Regione Siciliana
Assessorato Beni Culturali ed Ambientali e della Pubblica Istruzione
Dipartimento Beni Culturali ed Ambientali ed Educazione Permanente
Centro Regionale per la Progettazione e il Restauro

SCIENCE AND CULTURAL HERITAGE IN THE MEDITERRANEAN AREA

SCIENZA E PATRIMONIO CULTURALE NEL MEDITERRANEO

Diagnostica e Conservazione esperienze e proposte per una Carta del Rischio

LA MATERIA E I SEGNI DELLA STORIA

III

Atti del terzo Convegno internazionale di Studi

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Palermo

INDAGINI E DIAGNOSTICA – terza parte

INDAGINI E DIAGNOSTICA – quarta parte

INTEGRATED ARCHAEOLOGICAL AND GEOPHYSICAL SURVEY FOR SEARCHING THE ROMAN TEMPLE OF AUGUSTUS IN TERRAGONA, SPAIN

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Fig. 1 - Idealized illustration of the Au-gustus temple in a coin of Tiberian's emperor age.

INTRODUCTION

Tarragona's cathedral is located on the highest topographic place of the city. Romans occupied this space since the III century B.C. and converted it on a military camp since the wars against the Carthaginian, commanded by Hannibal, took place in the Iberian Peninsula. Subsequently, Tarraco was the place where the Roman soldiers arrived to conquer Hispania.

The evidence of this activity is the Roman wall that has been preserved and still surrounding the historic center of Tarragona (Aquilué, 2000).

After getting the rank of provincial capital, Tarraco started a set of urban transformations presided over the hill by a great sacred enclosure that surrounded the temple devoted to the emperor August. It is worth noticing that

Fig. 2 - Front of the Gothic Cathedral of Tarragona.

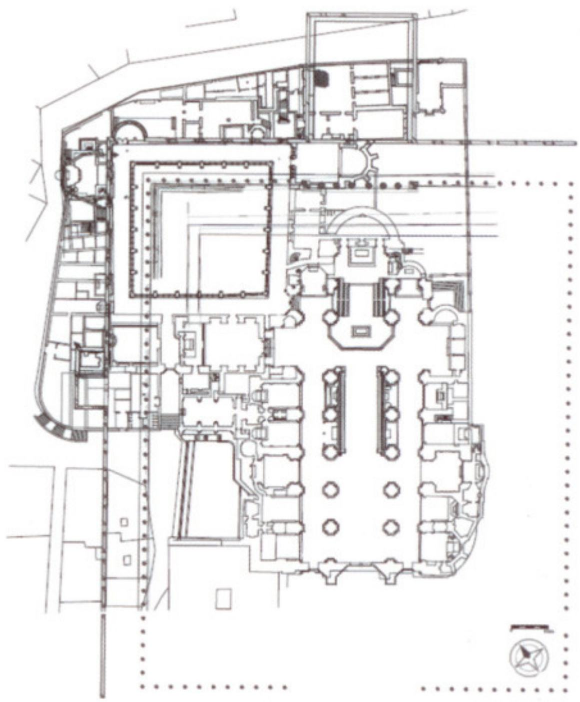

Fig. 3 – Plant of the Gothic Cathedral overdrawn are assumed the external structure of sacred area (dots).

the Roman cult was carried out outside of the temples and not inside.

Since the end of the IV century A.C. (the Christian religion was then the official one of the Roman Empire), the emperors ordered a gradual legislative process that favored the replacement of the pagan cults with the Christian ones. At this time, the site underwent many changes in urban planning and ideological reassessments. During the V and VI centuries, the urban characteristics of this zone changed radically with residential spaces - including open-air waste dumps-and spaces for official representations both civil and religious.

In this framework also the Medieval Cathedral was erected with the Bishopy and burial ground spaces.

At the beginning of the VIII century the Islamic invasion had a period of decline for more than four centuries until the definitive restoration of the metropolitan bishop and the starting of the new medieval cathedral in the middle of the XII century. Since this time, the Cathedral has dominated the skyline of Tarragona and probably concealing in the subsoil some of the answers we need to recognize and understand the historical evolution of the city (Muñoz, 2001).

The usefulness of geophysical techniques (e.g., dc current, electromagnetic, and magnetic methods) for archaeological investigation is well known and has been reported in many papers, for instance Casas et al. (1995), Dabas et al. (1993), Pérez-García (2000), Carrara et al. (2001), Negri and Leucci (2006). Therefore, as the latest archaeological researches from Macías et al. (2007) assumed that there are remains of older buildings under the Medieval See, related to the Roman emperor, a geophysical survey was considered - also taking into account the potential interest of the remains. The objective was to obtain a first picture of the archaeological remains existing in the subsoil without disturbing both the religious cult and the cultural visits to the temple.

On the other hand, the obtained results will be considered of interest to define some strategies in the future fourth phase of Director Plan for the Cathedral of Tarragona (Figuerola et al., 2002). The aim of the geophysical survey is to get as much information as possible on the structure and composition of the materials existing in the subsoil and, particularly to detect remains of foundations of previous buildings. For this reason, a detailed geophysical mapping has been conducted.

Methodologies

The geophysical methods used in this study area are based on the detection of variations in the electric and electromagnetic properties of the subsoil and the use of these data for identifying artifacts and distinguishing them from the natural variations of the subsoil. ERT, FDEM and GPR were applied.

Geophysical investigations play an important role in defining shallow subsurface structures. In particular, their application is a non-destructive and cost effective way to locate buried archaeological structures in the surveyed areas. Taking into account preceding experiences in other similar surveys three complementary geophysical methods were planned:

-Electrical resistivity tomography (ERT)

-Frequency domain electromagnetics (FDEM)

-Ground probing radar (GPR)

The first method (ERT) aimed to recognize the geometrical characteristics of the structures of the subsoil as a function of the electrical resistivity of the materials that constituted the subsoil, which in turn depends on the porosity, clay content and water content.

This method was carried out using two different multichannel resistivity meters. An Iris Syscal Plus with 48 channels for recording 2D sections and a MRS256 System from GF Instruments with 350 channels for 3D models. In both cases, the procedure for data acquisition was to apply a DC electrical current by means of two electrodes and to measure the potential generated over two other electrodes placed along profiles (2D-ERT) or regular grids (3D-ERT) spaced one meter apart over the pavement. In order to carry out the bi-dimensional profiles, stainless steel flat-base electrodes were used, similar to those used by Athanasiou et al. (2004), while to decrease the contact resistances a conductive gel was placed between the metallic electrodes and the soil pavement; with this strategy the contact resistances were set below 10 kohms.

Fig. 4 – Picture showing a portion of a 2D array using the flat-base stainless-steel electrodes.

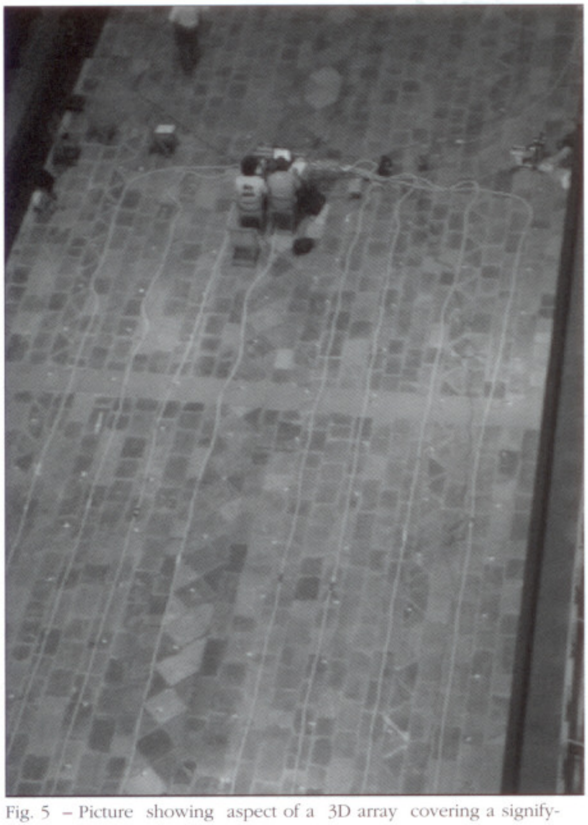

Fig. 5 – Picture showing aspect of a 3D array covering a signifycant area of the cathedral.

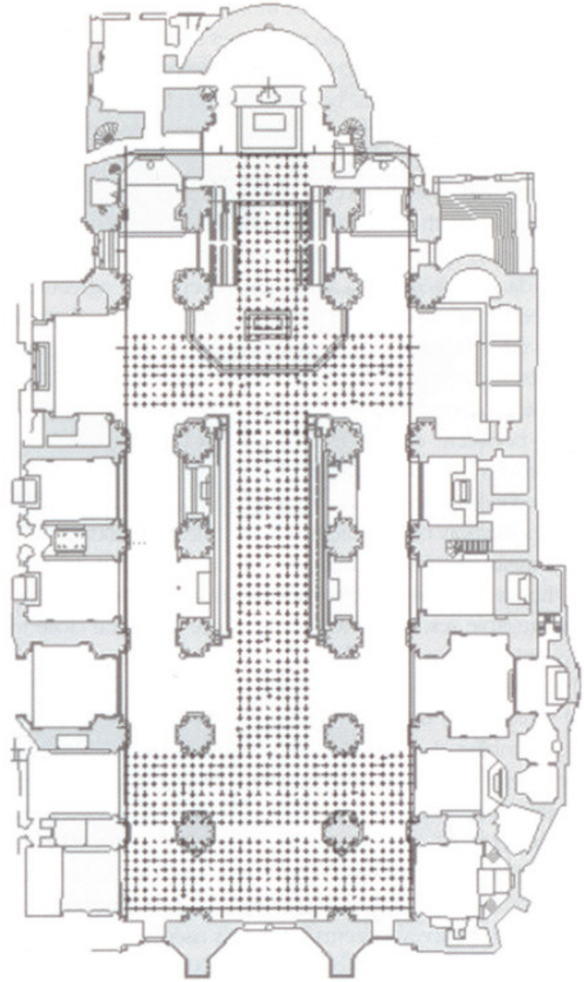

Fig. 6 – Distribution of the all the electrodes used for recording the different 3D arrays.

Twenty two profiles were recorded both in transversal and longitudinal orientation using a mixed Wenner-Schlumberger array, giving up to six thousand apparent resistivity values.
Also, for 3D acquisition the main technical problem affecting the measurements was caused by the contact resistances at the potential electrodes. In fact, we needed small-sized electrodes with limited but similar contact

resistances. A good choice was the use of disposable Foam Ag/AgCl ECG electrodes (Cosentino et al., 1999). The large amount of data, produced by multielectrode systems, requires automated data handling and processing.

To obtain a more accurate picture of the subsurface it is necessary to invert the apparent resistivity data. The inversion method was based on the smoothness-constrained least square method. In this method, the subsurface is divided into cells of fixed dimensions for which the resistivities are adjusted iteratively until an acceptable agreement between the input data and the model responses is achieved. It is based on a non-linear optimization technique by least-squares fitting (Loke and Barker, 1996). During the inversion process the root mean square value of the difference between experimental data and updated model response is used as a criterion to assess the convergence.

The second method, EM conductivity mapping, is based on the application of a variable primary field by means of a loop measuring the resulting field in another loop. In spite of the instrument used, an EM138 from GF Instruments, gave reliable results in the sectors of the cathedral close to the main door.

This effect has been justified as a result of the high electrical resistivity of the subsoil in most sectors of the cathedral which inhibit the electromagnetic induction phenomena. For this reason this technique was discarded to concentrate the efforts on the other methods which provided more significant results.

For the Ground Probing Radar survey (GPR) a Subsurface Interface Radar System (SIR 3000) manufactured by Geophysical Survey Systems, GSSI was used. Two antennae with centre frequencies of 270 and 100 MHz were used. Most of the work used the 270 MHz antenna, because the resolution obtained with the 100 MHz antenna was too low to be effective.

Appropriate data processing stacking, filtering, migration and advanced visualization techniques were applied to help in understanding and interpreting GPR data.

In addition, to obtain a significant "picture" of the underground electromagnetic discontinuities, both 3D data collection - along closely-spaced parallel survey lines with sufficient spatial sampling - and time-consuming 3D data processing were required. This in order to reduce aliasing problems.

Fig. 7 – Picture showing the record of a GPR profile along the central nave of the cathedral.

The surface of the temple surveyed by a grid of profiles spaced 0.4 m apart and a horizontal resolution of 0.02 m (50 scans per meter). Due to the need of having a greatest resolution on the central nave, a perpendicular grid was traced in order to obtain records in both directions.

The acquisition along the close parallel profiles allowed the assembly of GPR time slices making easy the correlation of anomalies recorded at the same time. This proved to be one of the most useful data presentations for understanding the nature of subsurface structures over large areas at different depths (Goodman et al., 1995). Depths were estimated from an approximate velocity analysis based on the geometry of hyperboles.

Results

Preliminary results obtained in this survey give us an idea of the archaeological potentiality of the anomalies after processing geophysical data. One of the main results is that the erection of the building of the Medieval Cathedral was carried out without completely removing the existing elements resting on the bedrock.

The anomaly, with high resistivity values up to 2000 Ω.m, which appears in the central part of most of the 2D ERT profiles is interpreted as remains of the Augustus temple basement (Figure 8).

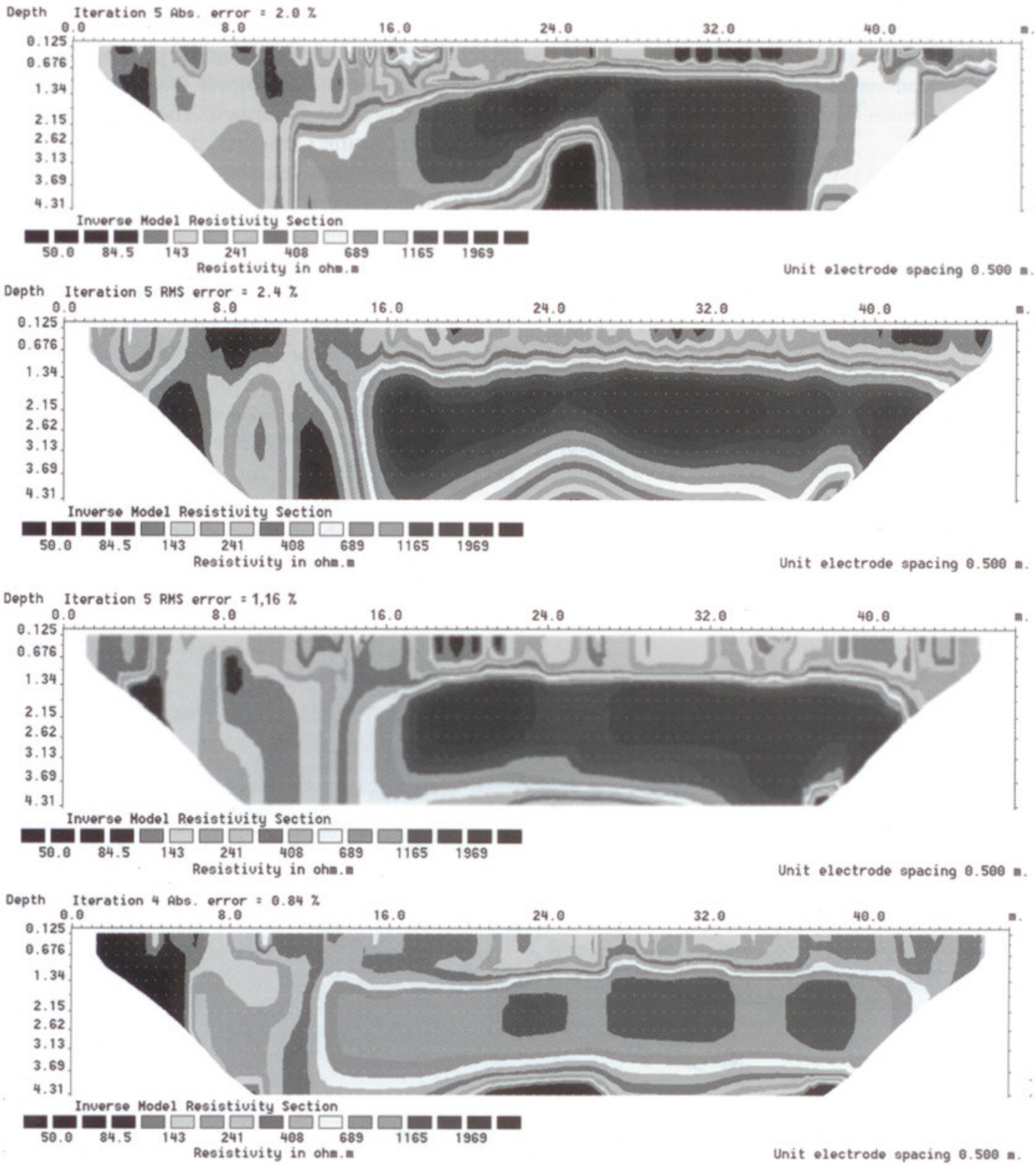

Fig. 8- Inverted 2D sections of the electrical resistivity tomographies recorded along the cathedral showing the almost rectan-gular resistive body

Using a GPR analysis, the existence of an archaeological stratigraphy is assumed and the analysis of the data suggested depth alterations or differences between the central and the lateral naves, as well as between the central nave and the main entrance to the medieval temple.

A general characteristic of the surveyed area is the good penetration of the electromagnetic energy, 100 ns corresponding to a depth of about 4.0 m when a mean velocity value of 0.08 m/ns is used. This is essentially due to the physical characteristics of the materials used for the construction of the temple (limestone), which have high resistivity values and therefore dissipate the EM energy only slightly.

In spite of the clarity of some of the described structures, it must be pointed out that their vertical projections are irregular. This would indicate a reuse of preexisting elements for the erection of the building and an irregular condition of preservation.

Conclusions

The effectiveness of the different geophysical methods in mapping the archaeological features in Tarragona's Cathedral has been confirmed. The 2D and 3D models obtained under the Cathedral of Tarragona will play an important role in archaeological investigations since they furnish a synthetic view of the location and sizes of the most important structures in the area.

The results indicate that the use of flat-base electrodes - instead of standard pointed electrodes - is a very good alternative in sites where the latter can not be nailed. It provides the advantage of fully nondestructive application and the expansion of using geoelectrical methods in environments that otherwise we would never consider.

The structure of the temple basement seems to be revealed both using 2D and 3D electrical imaging techniques. Furthermore, the anomalous areas detected by the different geophysical techniques are very consistent.

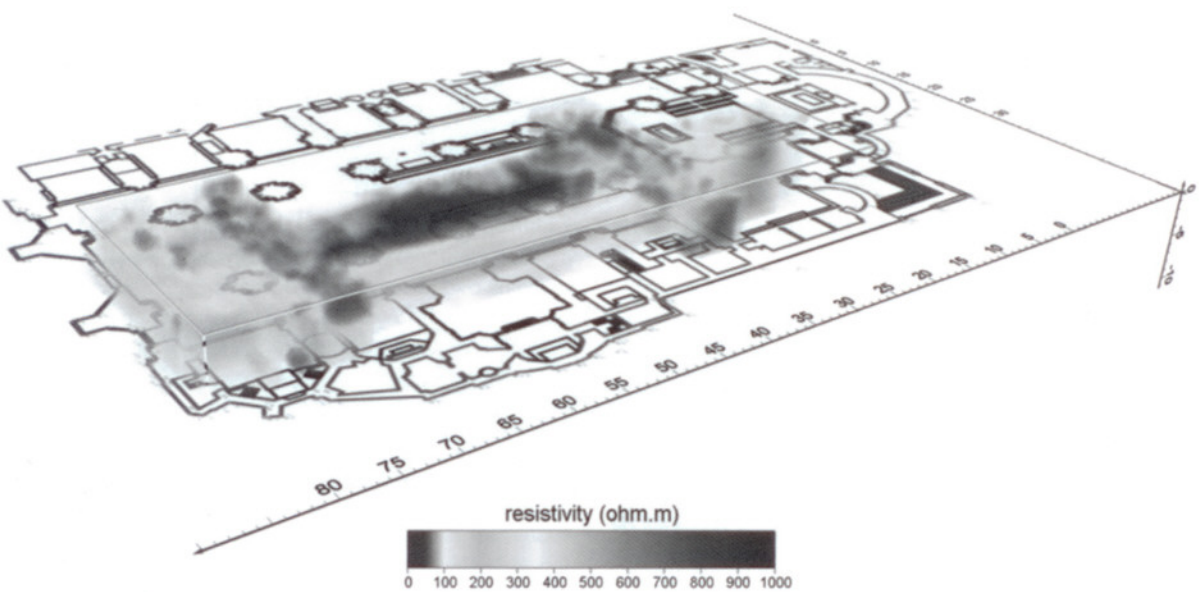

Fig. 9- 3D image of the high resistive anomaly detected under the central part of the Cathedral.

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