Geographic Information Systems and Archaeological Resource Management in Andalusia (Spain)

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Introduction

As can be inferred from the growing amount of published literature, Geographic Information Systems have become, over the last ten years, one of the main areas of application of IT, within archaeology, not only in the research of spatial dimensions of past societies, but also in Archaeological Resource Management - *cf.* specific volumes, such as Allen, *et alii*, 1990; Lock-Stancic, 1995; Jonhson-MacLaren, 1997; as well as the most recent CAA proceedings.

This paper describes the current state, of the process of GIS integration into ARM, within the Spanish region of Andalusia, following the establishment of a research project (*Sistemas de Información Geográfica y Patrimonio Arqueológico* - SIGPAR), by the *Departamento de Prehistoria y Arqueología*, of the University of Seville, in 1993. Since 1995, this project has ben run under the auspices of and the collaboration with the regional cultural authorities, the *Instituto Andaluz del Patrimonio Histórico* (IAPH), and the *Dirección General de Bienes Culturales*. This project has as its focus two main areas of work. On the one hand, it deals with the migration of all of the regional inventory, for archaeological sites, into a GIS, therefore, operating at a macro, or territorial level of analysis, and involving a large number of sites. On the other hand, it looks at the GIS-based management of the archaeological record, within the historic centre of the city of Seville, therefore, facing problems associated with a single, large, multi-stratifed site. Although the integration of GIS, within these two spheres of ARM, presents rather different implications and problems, both are regarded as equally important, towards the full insertion of archaeological information into the larger frame of land planning, and therefore, towards more efficient protection of the heritage. Some preliminary results of this work have already been published, for an international audience (Amores, *et al.*, 1998), this paper being basically intended as a further discussion of the problems encountered and results obtained, so far, within this ongoing project.

The Andalusian Inventory of Archaeological Sites

SMRs and Computers in Europe. A Brief Outlook

As is well known, the production and maintenance of archaeological site inventories, as the backbone for national policies, addressed towards the protection of the archaeological heritage, date back to the second half of the XIXth century or the turn of the XIXth century (Schnapp, 1984:49; Cleere, 1984:54; Kristiansen, 1984:22; 1989:25; Startin, 1995:138; etc.) in Western Europe. For a long time, the handling of data, contained within those inventories, was performed, basically, on the basis of paper and card-index files, that involved extremely cumbersome and time-consuming procedures on data input, retrieval, query and output by hand. It was not until the impact of computers within archaeology in the 1970s, that those methods evolved significantly: in France and England, the first computerised databases for archaeological sites, for SMRs, were developed in the middle and late 1970s (Chouraqui, 1974; Wilcock, 1981; Bourrelly-Chouraqui, 1981). Since then, computerised databases have gained increasing importance, in the management of regional and national archaeological sites inventories, in Europe - see for example RCHME, 1992; Larsen, 1992 and the CAA proceedings.

However, if the process of computerisation for SMRs has focused, until recently, mainly on the creation and maintenance of *bi-dimensional* (alphanumeric) databases, it seems that the present focus corresponds to the start of another major stage, where the *spatial* dimension of the archaeological record assumes a much more relevant role. Because of their non-spatial nature, alphanumeric databases, containing regional or national archaeological sites inventories, convey important limitations (Harris-Lock,1992:188). First, they require specific data collection and input for environmental features, associated with each site (land use, topography, geomorphology, etc.), that, within a GIS, are handled separately, as thematic layers, related as a whole to the archaeological information. Second, the availability of procedures for data query, retrieval and output, using spatial parameters, is rather limited; search for and selection of information for planning (which is spatial, in its very nature), within the traditional databases for archaeological sites, is sharply inefficient, as it necessarily demands the use of paper, map sheets; whereas, within a GIS environment, data queries and selection can be easily performed, following spatial criteria. Third, within alphanumeric databases, there is little, or no possibility of spatially analysing and modelling the data (digital elevation models, viewshed, predictive modelling, etc.); whereas, this is one of the most characteristic features of GIS. Fourth, the topology, between archaeological sites and other spatial entities (*i.e.*, spatial relations that define, geometrically, an object such as adjacency, connectivity, inclusion, etc.), is ill-defined, or not defined at all; whereas, this can be (in fact, it must be, for the system to work) easily accomplished within a GIS.

The integration of (i) new concepts, data structures and formats with (ii) new analytical software and with (iii) rapidly cost-effective and more effective hardware devices, both for data input (GPSs, digitising tablets, scanning devices) and output (plotters, colour printers), as well as data

exchange (networks), makes the relationship, between archaeological management and GIS technology, a case for a whole set of disciplinary functions, being profoundly transformed by the availability of new tools (Wheatley, 1995:163). Furthermore, apart from those specific benefits, that GIS technology is able to offer, in handling the archaeological sites inventories, a more general advantage to be gained, from its implementation, is the assimilation of an entirely new, *methodological framework* (Wheatley, 1995:171; Espiago-Baena, 1997: 38), which supplies a rationale for computer handling of spatial information, that, in addition, can be shared with other disciplines and systems, dealing with land management.

Yet, even though there has been widespread acknowledgement of the *potential* advantages, for the incorporation of GIS technology, into the management of regional and national archaeological sites inventories, at present, it seems that its *actual* implementation is, in many cases, still at a largely exploratory and early stage, or has not been as straightforward as initially expected (Lang, 1993:171; Harris-Lock, 1995: 352; Madsen, 1997). In some countries, the first reports, or even executive decisions, towards the adoption of GIS into ARM, have been made very quickly: this is the case in France, where the SCALA (*Système de Cartographie Appliqué à l'Archéologie*) system has been implemented and is already operative (Guillot, 1992; Guillot-Leroy, 1995). Similarly, in the Netherlands, the ARCHIS system was promptly setup, jointly, by a number of university departments and the Dutch central body, responsible for the national inventory of archaeological sites (Roorda-Wiemer, 1992a; 1992b; Van Leusen, 1995). In England, the RCHME system began in 1993, to assess the need to include GIS, within data management systems, of the centralised, National Archaeological Record (Lang, 1995:79), but at the SMR level, this seems to remain an issue, largely dependant on specific initiatives - see for instance Robinson, 1993; Harris-Lock, 1992. References to similar initiatives, in other European countries, such as Italy (VVAA, 1992a), Sweden (Flyg, 1997), or Germany (Göldner, 1997), are also becoming increasingly available in the literature and other information sources, such as the Internet.

The Andalusian SMR

However, how does the case of Andalusia fit into this general process, towards the computerisation of SMRs in Europe? The Spanish state legally committed itself, for the first time, to the elaboration of a national list of those important archaeological sites, that deserved protection, in 1911 (García, 1989:182), but in fact the creation of systematic inventories did not start until much later. As a consequence of the territorial re-organisation of the country, after the enactment of the 1978 Constitution, each of the newly created, seventeen autonomous communities devised its own policy, concerning ARM, on the basis of slightly different, legal and institutional models (Fernández, 1992:160; Querol et alii, 1995:234). Thus, the creation of (paper-based), archaeological sites inventories, since the early 1980s, has been rather *uneven* (Querol-Martínez, 1996:215); some of the communities faced this task, as soon as their governments assumed responsibilities in ARM, while some others waited, until very recently, to do so. Just a minority of regions have

moved already towards the creation of computerised databases, to handle those inventories (Burillo, 1993; Burillo-Ibañez, 1990; Hernández-Castells, 1993) and, only one region has, so far, accomplished its full integration within a GIS (Espiago et alii, 1992; Blasco et alii, 1996).

In Andalusia (Figure 1), the first comprehensive efforts, to create an inventory of archaeological sites, date back, effectively, to 1983, when the newly created regional administration of cultural heritage devised a long-term strategy for archaeological heritage management, which included a new legislative and institutional framework (Fernández, 1990; Guirao, 1990). The first records included a core number of variables, describing each archaeological site, and were based on paper index-cards, thus, facing the data handling limitations and problems, mentioned above. It was not until the early 1990s that initiatives were taken, towards the computerisation of the records, in the form of a database for excavation records (Molina et alii, 1996) and a database for the inventory of sites (González-Fernández, 1996). The first phase of the full computerisation for the Andalusian inventory of archaeological sites finished in 1997, reaches up to almost 9500 sites, a figure that underestimates, massively, the real amount of sites in the region, because (i) wide areas have yet to be intensely surveyed, and (ii) the database does not include, as yet, the record of sites produced by a relatively large number of research projects (involving survey), that have been operating in certain areas of the region, since the middle 1980s.

Both the number and range of problems, emerging from this particular computerisation process, do not differ much from the main issues, found in other countries: e.g., inconsistencies in data description and input, within the paper files, due to insufficient normalisation and standardisation of data definition and vocabulary, the duplication of records for multiperiod sites, and the input of strayfinds and spatial entities, such as urban plots, as records - sites. Most of these inconsistencies have been, yet again, caused by poor co-ordination, among local recording bodies, and a lack of tools for standardisation and normalisation, a situation that has been tackled, over the last few years, by the IAPH. In fact, the development of this computerised, archaeological sites inventory must be framed within a larger information system, implemented by the IAPH, which contains databases of historic buildings, as well as archaeological, artistic and ethnographic objects (Ladrón de Guevara, 1994; 1996), and for which, a thesaurus of terms for historical heritage (including archaeology) has just been developed (Muñoz, 1996).

After a pilot study was carried out in a specific area (*Sierra de Huelva*), in order to identify potential problems of data input and geo-referenciation (Amores et alii, 1998), the first stage of the transference into GIS, of the Andalusian database of archaeological sites, began, involving the creation of the first, regional archaeological computerised map, and it was finished in 1996; it is now progressing through its second stage. The next section briefly describes this work.

The Migration into GIS of the Andalusian Inventory of Archaeological Sites. Problems and Perspectives

The process of creating the first computerised map of Andalusian archaeological sites was based on ARC-INFO (ESRI, 1992), version 7.2, for Unix (workstation Apollo 715/33) and involved three main phases of work (Figure 2), namely (i) data manipulation and input, (ii) visualisation and further correction, and (iii) preliminary evaluation.

Initially, the basic bulk of data consisted of the 8501 records, that made up the Andalusian inventory of archaeological sites (*Inventario de Yacimientos Arqueológicos de Andalucía* – IYAA). However, a relatively significant number of records were dismissed, right at the start, because of incomplete, or missing site coordinates, which left a total of 7784 sites, available for transference into the GIS. Given that this set of records was divided into two main groups, with slightly different features, further filtering and processing was needed, before proceeding with the data input. On the one hand, the vast majority of sites (the core of the regional inventory started in the mid-1980s as mentioned above) are represented as a single pair of coordinates recorded on the 1:50.000 cartography according to the Spanish military grid system (CUTM). On the other hand, a lesser group of sites were represented as polygons, recorded on the 1:10.000 maps, with conventional UTM coordinates, following a programme for site documentation, that was started in 1992, and that involved re-visiting every site.

Therefore, three basic steps were required to process this raw set of data. First, because two different coordinate systems were used, the coordinates of all records from the larger group were transformed from the CUTM system, that had been used for their location, into the UTM, in order to obtain a regularly, spatially-referenced set of information. Second, since the region was divided by UTM zones 29 and 30, the coordinates of those sites, located in zone 29, were transformed to zone 30, according to the standard geo-rreferencing procedure, followed by the Andalusian administration, responsible for environmental GIS data. The pilot experience, carried out within the *Sierra de Huelva* area (Amores, *et alii*, 1998), proved to be of great help in this task. Third, the centroid of all polygonal sites was worked out, so that these sites could be represented as points, as well, thus, providing additional coherence to the data set.

Once the whole set of sites was evenly, spatially referenced, the first visualisation of the map made it apparent, that the coordinates of a number of sites were ill-defined. Some sites fell beyond the limits of either, the region or their province, suggesting errors in previous stages of data recording and input. Some other sites turned out to have exactly the same coordinates, suggesting that, because of the short distances that separated them, it was impossible to accurately represent their location on the 1:50.000 map sheets. For the human eye, it becomes increasingly difficult to recognise magnitudes below 0.50 millimetres, which, in 1:50.000 scale cartography, represents 25 meters (López, 1993:66). Therefore, when locating manually, on that particular scale, sites that fall within that range of distance, it is almost inevitable that human errors make different archaeological features become the same spatial entity. These sites represented different records, within the alphanumeric

database, but once they were plotted within the GIS, they became the same entity, which caused a loss of information. Finally, some records, included in the alphanumeric database, were not sites, strictly speaking, but archaeological interventions, carried out within large single sites (usually historic centres of large, towns or cities), an inconsistency found in other Spanish SMRs - *cf.* Burillo, 1993:20

The identification of these problems, concerning geo-rreferencing and data structure, led to a further reduction of the data set (7570 sites), which finally provided the basis for the first image of the spatial distribution, for the Andalusian inventory of archaeological sites (Figure 3).

This map showed an essentially, *irregular* distribution of sites, throughout the region, both between and within provinces, with areas of heavy site concentration contrasting with important blanks. For instance, in the lower course of the Guadalquivir river (which crosses the region from the north-east to the south-west), near the city of Seville, there were densities of up to 0.39 sites/Km^2, and average distances, to the nearest neighbour, of 0.6 Kms. In turn, moving a mere one hundred Kms. to the north, to the mountainous area of western Sierra Morena (still within the province of Seville), those parameters fell sharply, to levels of 0.04 sites per Km^2, with average distances of 1.1 Km, to the nearest neighbour (Figures 6 and 7 and Table 1).

This contrasting pattern of distribution, for the archaeological record across the region, can be explained by two main sets of variables. On the one hand, there is what could be called the *historiographic factor*, encompassing those variables, that account for how the construction of archaeological knowledge of past societies, settled in the region, has evolved. Basically, the differential intensity and quality of the archaeological survey, throughout the region, since archaeology started to operate as a discipline, in the late XIXth century, can be explained by (i) the location and interests of the main academic centres and other archaeological institutions, such as museums, (ii) the development of specific research projects, and (iii) the survey methodologies – see, for example, in Figure 7, how the boundaries of the 1:50.000 grid have been used to frame surveys. Similarly, the extent to which information has been efficiently handled, since the development of a regional ARM system, also accounts for part of the spatial variability of the Andalusian archaeological heritage: in a specific province, for instance, the density of archaeological sites is determined by the particularly high number of records, with ill-defined, or missing coordinates, and which become, therefore, missing data within a GIS.

On the other hand, there is the *historical factor*, comprising those variables that explain the differential intensity of human settlement in the region, during those periods of the past, more evenly represented in the Andalusian SMR (basically Prehistory, Protohistory and Ancient History, because of the predominant disciplinary tradition, medieval and contemporary sites are rather under-represented in the data set).

Thus, the distribution of sites plotted against the altimetry map (Figure 4), suggests that concentrations of sites tend to be higher along lower terrains, such as the Guadalquivir Valley or the Mediterranean, coastal alluvial plains, and

lower. In turn, across the higher grounds of the *Sistema Penibético* mountain system, in the Southeast, with altitudes well above 2000 meters, the concentration of sites decreases significantly. Another interesting blank, in the distribution of sites, can be perceived on the marshy terrains of the lower Guadalquivir River, which was, in fact, covered by the sea in prehistoric and protohistoric periods. Strongly correlated to altimetry is the influence of hydrology, in the distribution of sites (Figure 5); this can be best perceived in the arid, southeast area, where dense clusters of sites swarm around water courses, thus, indicating the nature of past settlement patterns. Finally, the map of potential, agricultural capability, which results from a combined assessment of a number of environmental variables (soils, lithology, erosion, hydrology, etc.), suggests that there is a positive correlation, between the density of archaeological sites (and, therefore, of human occupation) and those areas with excellent, or good potential, agricultural capabilities.

However, regardless of the interpretations, that may be put forward, about the spatial distribution pattern of this dataset (about which, obviously, only a rather sketchy discussion has been made here), a number of critical advantages have emerged, from its transfer into GIS:

- The process of data processing, prior to the final visualisation of the map, has highlighted a number of problems, concerning the structure and contents of the data, within the inventory, such as inconsistencies in site definition and poor geo-rreferencing, some of which had previously gone unnoticed.
- The resulting map of the whole inventory, as it stands now, is, in itself, a powerful tool to re-assess the regional ARM policy, pointing out areas that have been neglected in the past and suggesting new priorities.
- The digital nature of this map allows a more flexible and dynamic analysis of archaeological records, against a background of several environmental and social variables.
- The digital nature of the map permits much faster and more efficient data updates, queries, retrieval and output, as well as permitting an information exchange with other organisations, dealing with spatially-referenced information, within the autonomous community.

The full GIS computerisation, of the Andalusian archaeological sites inventory is still in its germinal stages and offers many other, and more satisfactory, perspectives. Currently, the work is focusing on the correction of geo-rreferencing errors, the input of polygon sites, and the association of further alphanumeric information to the archaeological coverages. In addition, the data held, in the source database, have yet to be updated with the information, resulting from several archaeological projects, involving surveys that have been operating across the region, over the last 15 years. This will significantly increase the number of records, under control, and provide a more realistic and updated understanding, of the spatial distribution for the archaeological record. Also, the first steps have been taken to carry out a future GIS mapping, assessing the risk for the archaeological heritage and taking into account the functional and chronological nature of sites, as well as the most relevant environmental and anthropic variables (land use, erosion, natural hazards, etc.).

GIS and Urban Archaeology. The Historic Centre of Seville

GIS and Urban Archaeology

The current situation of urban, archaeology management in Spain is probably as uneven and diverse as the situation for regional site inventories, referred to in the previous section. In addition to the diversity of heritage legislations and management models, derived from the existence of regional governments, in the case of urban archaeology, city councils play a very important role in the protection of the archaeological heritage.

Despite the fact that computing has largely been acknowledged as the most suitable tool to handle the complexities of the urban, archaeological record, from a wide managerial perspective, only a small number of comprehensive efforts have been carried out in Spain so far - see the discussion in VVAA, 1992b; Campos *et alii*, 1997 and Lafuente-Ruiz de Arbulo, 1996. The urban site constitutes an archaeological unit, but yet the collection of data usually takes place through rescue excavations carried out by several different teams: hence, databases have emerged as a means to centralise discrete sets of information, mainly for research purposes. Two main management models have been developed for urban archaeology, throughout the country, one based on municipal teams and another, based on a multiplicity of teams, co-ordinated directly by the regional governments. Both models haven proven flawed, in part, because of a lack of comprehensive, integrated, data management models.

In Andalusia, since the regional government assumed full responsibility in ARM, in 1983, a number of efforts have been made, in order to put to and end the dispersion and anarchy, within urban archaeological information, caused by the proliferation of rescue excavations, carried out by several different teams. First, a unified data recording system, that would grant a standard data structure, as well as minimum levels of quality, was implemented (Molina, *et alii*, 1996) - see reference above. Second, a special administrative program for urban archaeology (*Programa Especial de Arqueología Urbana*) was designed, to co-ordinate interventions in the most important historic centres of the region, establishing, for the first time, a general overview of the availability of data, for analysis of both their architectural evolution and their current state of preservation - see Biddle-Hudson, 1973, for a pioneering discussion, and Galinie, 1992, for a more up-to-date account, in this field of work. Furthermore, this document was intended as the starting point for the further development of a number of urban archaeology risk maps (*Cartas de Riesgo*), following the example of an early Italian experience (VVAA, 1992a). These studies are addressed towards the joint assessment of variables, such as the availability of ground lots, the location of those buildings ruinous in character, and other planning variables, which would eventually allow the forecasting and scheduling of the volume and the precise location of future excavations - see Campos, *et alii*, 1997, for the first published *Carta del Riesgo*. Hence, those municipalities, with the largest and most problematic, historical centres within the region, were provided with funding, staff and an

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infrastructure, to elaborate those maps, some of which have already been published.

One of the major problems involved, in the special program for urban archaeology, is its rather descriptive nature, based on traditional urban methodology. On the basis of the cadastre map of the city, the historical evidence and the protection needs remain largely unconnected. Therefore, one of the main targets of the plan is to produce a zonification of the city, according to levels of protection and measures to be taken, by development initiatives.

The Historic Centre of Seville

In the specific case of the historic centre of Seville, the application of that plan is being co-ordinated by the Department of Prehistory and Archaeology, of the University, and is partly focussed on the *Santa Paula* sector, as a pilot study (Figure 8). This work is based on the same hardware and software configuration, mentioned above. The cartographic base is the Cadastre Map, that reflects the geometry, urbanism and ownership structure of the city. The unique polygon and lot identifiers make it possible to cross-reference information, concerning archaeology and administration.

The first part of this work involved the creation of a coverage which includes the 43 1:500 paper map sheets, that cover the historic centre of the city as well as the 10 1:1000 paper map sheets, corresponding to historic surroundings. Altogether, this coverage encompasses 320 hectares and 33.000 cadastre polygons. The creation of this coverage involved scanning, vectorization, edition, error correction, geo-rreferencing and the union of all map sheets (Amores, *et alii*, 1998).

Second, a DEM was created, based on the spot heights of the 1:2000 cartography. Since the cartographic criteria, for the allocation of spot heights, are essentially meant for architectural and urban purposes, some problems were encountered in the creation of a truly topographic map, of the current surface of the city, such as spot heights on bridges, trig points on buildings, and minor variations in spot heights, taken from maps issued by different organisations.

Third, the alphanumeric information, associated to each ground lot, was loaded into the GIS. These data refer to the topography for each period, preservation, and other complementary data, and were collected, both from published material, as well as from direct fieldwork. The complete list of coverages, produced so far, both for the whole historic centre of Seville (SE) and for the *Santa Paula* sector (SP), reads, as follows:

- Georeferenced 1:500/1:1000 urban structure (SE) tested against the 1:10.000 cartography of the *Instituto de Cartografía de Andalucía*, to test matching, between cartography at different scales.
- Digital Elevation Model (SE).
- Archaeological interventions, carried out in the city, so far (including excavated extension) (SE).
- Historic reconstruction (including empirical evidence, as well as hypothetical estimations) of the city, since its foundation, including maps of the city for all the main periods: Prerroman (s. VII-II BC), Roman Republican (s II BC - I AD), Roman Imperial (s. I-V AD), Late Antiquity (s. V-VII AD), Islam until Caliphate (s. VIII-

XI AD), Islamic African empires (S. XI-XIII AD), Late Christian Middle Age (s. XIII-XV AD), Modern (s. XVI-XVIII AD) and Contemporary (s. XIX AD) (SE general and SP in detail). See Figures 9 and 10.
- State of preservation, according to the damage caused by building systems in different stages: 1) Until middle XIXth century, AD; 2) Middle XIXth - middle XXth century; 3) From 1940s until 1960s; 4) Later than 1970s (SE last update 1994; SP last update 1997).
- Destruction caused by underground car parks (SE: 1994; SP: 1997). See Figure 11.
- Preserved historic buildings (SE).
- Intensity of archaeological survey (SP).
- Buildings of archaeological interest (SP).
- Levels of archaeological protection (SE proposed for 1994; SP proposed 1998)
- Risk analysis in the *Santa Paula* sector (Figure 12).

At present, other studies in progress concern aspects, such as the palaeotopography of the city, the quantification of already lost archaeological stratigraphy, the analysis of the dynamics of risk (considering aspects ranging from scheduling of buildings and planning initiatives, to the geometry and the extension of ground plots), and the planning of future archaeological interventions.

Altogether, the introduction of GIS, as the technological basis for a more centralised control of the archaeological work, within the historic centre of Seville, has resulted in a clear enhancement of the procedures for data handling, visualisation and analysis, previously used, and that were becoming, clearly, obsolete. However, the validity of GIS, within the urban environment, for ARM purposes, relies heavily on the existence of a precise co-ordination among individuals, teams and organisations, responsible for the collection and storage of data, *before* their input and management into the GIS. This requires, for example, efficient mechanism of computer data input, for each archaeological intervention, permanent updating, and ease of access to cartographic information, reflecting new planning applications or transformations, of the administrative status of ground lots, and also more efficient coordination among the institutional bodies, responsible for ARM.

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