

STUDIES AND KNOWLEDGE FUSION IN ARCHAEOLOGICAL SITE MAPS MANAGED IN A 3D GIS

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ABSTRACT:

The protection and conservation attempts of ancient monumental heritage of the city of Hierapolis of Phrygia, during the last few years, are more delineated than in the past as inevitably connected to the environment context, which is characterized by the more extended and significant limestone concretions phenomenon in the world.

Studies, excavation works, ancient monuments restorations, carried out through the cooperation between the archaeological Italian Mission (directed by Prof. F. D'Andria, University of Lecce) and the Turkish Cultural Ministry are more and more connected to the safeguard and valorisation of the environmental heritage.

In such state, specific and variegated issues are requested to every group; so even the Polytechnic of Turin research unit, involved in the large scale map adjournment and the architectural metric survey of several city structures, moved objectives and researches in new directions.

The actual city map updating, realized mostly by topographical methods for ruins and architectural buildings and by contours extractions from a traditional cartography, needed an updated source of spatial data to obtain the enlargement of the original map to the surroundings areas of archaeological ruins. New fields of spatial data acquisition and data processing and managing have been adopted in order to use and adapt them to the new perspective of archaeological site conservation and management. As the realization of a new photogrammetric flight in the area of Hierapolis is not so simple to achieve for strangers, the best way to obtain a good product at low cost is the use of remote sensing techniques.

The objective of the present work is to highlight the following topics:

- Orthophoto production from remote sensing data in order to carry out geographical data.
- Data integration to supporting thematic studies (streets organizations; digital elevation model and water sliding).

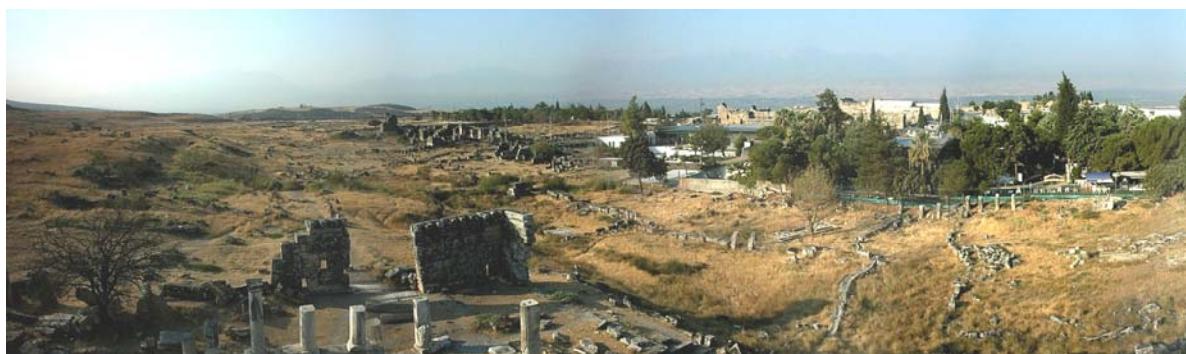
1. GEOMATIC TECHNIQUES TO SUPPORT ARCHAEOLOGICAL RESEARCH

The protection program of the environmental and monumental site, started with the inclusion of Pamukkale/Hierapolis into the UNESCO humanity patrimony list, has strongly evolved in the direction of conservation and valorisation of the whole site with significant and tangible evidences. The more important recent interventions, realized by the Turkish administration, consist in the planning and realization of visit routes to facilitate and improve the interpretation of archaeological evidences related to the environment. Moreover several areas inside the city have been submitted to a strong requalification, gained by the destroying of the hotels which were cause of a serious environmental pollution and of a real threat to limestone conservation.

The general updating of the city map has been focalized in archaeological urban zone (excavation areas) and in extra city walls areas, where the modern urbanization grown has never been surveyed and integrated in the ancient city plan. Good portions of land, inside and outside the ancient city territory, has been walked across by archaeologists to set up the so called archaeological survey, that is careful searching out and observation of human traces of settlement on terrain.

The important integration with geomatic techniques and archaeological survey allow to obtain meaningful further issues about land description, and it enable to decrease the time for map updating (scale 1:1000), on the other hand very much time is require for excavation works and close range detailed survey (by topographical and photogrammetric methods)

Figure 1. Sight of ruins and ancient limestone trenches.



In Hierapolis area remote sensing techniques has been used in order to increase data to integrate in site map, and to create a new mapping product (Orthophotomap). First of all, for orthophoto production some surveyed points are needed: in the research has been utilized points extracted from the 1:1000 scale map and some other points specifically surveyed in order to rectify the satellite image.

Moreover the orthophoto production obviously requests a digital terrain model; the altimetric model, described by triangulated irregular network or bidimensional raster, is one important component of spatial data that coexist in the GIS.

Digital map, organized in a topographic multiscale database, a raster mosaic of a traditional terrain map (produced by the Turkish administration and from which we derived the altimetric model), and the satellite projected image are data describing the site at the urban scale.

2. REMOTE SENSING DATA AND THEIR USE

The large diffusion of high resolution remote sensing data for medium scale cartographic productions, allow to obtain accurate land representation especially in areas where is difficult to find map information.

For the archaeological area of Hierapolis of Phrygia a satellite image has been acquired in order to update and to extend land description of 1:1000 the digital map realized during last 10 years by different surveys in the zone.

The digital map has been carried out by an integration of different data: topographical and photogrammetric surveys for ruins and architectural buildings (total station, GPS, digital photogrammetry) and by contours and elevation points extractions from a traditional cartography (date back 1970).

At the moment Quick-bird (Figure 1) is the satellite that provide for civil use the highest image resolution (Panchromatic data, ground sampling distance of 0.60 m and Multispectral data, ground sampling distance 2.40 m), therefore an orthoready image (georeferenced in UTM-WGS 84 coordinate system) chosen from the Digital Globe archive (March 2005) has been acquired (extension 25 Km²).



Figure 2. Quick-Bird satellite

2.1. Image processing

The image has been processed by a commercial software (PCI Geomatics an RSI software) in order to obtain an orthophoto of the research area.

First of all the pan-sharpening process has been perform by Focus PCI algorithm to carry out an high resolution colour image (Figure 2).

Moreover to obtain the orthophoto a rigorous process has been performed:

- Ground control points collections
- Check Points collections
- Digital Terrain Model generation
- Orthophoto production

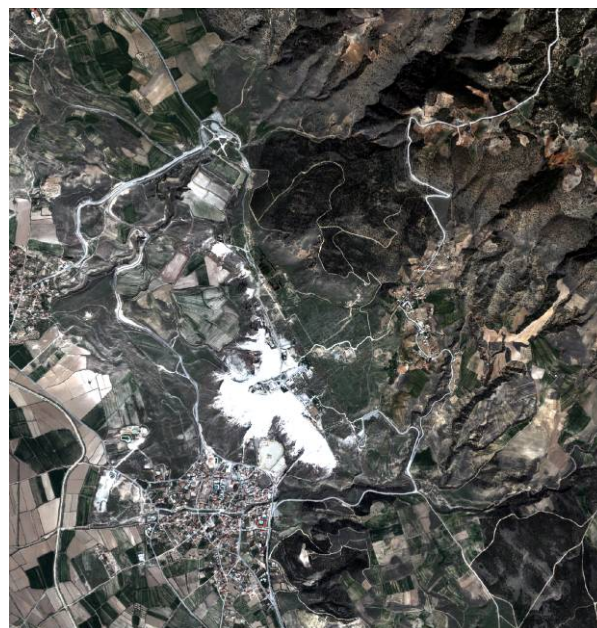


Figure 3. Pan-sharpened images of the zone

Ground control Points collections

Different points has been used for the orthophoto productions:

- Specific GPS points for general georeferentiation close to the image borders, measured in static mode (acquisition time 2 hours sample rate 10 sec)
- Points outside the ancient city measured by rapid static GPS operation (acquisition time 2 hours sample rate 10 sec)
- Total station points surveyed during the archaeological and architectural measurements
- Points measured by GPS in RTK mode and celerimetric points on architectural ruins and archaeological excavations.

Table 1 highlights the residual average on ground control points (35 GCP).

Ground X (m)	Ground Y (m)
1.10	0.86

Table 1 Ground control points. RMS

Check points collections

Another way to verify the accuracy of the model is to collect some ground control points as check points; check points are not used to compute the math model, but the software calculate the difference between their position and the position determined by the model. Therefore, the check points provide an independent accuracy assessment of the math model.

For the zone of Hierapolis some points has been used to estimate the accuracy of the product.

Table 2 show the average residual for the check points (15 CP).

Ground X (m)	Ground Y (m)
1.25	0.95

Table 2. Check points RMS

Digital Terrain Model generation

To perform the orthorectification process a digital terrain model has been realized.

The model has been carried out by different data: contours and elevation points digitalized from the old raster turkish maps of the archaeological site and quoted points surveyed during the topographical measurements.

Orthoengine (a part of PCI software), can calculate the elevation from vector layers to generate the raster digital elevation model. To perform the process a vector autocad file (.dwg) has been used.

Digital elevation model may contain pixel with failed or incorrect values, to smooth out the irregularities and create a more pleasing DEM some editing operations has been carried out.

The results is show in figure 4.

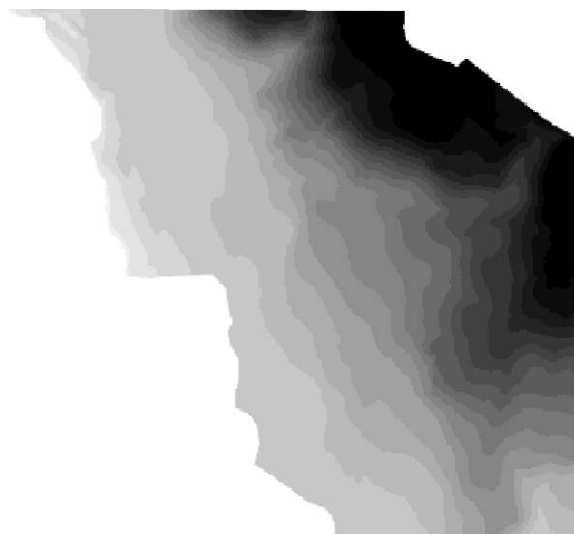


Figure 4. Digital elevation model of Hierapolis

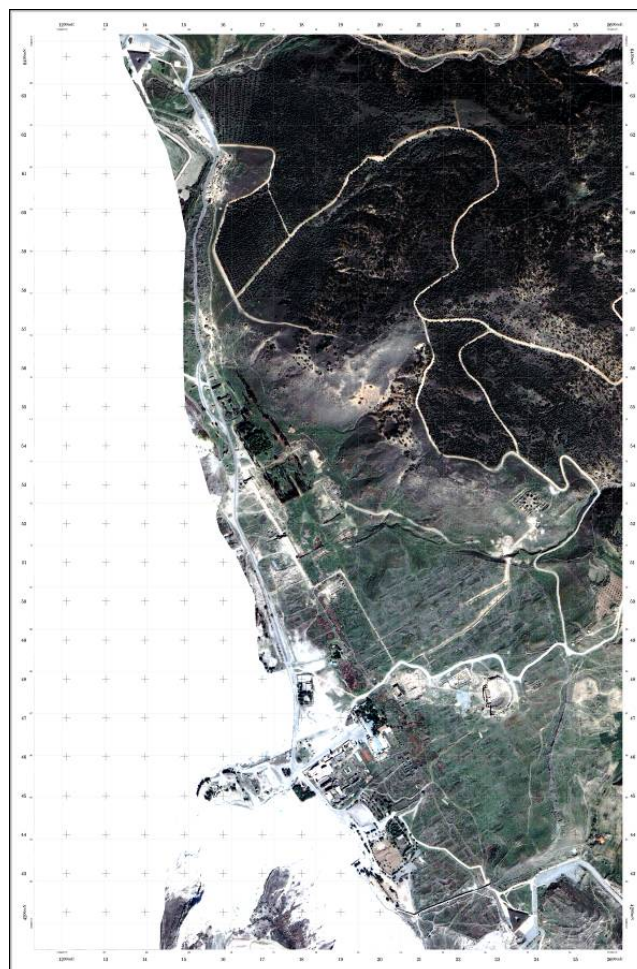


Figure 5. Orthophoto of Hierapolis original scale 1:5000

Orthophoto production

For the orthophoto generation the rigorous orbital satellite model (Development by Dr. Toutin), has been used, the model has been developed to compensate distortion such as sensor geometry, satellite orbit and attitude variation and earth shape, rotation an relief. The results is in the following figure 5.

2.2. Cartographic updating

The orthophoto of the ancient site of Hierapolis has been used for updating and testing the map scale 1:1000.

In particular in order to obtain a complete digital product some modern roads and buildings (several never surveyed by topographical instruments) has been extracted by the orthophoto (Figure 6).

Moreover some tests have been carry out to allow the accuracy of the results, the gap between some check points measured on the map scale 1:1000 and the orthophoto shows a good correspondence between the two cartographic products.

Every single architectural building respect the accuracy for a representation at scale 1:1000.

Figure 5 highlights a "new" part of the city represented in the map scale 1:1000 by orthophoto digitalization



Figure 6. Overlapping of vector data resulted from satellite data extraction.

3. DATA INTEGRATION TO CREATE NEW INFORMATION

The construction of a cartographical product in archaeological areas requires data integration from different sources and a continuous updating.

In particular, as the data derive from different sources, the management must be articulate in order to identify the origin, to outline the semantic value, and to set the correct representation of them. Adding to a meta-data collection, a very articulate and mindful sharing of information among specialists is necessary.

3.1 The ancient urban road system

The knowledge and the analysis of the ancient urban road system and, partially, of some streets outside the city walls, are one of the most interesting topics which, constantly, have been studied beginning from the foundation of the Archaeological Italian Mission of Hierapolis - MAIER (1957).

The interpretation of the urban road system, which has been a fortunate remark of the founder of the Italian Mission, prof. P. Verzone, has found the first confirmation thanks to excavations in some crossroads (Figure 7) and along some *stenopoi* (the urban streets – Figure 8).



Figure 7. An excavated crossroad



Figure 8. A lightened *stenopos*.

The researches revealed the existence of a long monumental road (*plateia*), which follows the NW-SE direction, and of a regular network of secondary roads (*stenopoi*) which are perpendicular each other.

From some years, this theme of research has recovered new force thanks to the use of remote sensing and digital aerial photogrammetry techniques, which are more and more necessary applications for the different disciplines working around the territory of Hierapolis.

First of all, the reading of the ancient road system finds, in these kind of application, a useful support for its knowledge. In fact, this is the only way to have a unified and organic view of the whole site in contrast with the terrain activities which are anyway necessary.

The regularity and orthogonality of the original road system according to Hippodameus plan system, whose planning idea goes well with the orography of the area (Figure 9), has showed

to have some irregularities due to the different form of the city during the century.

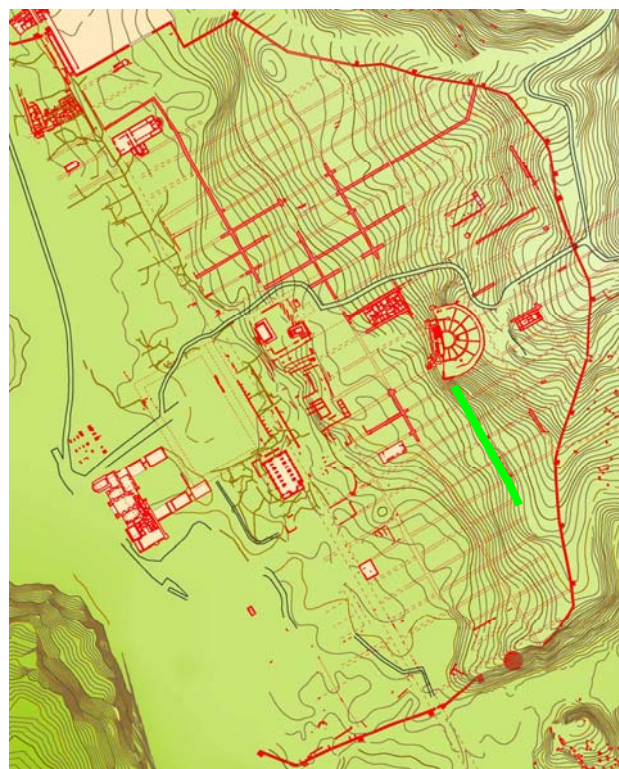


Figure 9. Map of Hierapolis: the regularity of road system and, in green, the *stenopos* of Figure 10 (original scale 1:1000)

A non metric interpretation of satellite data has been fulfilled by the University of Lecce archaeologists; some years ago they studied anomalies on raster data and they found indications about new submerged ruins.¹ Using this kind of spatial data analysis, new systematic diggings has been done and some excavated structures, located in a certain area closed to urban wall, brought to change some details about the original thesis regarding the street distribution in Christian age.²

The primary acquisition of data to analyze the road system, integrated in our digital map of urban site, has been carried out using integrated methodologies and following the two primary side of the research:

- archaeological: survey activities;
remote sensing;
- geomatic: detailed classical and GPS survey;
orthoprojection.

From many years, the topographic measurements had shown the almost perfect orthogonality of the roads distribution in a part of the urban area thanks to the acquisition of point data on visible edges of building walls and on columns and doorposts which have allowed to identify wall alignments along the streets (Figure 10).

¹ Scardozzi G. 2004.

² D'Andria F. 2003. D'andria F, (edited by) 2007



Figure 10. Identification of walls alignment

The expert reading of the wall signs on the ground, carried out by archaeologists during the last survey seasons, had enabled to integrate these kind of data providing new signs and confirmations about the regularity of the urban road setting.

Such integration of different spatial data and their management in the same reference system can be very important in order to support and deepen studies of city organization.

For these reasons, managing these kind of data to create a dataset of general topographic database, needs to classify data in a unique class “*ancient network road*”, to distinguish from *modern road network* (each of them belong to larger dataset called “*ancient human artefact*” and “*modern human artefact*”). In both *dataset*, one attribute concerning the origin of data reports the method used to acquire them:

- classical topographic survey;
- GPS in RTK mode survey;
- orthophoto vectorialization;
- archaeological interpretation.

The most import attribute that need to be symbolized is a semantic value of DB objects; such semantic value has to be shared between all specialists and has to synthesize many contents, starting from evidences to archaeological or architectural hypotheses. The representation of them in the city map scaled 1:1000 must agree with the standard way to draw an archaeological map too. For these reasons, the representation of the ancient roads network follow these rules:

- excavated *stenopoi* or part of them are represented with polygons painted in red; they are all measured;
- *stenopoi* or crossroads which has been measured and recognised thanks to walls alignments, but which are not excavated, are represented with continuous red polylines;
- *stenopoi* or crossroads which are supposed to follow the regular distribution are represented with dashed red polylines; generally, these data derive from archaeological interpretation and survey (clearly they are not measured).³

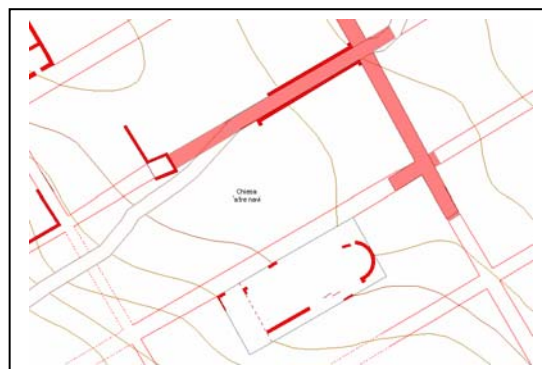


Figure 11. Excerpt from digital map managed in GIS showing ancient roads distribution in a zone of the urban area

3.2 Towards the water sliding analysis.

One of early effort is directed to refine the altimetric model of the city territory. The aims of this project are numerous: we have just refer about one purpose that coincide with an operative need connected to the satellite data projection. A second main reason consist in the requirement of represent by a traditional description, i.e. contours, the morphology of city environment.

At last, another good reason to enhance the altimetric model is aimed to arrange a metric base to deepen the water sliding analysis. Water in fact has been an important presence in the city in the past and it is still now; the richness of water has produces the limestone concretions, it has defined the buildings of various nymphaems, and it caused the rapid growth of limestone canalizations that can help the investigations on the settlement in Christian age.

In spite of some suitable differences, it is possible to assert that as the topographic DB, realized from data with various origin, has a multiscale characterization, even the terrain orography is documented with different precisions and varying detail levels, according to different zones requirements.



Figure 12. Different coloured symbol for contours to show diverse level of accuracy

³ Scarrozzi G., 2004.

The altimetric model has been produced by the following scheme:

- Extraction and vectorialization of contours (equidistance 1m) from the raster traditional terrain map, produced by Turkish administration
- Extraction and vectorialization of contours (equidistance 5m) from a mosaic of previous map.
- Processing of a general vector model (TIN)
- TIN editing integrating new break lines and altimetric mass points, surveyed on terrain. (Figure 13)
- Smoothing process applied to TIN; to perform an extraction of further interpolated contours (equidistance 1m, lower accuracy than first class).

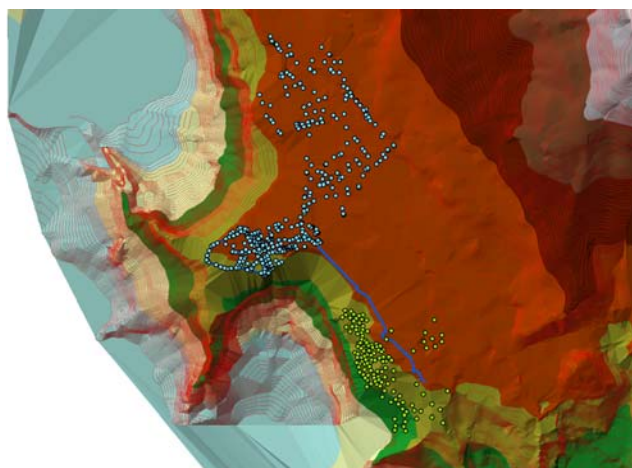


Figure 13. An editing phase of TIN production: integration of breaklines and altimetric points.

In some limited areas instead, the more accurate altimetric model can support studies regarding the slopes, suitable to analyze the sliding water that since antiquity has rendered famous Hierapolis. It will be a strategic choice to compare and interconnect many detailed data concerning adduction and sewer pipes and trenches in the general topographic database.



Figure 14. A large trench shaped by sliding water

Figure 15. Representation of an *insula*: detailed survey provide reference of adduction and sewer pipes.

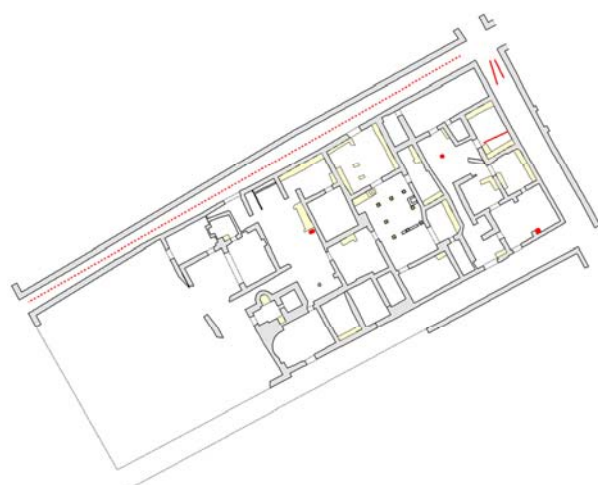


Figure 16. Big water cistern (*castellum aquae*) with pipes referencing.

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