (excavations databases, territorial databases, historical documentation).

Our methodological approach has been to represent and analyse archaeological data from micro-scale (intra-site) to macro-scale (inter-sites), in particular exploring the perspectives of 3D GIS visualisation and processing; therefore we have concentrated our attention towards the topographical reconstruction of the microrelief in relation and in comparison with the aerial photos (taken in different periods), as textures, the geomorphological features, the archaeological data. We can define this kind of processing a visualisation of an invisible landscape, because we can get back much more information from the terrain than the traditional techniques (aerial photo-interpretation, field survey, and so on), reconstructing archaeological and geomorphological features, poorly recorded by traditional approach.

Moreover in a lot of cases these results help us very much to plan further excavation campaigns or for monitoring visibility and conservation of the archaeological structures; in fact this approach increases our knowledge of not investigated sites, by generating detailed 3D models, and describing by digital way all the morphological features.

With respect to acquisition and processing of multi-temporal, multi-layer and multi-dimensional data, this research deals with a large-scale detailed study of the data collected by topography, but upgraded with surveys and acquisition of data on the ground. In fact the main task of our project is the creation of detailed models on the basis of the microrelief, by the following steps:
- DEM creation by geomorphological and cartographic data (macro-scale, Tavv. III-IV);
- DEM creation by total laser station (with grid of about 1000-7000 altimetric points, for each site, Tavv. III, VIa, VIIa; Figs. 7, 8);
- georeferencing and rectification of raster data and aerial photos;
- histogram matching of aerial photomosaics (in order to produce an homogeneous raster basis, Tavv. IVb-Va);
- digital monitoring of the territory by the panchromatic analysis of aerial photos through the time (Tav. Va);
- integration and overlay of all vector and raster data on the DTM (Tavv. IVb-Va; Figs. 1-4);
- texture mapping of the photomosaics on the DEM (Tavv. IVb, Va);
- multidimensional and multilayer (on different surfaces) analysis (macro and micro-scale) of 3D models (Tavv. VIa,b-VIIa; Figs. 4, 7);
- interactive 3D navigation through the model of the archaeological landscape (inter-sites: territory and settlement systems, Tavv. VIb-VIIa);
- interactive 3D visualisation of stratigraphical surfaces (layers), including raster data (perpendicular photos of excavation areas) and vector data (digitalisation of archaeological finds, stratigraphical units, and so on, Tav. VIa);
- creation of a GIS system specifically for the archaeological excavation with the digital acquisition of data on site;
- development of 3D GIS models on line for Internet applications (Tav. VIb).

2. Terramare

Terramare are pluristratified archaeological sites dating back to the Middle Bronze and Late Bronze Age. They were exploited, during in the 19th century as quarries of fertiliser and they were at that time a main topic of the first Prehistoric researches in Europe. At the beginning of 20th century they were completely forgotten and only recently they attracted again the attention of the scholars (Bernabò Brea, Cardarelli, Cremaschi 1987). The terramare basically consist of villages roughly quadrangular in shape, surrounded by a ditch and, at least during their last phase, enclosed inside hearth ramparts; they were built according to a systematic urbanistic plan, which lasted, in some cases, for more than four centuries. They developed in the Po Plain from the XVI century BC and disappeared suddenly at the end

Fig. 1 – Geomorphology and Bronze Age sites in the northern Enza basin, Emilia Romagna, Italy: 1) S. Ilario alluvial fan (Late Pleistocene); 2) paleochannel; 3) Praticello paleochannel deeply cut down, active during the Bronze Age; 4) fluvial ridge; 5) small meandering water courses; 6) low lying flood basins; 7) unstructured Bronze Age sites (a: on surface; b: buried); 8) terramare; 9) main axes of the Roman centuriation; 10) contour lines, eq. 1 mt. (after CREMASCHI 1997).

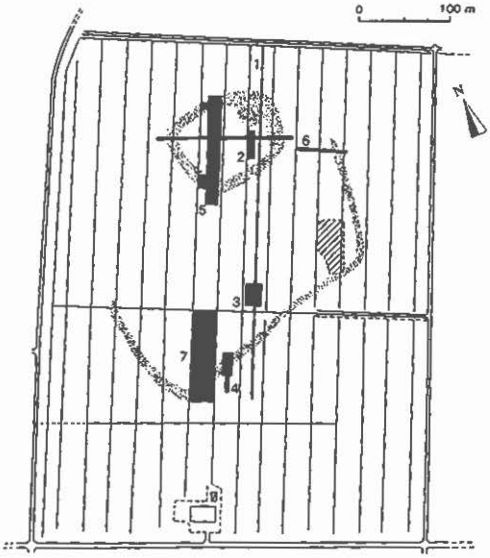

Fig. 2 – Map of the S. Rosa terramara. Dotted areas indicate ramparts as they appear in aerial photographs; in grey, area excavated up to now.

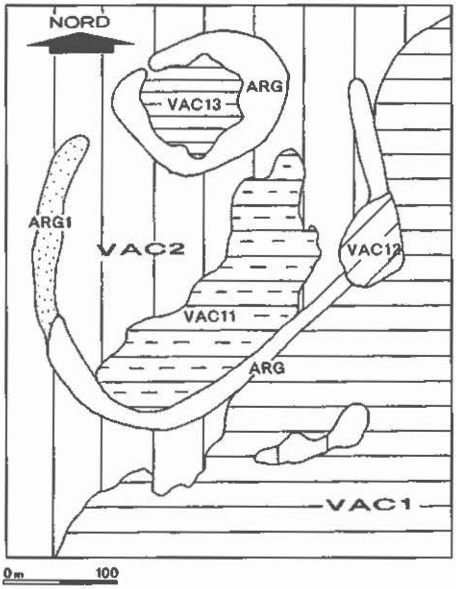

Fig. 3 – Main soil series in the area of the terramara. VAC1 indicates the 'serie estense' of chromoxerert developed on early medieval fine textured alluvium; VAC2 indicates the 'serie fiuma' developed on late medieval fine textured flood deposits (after CREMASCHI *et al.* 1994).

MACROSCALE	DIGITAL TECHNIQUES	MICROSCALE
DEM (cartographic, contour level 1 mt)	Contour lines interpolation (kriging, bicubic). Surface visualisation	DEM (created by total laser station, contour level < 30 cm)
RASTER Photomosaic of aerial photographs (1:10.000)	Histogram matching and digital overlay of all images (aerial photos)	**RASTER** Photomosaic of archaeological excavations (grid, sectors, etc.)
VECTOR • Cartography • Geology • Archaeological sites • Paleoenvironment data	Cartographic data input, georeferencing, digital classification of layers	**VECTOR** • Stratigraphical Units • Topographical data • Archaeological finds • Non anthropic data, etc.
IMAGE PROCESSING Digital processing of aerial photos for enhancing features	Segmentation techniques, digital filtering and classification	**IMAGE PROCESSING** Digital processing of excavation photos, photomosaics
DATABASE • Topographical units • Sites classified	Database standardization, statistical analysis, data input	**DATABASE** • Stratigraphical Units • Pit and post holes • Excavation data
3D PROCESSING Virtual landscape reconstruction	Texture mapping, 3D contour lines interpolation	**3D PROCESSING** Virtual site reconstruction (using stratigraphical layers)
VIRTUAL REALITY Real-time navigation through the 3D archaeological landscape	3D interactive navigation using ArcView (3D Analyst) and VRML browsers (SGI Cosmo Player)	**VIRTUAL REALITY** Real-time navigation through the 3D archaeological excavation

Tab. 1 – Summary of the main features and sources of the project.

of the XI century BC (Bernabò Brea, Cardarelli, Cremaschi 1987; Cardarelli 1988; Mutti 1993; Bernabò Brea, Mutti 1994; Bernabò Brea, Cardarelli 1997).

Subsistence strategy of the terramare civilisation was mainly based on intensive agriculture and pastoralism, which required a systematic deforestation and some management of the drainage net. In their apogee the terramare reached an high density peopling (a site each 10-25 square kilometres) and represented the "monumental" aspect of a diffuse and dense settlement system of small sites, not structured, showing the existence of a detailed exploitation of the rural territory. The Bronze Age settlement as a whole produced an outstanding impact through deforestation and agriculture and turned the natural environment in a ranked landscape of power for the first time in Northern Italy (Cremaschi 1991-1992; Balista, De Guio 1997; Cremaschi 1997).

Integration of traditional research fields (geomorphology, palaeopedology, surveys, archaeological excavation) with Remote Sensing and GIS techniques has been made in order to reconstruct the diachronic landscape sur-

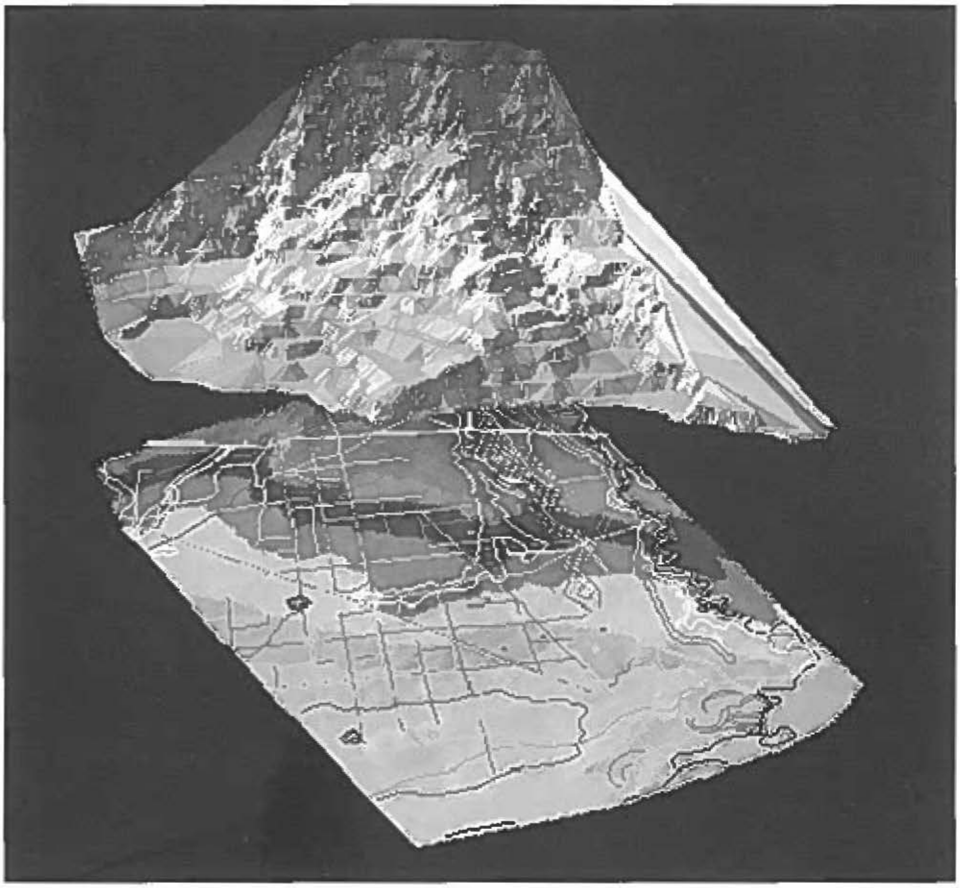

Fig. 4 – 3D multilayer visualisation (TIN and grid interpolation) of the central Po Plain (Reggio Emilia): by thematic layers (bottom) and by geomorphology (upper).

rounding the terramare, the structure of the sites and the physiographic relationship between sites and territory.

A sample, here illustrated, concerns the northern valley of the Enza (Reggio Emilia-Parma) where the largest sites (from 7 to 14 hectares) of the whole terramare system exist (Fig. 1). On the basis of Remote Sensing and GIS applications, geomorphological, pedological (Holocene alluvium) and archaeological data (coming from extensive excavations and systematic surveys) have been processed in 2D and in 3D (DEM, digital aerial photographs, raster data, vectorial data and cartographic data). Final reconstruction of a 3D ancient landscape has been made integrating every level of information and interpretation.

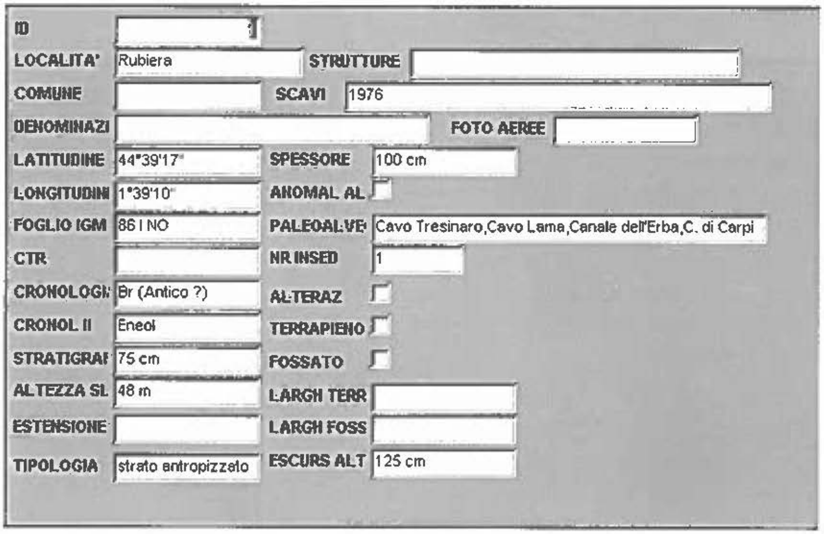

Fig. 5 – Screenshot of a record of the territorial database.

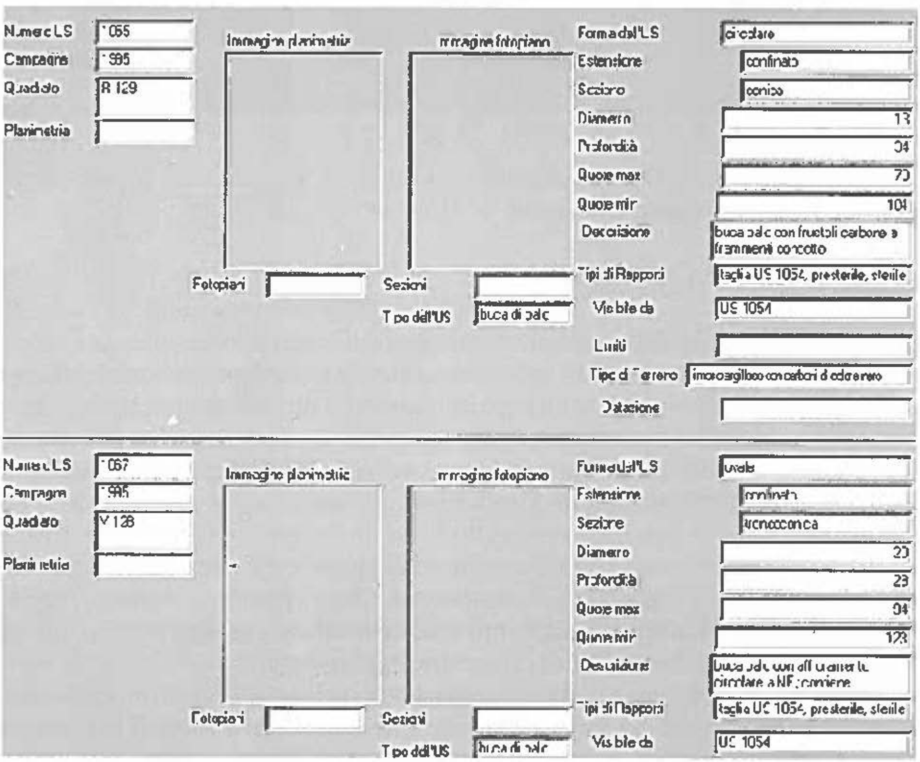

Fig. 6 – Screenshot of a record of the post holes database.

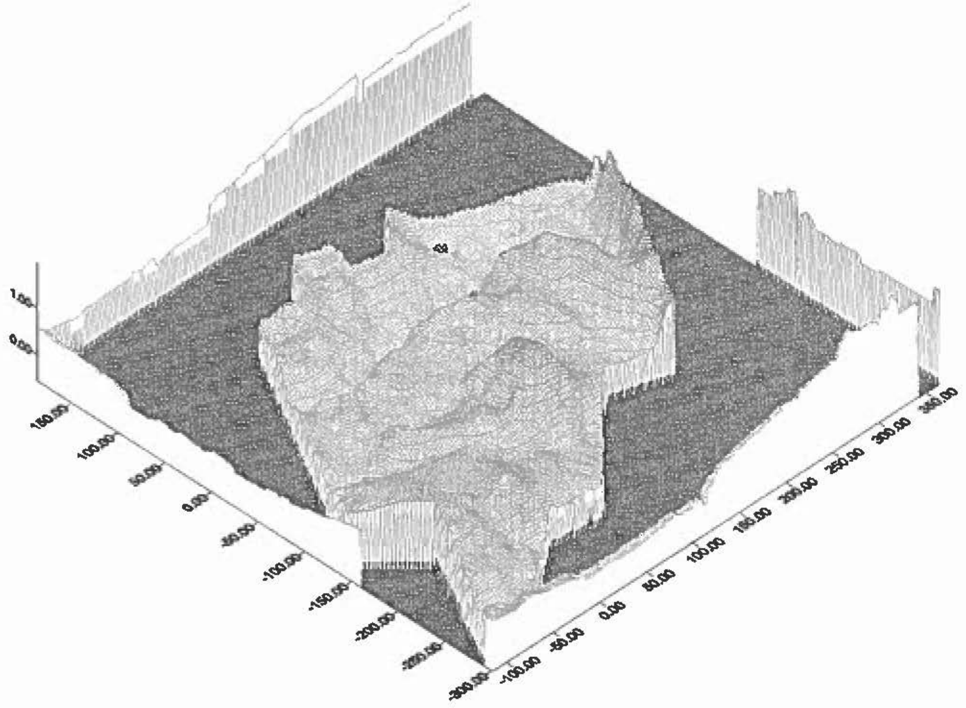

Fig. 7 – 3D DEM visualisation of the site of Monticelli (Reggio Emilia).

3. Terramare and landscape

Geomorphological evidence, integrated with microrelief and aerial photograph survey has shown that only a part of the Bronze Age landscape is still preserved. The shift of the main river course and the overbank deposition (since Roman Age: Cremaschi, Marchetti, Ravazzi 1994) buried a large part of the Bronze Age landscape of the Po Plain. It is possible to identify traces of this ancient landscape on the present topography and, specifically, in the northern part of the Enza river basin. So we have created specific DEM (isolines 1 mt) correlated with other raster (aerial photos, digital cartography, Tavv. IIV-V) and vector data (thematic layers, Fig. 1): the comparative analysis of each information allows us to reconstruct dynamic models of different landscapes through the time.

The results of this articulated process produce a digital model which allows us to move, navigate and explore like a real landscape. This is especially useful for investigating the evolution of a landscape and its ancient settlements and for interpreting the main geo-archaeological features: a main

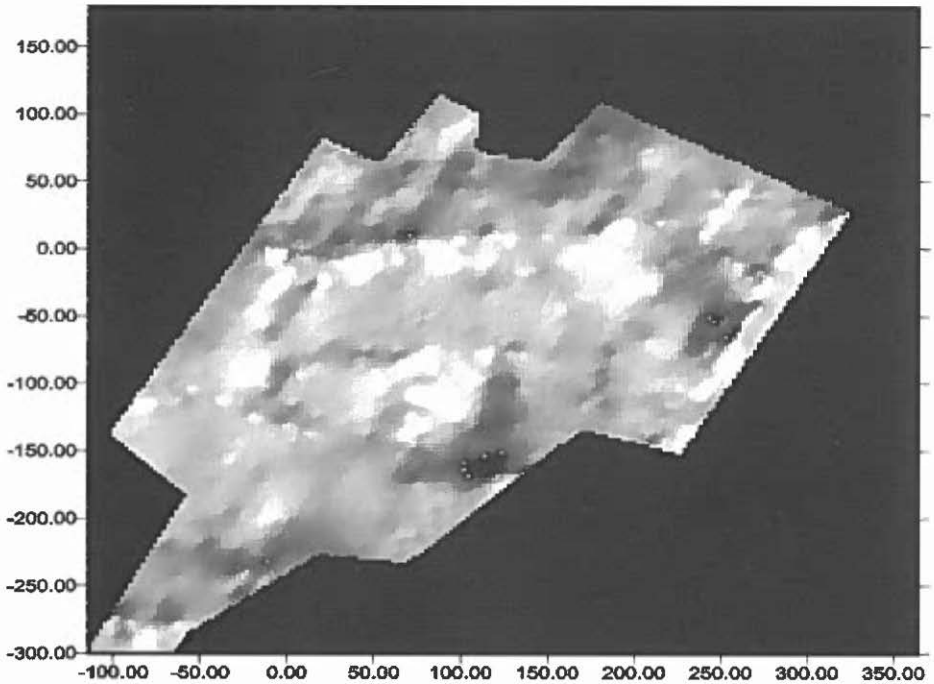

Fig. 8 – Shaded relief image of the DEM of Monticelli: in evidence shape and morphology of the embankment.

paleochannel of the Enza river (Fig. 1, Tav. IVa) is cut in a Late Pleistocene alluvial fan, the northern fringe of which was delimited by a paleochannel of the Po river. Both paleochannels were active in Middle and Late Bronze Age (Middle Holocene); in this area some of the largest sites (Case Cocconi, Case del Lago, Monticelli, S. Rosa, Motta Balestri) of the whole terramare system occur, which connect the Apennine fringe to the Po river. These sites are disposed along the Enza paleochannel up to the Po paleochannel but not in direct relation with it, and their ditches were fed by a net of minor meandering water courses, trending toward N-E.

Observing aerial photographs of this area, the orientation of the meandering water courses is in clear contrast with the present drainage pattern which is oriented to the North. Main trend of the field orientation of the area is NE-SW and it is inherited from the Roman centuriation frame (CREMASCHI, MARCHETTI, RAVAZZI 1994). However, terramare structures are in conflict with this orientation because they are tilted toward NE, such as the minor water courses pattern.

Furthermore centuriation covered and some times surrounded a former agricultural frame. In the study area this is particularly evident at Case Cocconi where a quadrangular area, delimited by ditches (CREMASCHI 1997), about 60 hectares wide, surrounds the site, seven hectares wide (Tav. III). Similar pattern was also recovered around the terramara Castello del Tartaro, north of the Po river (BALISTA, DE GUIO 1997). These patterns occur mainly around the largest terramare and they can be interpreted as features of a structured agrarian landscape (CREMASCHI 1997). This fact and the evident rank site distribution indicated that the Bronze Age landscape in Northern Italy was mainly man made and correlated to power strategies: in a few words, a *landscape of power* (CREMASCHI 1997).

4. DEM AND MODEL CONSTRUCTION

Geoarchaeological analysis of the landscape in the central Po Plain (CREMASCHI, FERRETTI, FORTE 1994) has shown the need to create specific cartographic and microrelief detailed models (FORTE 1995, 1997; FORTE, GUIDAZZOLI 1996), because the cartographic data available (printed or in digital format from 1:50.000 to 1:10.000) were inadequate for significative archaeological representations. So in our cases the construction of the models has been made on two different level of detail:

– micro-scale (level of detail = site, intrasite analysis); DEM construction on cartography 1:10.000 (contour levels digitalisation, with interval of 1 mt);
– macro-scale (level of detail = territory, inter-sites analysis); DEM creation on the ground by total laser station (grid size of 1 x 1 mt, contour levels interpolated each 20 cm).

Both DEM have been processed with ArcView 3.0a (3D Analyst) by grid, and by TIN (triangulated irregular networks) models in order to have comparative situations of raster interpolations.

Grid interpolation is a representation of surfaces using a mesh of regularly spaced points (Fig. 9). The grid model is simple and processes on them tend to be more efficient than those on other models. Elevation data in grid format is relatively abundant and inexpensive. On the other hand, since the rigid mesh structure does not adapt to the variability of terrain (losing information between mesh points), source data may not be captured and reflected properly in resulting analysis like interpolation. Moreover the mesh structure prevents linear features from being represented sufficiently for large-scale applications.

Triangulated irregular networks (TIN) represent surfaces using contiguous, non-overlapping triangle facets (Fig. 10). One can estimate a surface value anywhere in the triangulation by averaging node values of nearby

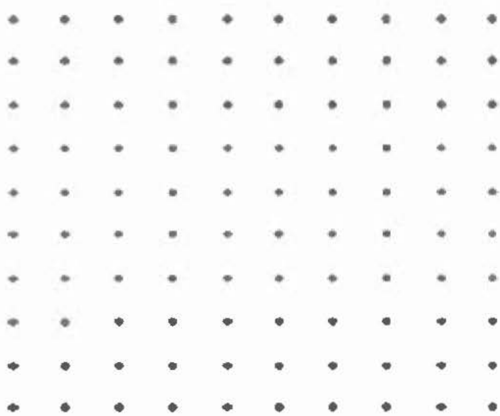

Fig. 9 – ArcView 3D Analyst: grid interpolation.

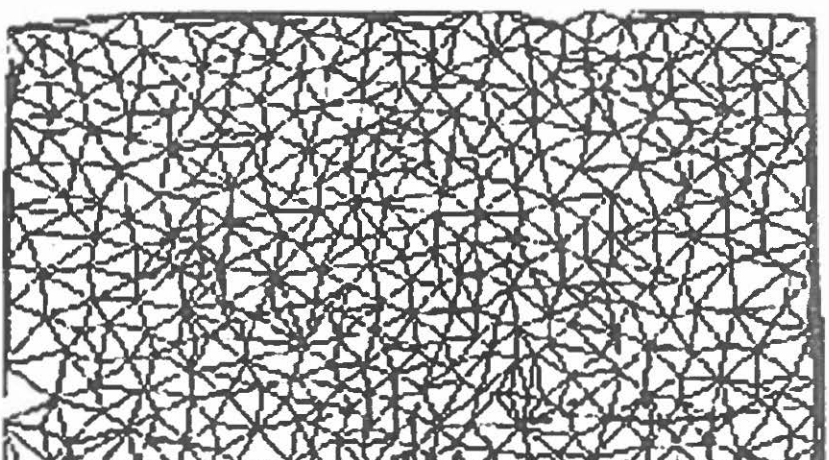

Fig. 10 – ArcView 3D Analyst: TIN Interpolation.

triangles, giving more weight and influence to those are closer. The resolution of TINs can vary, because they can be more detailed in areas where the surface is more complex and less detailed in areas where the surface is simpler. The coordinates of the source data are maintained as part of the triangulation, so subsequent analysis, like interpolation, will produce the source data precisely; no information is lost. Unfortunately TINs tend to be expensive to build and process. The cost for having good source data can be high and processing them tends to be less efficient than grids (ArcView 3D Analyst Handbook).

Tipically, grid are used for micro-scale applications, in our case the site, and TIN are applied in macro-scale processing, in our case the whole territory and settlement system of the Middle and Late Bronze Age.

It is very important to consider the quality of the DEM, knowing the type of the original source of data and the raster processing algorithm used to convert the original elevation data into a regular grid. Once a DEM has been created, we can apply a wide range of processing and display techniques in order to extract information held with a DEM:

– DEM interpolation, i.e. using IDW, Inverse Distance Weighted interpolator, assuming that each input point has a local influence that diminishes with distance; Spline, a general purpose interpolation method that fits a minimum-curvature surface through the input points; Kriging, where the distance or direction between sample points reflects spatial correlation that can be used to explain variation in the surface; Trend method, that fits a mathematical function, a polynomial of specified order to all input points;
– DEM processing by alghoritms: interpolation, slope (percent and degree), shaded relief, image, colour drape, etc.;
– DEM visualisation with the possibility to navigate through the model;
– integration with other kind of data (vector or raster, texture mapping).

So we have decided to apply these methods on all archaeological sites, comparing the DEM processing with detailed surveys and mapping. The case of terramara of Monticelli (Castelnovo Sotto) appears to be rather well preserved: the plan of the village, rather complex, is quadrangular in shape, but similarly to Poviglio a smaller squared structure is surrounded by a larger archaeological area which lies on the back on the external rampart (Figs. 7-8). A minor water course, which probably fed the ditches, is now interposed between the small and the larger village.

The terramara of Case del Lago is probably the largest terramara of the area being 20 hectares wide. The digital model (Tav. VIIa), assembling the microrelief and the aerial photographs, shows the large squared rampart which delimits the south-western part of the site: also in this case the thickest part of the stratigraphy in shape of shallow mounds is in the internal part of the rampart. A large depression appears in the centre of the site and it corresponds to the 18th century quarry. However a depression is still evident connected with perennial springs on which the oldest part of the village was built up (CREMASCHI 1997).

The terramara of Case Cocconi (Tav. III) was presumed to be definitively damaged by quarrying and agricultural practices, and the reconstruction of the original shape of the village was difficult and ambiguous (CREMASCHI 1997) on the basis of traditional approaches. On the contrary (Tav. III) the microrelief (DEM model) has shown that a square mound corresponds to the present site extension, while it is slightly damaged in the south-western part by recent land reclamation.

5. DATABASES

Our present effort is to input in digital format the most part of the documentation available (from the excavations of S. Rosa to all the settlements known in the Po Plain): so we are studying protocols and interfaces of standardisation so as to input all the data in a GIS. This step is very important because the risk is to lose information and the possibility to undertake adequate researches crossing every kind of alphanumeric datum. The software used for these application is Access, choosing specified interfaces on the basis of the information fields.

The first database created concerns the post holes (about 7000) of the Bronze Age houses and village of S. Rosa (Fig. 6): the aim is to process these data by GIS spatial analyses for identifying planimetries of houses and other anthropic structures. In fact, combining the 3D analyst and the spatial analyst of ArcView, it is possible to compare in 2D and in 3D distinct hypotesis about orientation and features of the structures. The file involves: shape of US, extension, section, measures, height, description, stratigraphic relationships, visibility, type of terrain, chronology (Fig. 6).

The second database (Fig. 5) includes documentation of territorial data, concerning settlements not excavated, investigated by surveys, excavated in the last century. In this case the file includes these information (Fig. 5): ID and topography, UTM coordinates, chronology, height, extension, tipology, excavations data (chronology), thickness of deposit, aerial photos, anomalies, paleochannel, stratigraphy, number of settlements or identified structures, presence/absence of embankment and ditch, maximum and minimum 2 scale of surface.

6. FROM THE LANDSCAPE TO THE SITE: THE CASE OF S. ROSA

The terramara of S. Rosa is 3 km south of the present course of the Po river, but close to its paleochannel active during the Bronze Age. The archaeological excavations under direction of M. Bernabò Brea (Soprintendenza Archeologica dell'Emilia Romagna) and M. Cremaschi uncovered about circa 4000 square metres of the ancient village. The site was a large settlement directly linked to an active Po river paleochannel. The plan of the village is rather complex: it is about 7 hectares wide and in aerial photographs it appears clearly composed by two units: a smaller village surrounded by a large earth rampart which appears on the ploughed terrain as a strip of light coloured earth contrasting with surrounding dark vertisoils, and a larger part which is surrounded by a u-shaped rampart, delimiting the site to the south and facing the smaller village to the north (Fig. 3).

Archaeological excavations demonstrated that the small village is the oldest part of the terramara, which was founded in the XVI century BC; the large village and the rampart in the small village were built up in the XIV century BC.

Comparing aerial photographs with the results of DEM visualisation techniques (CREMASCHI, FERRETTI, FORTE 1994) it is possible to interpret a more detailed model of the site (Tav. VIIb). A new 3D visualisation (grid interpolation, Tav. VIIb) shows the earthwork of the large village, while the surroundings of the small village are level and it is low in the centre. It is very important to emphasize the minimal differences in elevation because in 7 hectares the maximum difference in level is only 93 cm. In the southern part of the site a depression still exists where the former ditch surrounding the village was filled by alluvial deposit mainly during Roman and medieval times (RAVAZZI, CREMASCHI, FORLANI 1992).

The maximum stratigraphic thickness of the large village is not connected with the rampart but with the internal part of the village. The results of the archaeological excavation (BERNABÒ BREA, CREMASCHI 1995; CREMASCHI 1997) have shown that the rampart is a large but flat structure, and the highest areas are connected with the thickest stratigraphic sequences and with rectangular houses. As the dwelling structures were mainly made by wood, dissolved by pedological processes, the thickness of the archaeological layers is mainly due to the high content of pottery fragments and remnants of clay hearths.

The area of the small village is unexpected flat; this fact is in contrast with a 19th century map indicating the area as 'Castione' (small hill) and with the large rampart surrounding this part of the site. Archaeological excavation demonstrated that the original archaeological stratigraphy (a small hill some metres thick) was removed by quarrying dating back to the last century (BERNABÒ BREA, CARDARELLI, CREMASCHI 1987; CREMASCHI 1997).

Late alluvial processes concerning the area of the terramare are clearly highlighted by DEM processing and by the interpretation of a new soils map (CREMASCHI, FERRETTI, FORTE 1994, fig. 3). Two series of chromoxerert surround the terramara: the VAC2 "serie fiuma" is weakly developed and only light coloured, while VAC1 "serie estense" is dark coloured and has evidence of carbonates removal (Fig. 3). They were deposited in two phases after the Roman period, as Roman age archaeological finds lie at the base of the older serie of soils (VAC1) coming by floods from NW which submerged the more depressed area of the terramara and sealed the ditch depressions. These floods show the shift of the Po channel to north and that large part of landscape of the terramare is buried by later alluvial deposits.

7. Digital dig: an experiment

One of the scientific aims of the project, in intra-site applications, is to integrate in a GIS all the documentation of the archaeological excavations (in our case the site of S. Rosa, Reggio Emilia), in order to include every information in a single digital georeferenced platform.

After 14 campaigns of archaeological excavation more than one thousand archaeological units have been recorded. At present it is an imperative need to study protocols and digital systems fit to archive different kinds of data, getting then new information from the stratigraphic surveys. Moreover a digital system is needed to record and archive data (graphic, image and alphanumerical data) which should substitute the time consuming and expensive conventional techniques.

During the 1998 field season a system has been experimented including following tools and procedures:

– semi-automatic raster to vector conversion of all the documentation on paper;
– high resolution digital cameras (1280×1680 with a true 1.3 million pixel sensor; 6× zoom capability, 3× optical, 2× digital) connected with RGB monitors for grabbing all the stratigraphic surfaces;
– professional boom (4-5 mt high) for perpendicular shooting;
– 2D photogrammetric software (we have used ER Mapper and Realview) in order to correct distortions, making photomosaics, drawing finds and structures in vector format;
– DEM creation with total laser station;
– vector digital drawing, step by step, by monitor and by attributing information layer (during the excavations);
– GIS connection of each vector element with databases and alphanumeric data;
– 3D reconstruction of any stratigraphic unit with texture mapping of photomosaics on the DEM;
– final 3D reconstruction of a virtual multilayer model of the excavation, a true cognitive model of archaeological data available in real time.

The final result is the digital conversion of every type of data in a micro-scale GIS, with the possibility to record information on CD ROM and, subsequently, in Internet. The whole system is very cheap and in a lot of cases it is possible to organize a micro digital lab on the site fit to input all the documentation in GIS.

8. GIS, Internet and virtual models

One of the most important final steps of GIS applications should be the communication of data available on line. In fact the chance to put information (raster, vector, 3D, etc.) in Internet give the scholars the possibility to interrogate remote systems for comparing and analysing archaeological data, from the single site or find to a whole territory or settlement system. This kind of interactivity is very important in all the cases in which we have 3D models to explore and to navigate in real time. In our sample (Tav. VIIb) the 3D GIS model of a stratigraphic surface has been exported from ArcView in VRML (Virtual Reality Modelling Language) 2.0 thus to it can be available on line using a VRML browser (we have used SGI Cosmo Player, Tav. VIIb).

The development of multimedia applications in GIS is now in progress but it will represent one of the most interesting possibilities for communicating information in the future. In particular Internet or a net of georeferenced databases could constitute the final goal of GIS, giving the users the possibility to get and to put information in real time. In our case, using the 3D analyst of ArcView, the GIS 3D models have been converted in VRML 2.0, so as to explore them in interactive way by Internet browsers (Tav. VIIb).

For instance a 3D model of a stratigraphic surface on the site of S. Rosa (including DEM and texture mapping of perpendicular photos) has been created and explored with Cosmo Player 2.1 (Silicon Graphic) as browser. Using the virtual console of the browser, and visualising the model, it is possible to move forward and back, turn left and right, tilt up and down, seeking, sliding, and so on. The interaction in real time and a user friendly interface allows us to describe the model as cognitive model: in fact during the virtual navigation we perceive new information and new ways of visualisation, without the need to have GIS softwares for representing the data. Comparing in 3D geological and archaeological data and ideas, our team has suggested new interpretations and lines of research for the project.

For instance, physical units can be described by the DEM, by slope and aspect and, in particular, the topography of sites can be determined by a visibility analysis. An inter-visibility index determines, for example, which areas are visible from a view point, given the height, the distance, and the presence of morphological structures in the field of view. The study of the

DEM is very important both in micro-scale and in macro-scale and if the DEM is integrated with the texture mapping a complete landscape representation is produced.

9. Conclusions and preliminary results

A GIS project is a very articulated set of information: micro and macro archaeological landscapes are multilayers and diachronical subjects; in particular the case study of the terramare has pointed out new and important possibilities for reconstructing an invisible landscape, integrating Remote Sensing techniques with GIS applications. Considering these virtual landscapes as cognitive models, we can maybe define them as "mindscapes" (Maruyama 1980), because through a dynamic perception we can reconstruct the global context of distinct types of data.

In fact GIS and Remote Sensing applications (in our case using ArcView 3.1 and ER Mapper 5.5a), integrated with aerial photo-interpretation, have underlined meaningfull data which cannot be obtained by traditional techniques both at the level of landscape (macro-scale) and of the site (micro-scale). At the landscape level, in comparison with traditional geomorphological and geoarchaeological approaches, computer applications lead to a better integration of data and the best knowledge of the evidence. At the level site, the construction of the DEM, texture mapping, and digital image processing has shown the structures of the terramara which did not appear clearly from aerial photographs and which were confirmed by the archaeological excavations.

Furthermore, together with the forming processes, also the degradational events which followed the abandonment of the site were highlighted. Therefore all these techniques, which are at present tested on other sites, have proved to be a valuable non-destructive method to evaluate the state of preservation of the terramare sites.

Finally, we can summarize in a few points the main applications we have processed:

- macro-scale GIS (ArcView 3.0a) for archiving and studying the territory of the terramare (Tavv. IV-V);
- micro-scale GIS (ArcView 3.0a) for archiving and analysing site and excavation data (Tavv. III, VI);
- Remote Sensing techniques (ER Mapper) in order to interpret the DEM (sites and territorial morphology, Tavv. III, IVa, Fig. 4);
- creation of GIS for archaeological excavation made by a digital system used on the ground (ArcView 3.0a);
- DEM visualisation (grid and TIN, by 3D analyst of ArcView);
- DEM 3D processing by different algorithms (ER Mapper and 3D analyst);

– analysis of visibility inter-sites (3D analyst);
– spatial analysis in micro and macro-scale (spatial analyst of ArcView);
– orientation analysis of anthropic structures (buildings, pits and post holes, stratigraphic units);
– Virtual Reality applications in VRML for displaying and navigating the models in Internet and in real time (3D analyst, Cosmo Player 2.1).

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ABSTRACT

This paper illustrates preliminary results of the research project "An inventory of the Terramare in the central Po plain: physiographic context, stratigraphic and structural characteristics, state of preservation", included in the Finalized Project Cultural Heritage, promoted by Italian National Research Council. The project involves GIS and Remote Sensing applications in order to integrate different 2D-3D georeferenced data (sites, excavations, surveys, landscape and territorial data) such as:
- raster data (aerial photographs of different periods starting from 1950, regional cartography, DEM);
- vector data (cartography, thematic layers, archaeological sites, etc.);
- DEM created by cartographic contour lines and using total laser station on the ground;
- alphanumeric data (excavations databases, territorial databases)

The methodological approach has been to represent and analyse archaeologycal data from micro-scale (intra-site) to macro-scale (inter-sites), in particular exploring the perspectives of 3D GIS visualisations, therefore we have concentrated our attention towards the topographical reconstruction of the microrelief in relation with the aerial photos (of different periods), as textures, the geomorphological features, the archaeological data. We can define this kind of processing a visualisation of an invisible landscape, because we can get back much more information from the terrain than the traditional techniques (aerial photo-interpretation, survey), in a lot of cases very useful also in order to plan an excavation campaign. Regarding acquisition and processing of multi-temporal, multi-layer and multi-dimensional data, this research deals with a large-scale detailed study of the data collected by topography, but upgraded with surveys and acquisition of data on the ground. In fact the main task of our project is the creation of detailed models on the basis of the microrelief.