GIS APPLICATIONS FOR KNOWLEDGE AND PRESERVATION OF HIERAPOLIS OF PHRYGIA SITE.

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ABSTRACT

Lately, Geographic Information Systems are increasingly exploited in archaeological studies or, generally, in projects aimed to the preservation of cultural heritage. Among the large number of reasons that make GIS a suitable tool to manage this kind of programs, at once it's possible to identify two main topics for this achievement.
The first one concerns the high capacities of GIS to enable advanced storage, representation and management of spatial data, connecting them to collections of different nature data (archaeological, architectural, historical, etc.); these archives can be suitably set and managed in several semantic levels with a spatial reference, overlaying topogaphic maps. The second order of reasons is connected with present development of geographic mapping: the improvements in acquisition, processing, management and digital representation metodologies request proper tools, in order to make new mapping products usable and widespread.
The recent growth of satellite images analyses and aerial photograms interpretation have in fact substantial role in cultural heritage documentation, supporting objectives of modern Archaeology in spotting areas of probable location of archaeological sites or finds.
The designed GIS of Hierapolis, whose carrying out is going on, can based itself on a huge amount of metric data relating monuments and diggings, collected during the last years thanks to topographic and photogrammetric surveys. Besides close range surveys aimed to document architectural structures and ruins, always originating vectorial representation, a complete digital site map at the urban scale 1:1000 has been accomplished.
The purpose to offer the chance of global data managing of city environment and architectural structures (scientists of different disciplines register and store data covering the most diverse aspects of research) have to be founded upon very precise choices about (geo)graphical database organization, mainly applied to proper arrangements of multiscale and multidisciplinary data.
This paper mostly presents our efforts and experiences to achieve this last object.

1. INTRODUCTION

For many years they used to produce ancient cities and archaeological site *plans* in which buildings location were represented along with their urban system into the point of view of town planning.
Nowadays the most common trend is replacing archaeological site *plans* with *maps* in which anthropic elements representation doesn't prevail over territorial ones, since there is a spreading trend of analysing the signs of an ancient civilization and the human organization in relation with the environment and the territory on which they developed.
Since the representation of environment and its features is increasingly felt as a need to study and interpret the human and urban settlements, the GIS turn out to be the proper instruments through which the different kinds of spatial data should be managed and connected or compared to by other data having a spatial reference. This kind of condition manifests itself in all branches of study operating in an archaeological mission.
Another interesting reason about GIS is the fact that traditional cartography, and often its corresponding vectorial products, photograph a temporal static situation when an archaeological site land, frequently subjected to fast transformations due to excavations and restorations, needs a system of documentation and representation which manages and ensures a continuous flow of information (from the point of view of the updating needs here the requests are many than in high urbanization areas).
We can say that structuring this GIS the main features that have been held into account could be sumarized in this way:

- the multiscale trait of GIS, which is one of the most important characteristics to satisfy the needs of study ranging from the archaeological findings to the architectonic structures and to the town and territory;
- the second important feature is the peculiar organization of the system arranged to aid a continuous updating of spatial data (about new excavated areas, stratification of metric information produced by excavations and restorations, in short keeping traces of any trasformation)

This last aspect is supported by the realization of a relational database (based on serverDBMS) archiving data about topographic points and their landmarks on earth. This archive, on one side, ensures the possibility to use the plano-altimetric known coordinates of a great amount of points distributed on the territory of the city to working groups of each branches for detailed surveys, and, on the other side, the relational database structure and its continuous implementation, constitute a first step for a future retrieval of spatial information and other data collections in the World Wide Web.

2. DATA ORGANIZATION

One of the basic concepts used to plan the GIS is the consciousness that the reading capability and data thematization, and, moreover, the interrogation and institution of relationships between different classes, depend on primary data organization: it means that the real system ability to develop complex and advanced analysis and data managements, is entirely due to the primary structuring of arrangement.
At the moment the multiscale organization of the global system is mostly evidenced by the presence of spatial datasets at

different scale; quality control procedures according to spatial data quality evaluation components, are used to validate data.

Next step of project will be the fulfilment of a multiusers GIS which could allow to gain access to a map server, enabling retrieval of spatial information and other nature data; this is the reason why we chose to organize datasets into a geodatabase format, which, at the moment is configurated as a simple datasets collection with closely linked attributes.

As one of the most important things to use spatial data correctly is knowing their nature, characters, boundaries in which to use them, etc., an access database having quite a simplified scheme of metadata has been devised; knowing data about data is a necessary condition in order to permit to any operative unit working at the archaeological Mission to access to spatial data and to use them consciously.

2.1 Spatial database of the city of Hierapolis

The spatial database of the ancient city of Hierapolis is mainly built in agreement with standards set for largest scale numeric cartography, meanwhile showing the evident specificities related to the requirements of an archaeological site. For example, the data grouping regarding territorial and anthropical elements has peculiar reasons within archaeological sites where, no doubt, the updating needs are marked by time in a different way; this aspect is more emphasized because the generation processes of these two data types are completely different on the map of Hierapolis.

The map of Hierapolis was born by an integration of a 1:1000 scale plan built through a topographical survey and, moreover, that land features have been extracted from a traditional map (taken over by dated photograms) first rasterized and then vectorialized (Spanò, 2002; Astori, Spanò, 2003); these two elements provided together are the information which the users learns from the first metadata form describing map.

This form includes a list of data types come together in the map; highlighting their lineage heterogeneity (adding to the previous data types, users have to know that a small number of ancient building plans have been vectorized from traditional surveys, and than registration processes based on control points constraints led their positional accuraty to tolerance range.)

Outstanding important to the users is the main information about the reference system: every user, (geologists, archaeologists and all other researchers) usually need to know if map is referenced or not to national cartography reference system.

Figure 1 shows an hardcopy sheet of site map and a mask of metadata database: while the first one, as usual, refer schematically the definition of local and geographic reference system, for planimetric and altimetric data, the second one is much more richer, showing to users also details concerning elaboration process of map.

Even datasets metadata scheme has been simplified in comparison with standards; lineage, positional accuracy, temporal accuracy and tematic consistency have been endowed upon other parameters. It is a central aspect in such GIS a proper updating of these metadata parameters concerning buildings, ruins and diggings datasets.

Afterwards we try to synthesize main topics about cartografic items organization, highlighting the geometric object type of corresponding to datasets (points, lines, polygons).

A dataset of lines and one of polygons have been arranged to group ancient city elements; the former means to represent and communicate the basic planimetric structure of ancient buildings whose thematization recalls the generical temporal periodization of the city suggested by the founder of the Italian Mission (Verzone 1977). (Fig. 2)

On the other hand polygons dataset contains objects which coincide with the buildings profiles at earth level (it is the same for the excavated streets); it has the main role to associate historical-architectonic and archaeological information in any format and photographic documentation of each building to a single identification code, and also the function to visualize and effectively point out the presence of the ancient structure. (Fig. 3)

The terrain objects are grouped in lines and polygons classes; there are the edges and the boundaries of slopes and also of excavated areas but great attention has been dedicated to the limestone trenches which are a clear sign of the water overrunning on the urban area, at first in a regulated way and then, as a sign of the city decadence, in a frean uncontrolled stream (Pamukkale is the theatre of one of the greatest natural

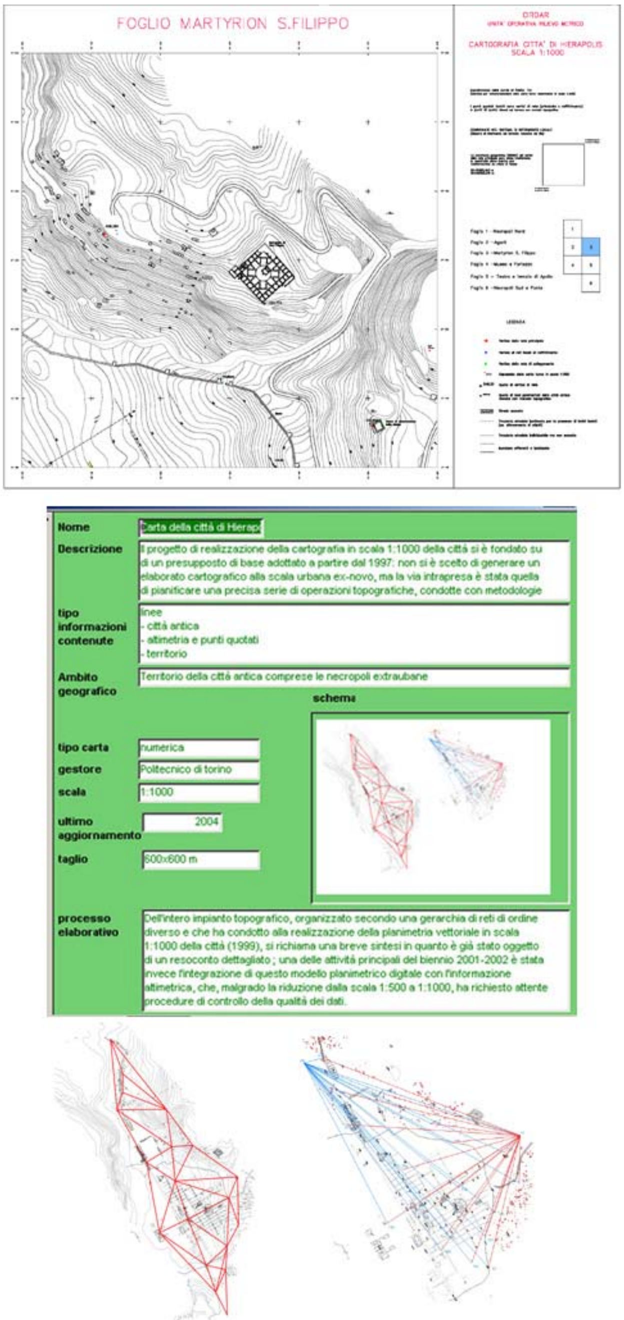


Figure 1. Comparison between essential metadata provided in sheet legend and deeper information included in map description metadata form. In the bottom the enlargement of GPS general network and a planimetric accuracy control scheme of the referencing of altimetric data to GPS network.

Figure 2. An example of ancient city dataset thematization in a zoom-in view of digital map, spotting the Agorà.

Figure 3: HTML pages are linked to objects representing buildings to visualize catalogues of images [1]

Figure 4: Limestone trenches in the western area of the city.

events in the world, the formation of limestone basins; even in the ancient time the city of Hierapolis was presumably very rich in water and trying to walk along its distribution today could add new information to reconstruct the city history).
About altimetry, all contours vectorized from Turkish map, has been arranged in a dataset; moreover a point objects dataset comprise altimetric points measured with various topographical

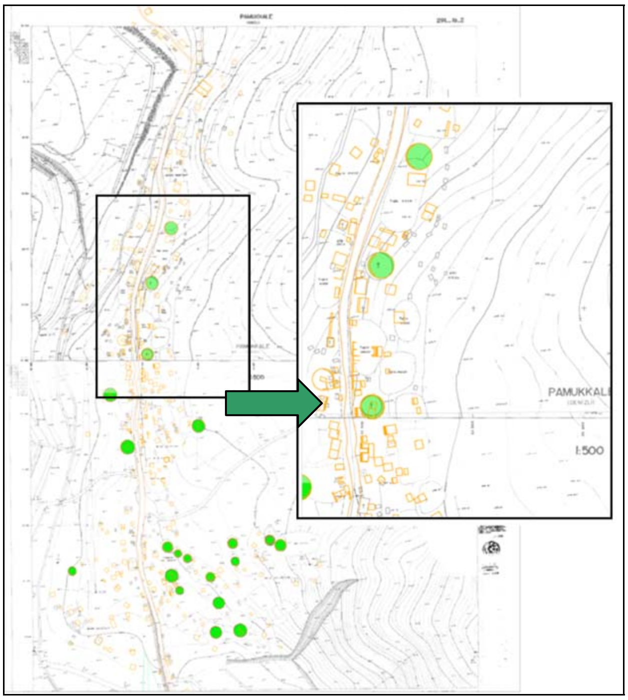


Figure 5. The Necropolis vector data overlaying rasterized and georeferenced Turkish map sheets. The rich presence of elevation points is a useful dataset stored in GIS.

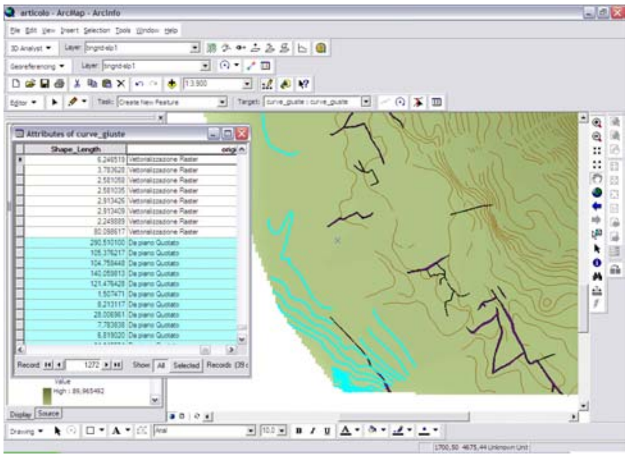


Figure 6. This selection by attributes highlights contours subset deriving from elevation points of rasterized sheets; points have been vectorized in a part of the map where there were lack of altimetric informations.

methods. This last layer contains all the plano-altimetric points belonging to three orders of networks (the main network measured with GPS survey, the second order networks and a third connection network between the two previous ones). Secondly, another large set of plano-altimetric points comprises the ground control points used to weld terrain relief data, belonging to Turkish map and measured by topographical intersections, to the GPS network. Finally numerous points measured by detailed surveys are included because their elevation is considerable in relationship with ancient structures. Obviously, attributes concerning different measurement metodologies and than points value, enable to perform thematization or any kind of query to select them.
A layers group contains all the Turkish map rasterized sheets; the raster format of this map at the scale 1:500 has been subordinated to warping processing to recover the irregular and

[1] Photos acquired from aerostatic ballon. Cassanelli (University of Pisa), 1997

Figure 7. The whole digital map displaying a possible visualization.

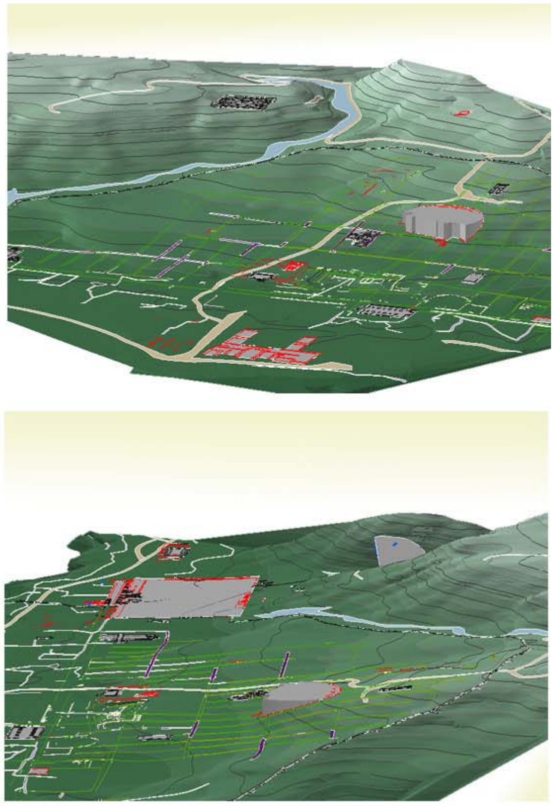


Figure 8 (a,b) 3D scenes showing volumetric relationship between theatre structures and hill slope.

strong original deformation due to wrong reproduction; their georeferencing has been possible thank to a very accurate recognition aimed to discover their marks on terrain and to the above-mentioned topographical intersections.
One of the functions of raster data is the documentation of some elements existing in the past, as the hotels occupying some areas of the site and now destroyed; another important role is the ability to provide altimetric data through dense aerophotogrammetrical elevation points which constitute an important and useful archive in case of need. (Fig 5)
Another important layer is the TIN, generated by contours; the jointly thematisms of each dataset produce a final visualization observable in the image of Figure 7.

2.2 TIN creation and 3D visualization

One of the main effects of innovation in cartography, that has led to the development of digital mapping, has been the advanced use of altimetric data; the natural consequence has been an increasing request and production of 3D mapping.
TIN creating is a very important topic within the actual researches in Geomathics, primary for the high requirements of three-dimensional reconstruction of land surface; but it also is important to perform advanced spatial analysis employing altimetric data, which can assume different shapes (vectorial formats: surface, dtm, contours; or raster formats: elevationgrid, slopgrid).
The TIN creation of central territory of Hierapolis has been realized using contours; polygons of ancient buildings and ruins and land natural objects have been used as the break-lines.
The TIN west limit, towards the declivity of the limestone basins, has been intentionally interrupted on the last contour available at 1:1000 scale, while the lack of informations interrupts the TIN in the other directions.

Generally, modelling ancient buildings or their ruins require more articulated needs in comparison with the usual extrusion of the outline of built up areas in 3D urban cartography; thinking to the important valences of the representation of the reconstructive hypotheses concerning buildings, a suitable ancient city modelling would have developed using a more appropriate environment software (CAD). Anyway, a schematic volume modelling of the buildings in a Geographic Information System can highlight the relationship between built up structures and land. We propose an exemplification considering the theatres of the city: the theatre of Flavian age, under restoration in the last 30 years of Mission activities, and the more ancient hellenistic one.
Figure 8 emphasizes the deep difference between roman and ellenistic theatres: while the more ancient ones take more advantages by peculiar terrain orography, the roman building tecniques evolution lead to the use of impressive retaining walls.

3 MAP UPDATING, MULTISCALE GIS AND TOPOGRAPHIC POINTS DATABASE.

We have just suggested that topographic points relational database is related to map updating and to the plannig of next Web GIS configuration
Before explaining archive structure we want to expound the reasons why we decided to start from topographic data as the ones to assign first to web sharing (it would be a sharing limited to italian mission working groups).
Archaeological and architectural survey demand critical reading of building structures; they need also a wide acquiring and suitable collecting of tematic and metric data that will come together in the final representation performing a very closed

integration. Then final representation is a result of objective data and detailed interpretation of the object of interest that also become graphical elements; this knowledge process is set at a very large scale, 1:20÷1:100

Contemporary it is necessary to use a smaller analysis scale to read and than visualize and comunicate the relations between case study and the environment where it lies.

The city vector plan, that has been accomplished before the site map and that has become a main part of it, arise mostly from large scale acquisition processes applied on monumental remainigs and diggings. A great deal of a low order of total station traverses were set to encompass buildings, excavation areas or other areas of interest, these networks, largely spread on ancient city territory, have the role to base topographic detailed surveys on architectural structures and ruins.

If updating of urban maps generally need aerophotogrammetric flies every 5-10 years, in a archaeological site it is interest-bearing to perform updating deriving them from large scale surveys, that are produced in any case.

Stratigraphic survey is the typical operative approach of modern Archaeology and it requires a continual assistance by topographic measurements. Since in Hierapolis every working group manages its own detailed surveys, the chance to implement a relational database, storing data useful for searching points on terrain and for using known coordinates, become clear.

After carrying out large scale surveys, typical topographic measures and processes, together with accuracy data control procedures evaluating nominal scale change, enable to achieve data integration in general map.

MySQL is the *DataBaseManagementSystem* used to manage data storage, while data entry web interface is based on PHP language

For istance, if in a certain city sector a new digging opening is decided, measurements operators will look points up in geodatabase graphic interface. If they find any, the server database connection will allow access to data, regarding precise location, precision index of points coordinates, etc.. The query result is a set of alphanumeric and photographic data visualized in a HTML page. (Fig. 9a)

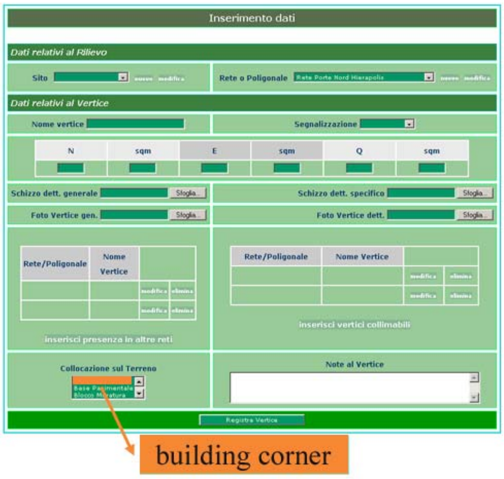
Another important utility is the chance to select topographic points with criteria connected with their location which is obviously a typical ability of GIS. Many points are located on ancient structures, and a considerable number of them are located in buildings corners. The first topographic points feature is selectable through a typical selection by location while the second one is an esplicit attribute that data entry mask interface require to fill. (Fig. 9 b-c)

This selection of selection raise to a remarkable role: if the registration of aerial or satellite images is needed, selected points can be used as high precision ground control points, to be managed in warping tecniques.

4. PERSPECTIVES

One of the most important perspective of developement is the systematics organization of data concerning each building and excavation area. The implementation of spatial datasets characterized by a larger nominal scale in comparison with the datasets which costitute the 1:1000 map, is easily reliable such as the forced visualization among a fixed range scale.

(a)



(b)

(c)

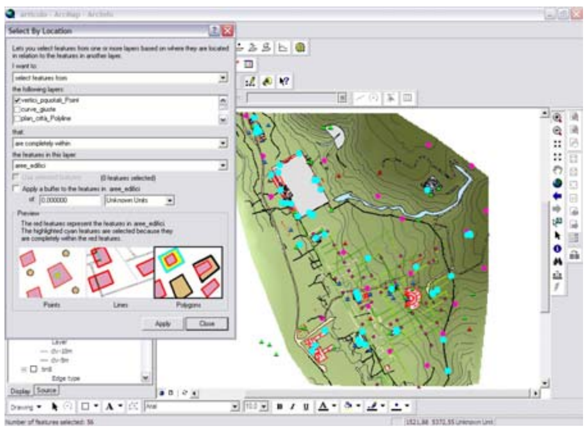


Figure 9. (a) Main topographic points query. (b) Data entry mask, with building corner attribute highlighed. (c) Topographic points over buildings spatial query.

Figure 10. Different limestone trenches spatial distribution in diverse city areas.

(a)

(b)

Figure 11. Slopegrid (a) and elevationgrid (b) are raster data useful for further advanced spatial analyses: they will be exploited to study water flow and aspests related to hills relief of streets net.

The interesting and deeper work we desire to develop on datasets at 1:100 scale and larger, is to choose geometric type classes to assign to dataset features (point, lines, polygons), in order to effectively connect existing relational database, regarding archaeological data of digging documentation or the analysis and the interpretation of collapsed walls. (D'Andria 1997, D'Andria 2003).

At the end of this first project phase, GIS managing shows that a considerable range of utilities can be directed to favour and strengthen Conservation and Valorization of archaeological site. Such map can improve potentialities of more linked works among different research branches; digital map also constitute the basic tool for proper design of tourist routes crossing the site, which will be probably set soon.

At the moment we are working on two types of spatial analyses that probable will give a contribution to some investigation sector of general researche on the site. The first one concerns the study of spatial distribution of limestone trenches crossing whole city areas, sometimes coming after contours and sometimes approssimatively following streets net.

Trenches vectorial dataset, overlaying slopegrid, derived from TIN, are the imput data to establish, through spatial anlysis, a possible setting of water flow.

In a similar way, we expect that another application, using streets vector dataset and elevationgrid, will be able to provide some data about possible connection between roads width and their directions (West-East climbing the hill, North-South coming after contours).

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