

Geophysical Exploration of Subsurface Structures in the Presbytery of Tarragona Cathedral

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Abstract – The characterization of the Visigoth episcopal see of Tarragona remains one of the most complex areas of research, largely due to the architectural superimposition of the medieval cathedral atop the Late Antique acropolis, which has significantly compromised the preservation of underlying archaeological remains. In this context, non-invasive surveys offer a valuable alternative for investigation. This study proposes a hypothesis regarding the location of the baptistery associated with the Visigothic cathedral, which has yet to be confirmed through archaeological excavation. While we acknowledge the provisional nature of this hypothesis, we have chosen to present our findings as a constructive contribution to future research in the area surrounding the cathedral's presbytery.

I. INTRODUCTION

An intensive geophysical survey carried out in 2007 aimed to locate the foundations of a 1st-century Roman temple dedicated to Emperor Augustus, believed to lie beneath the central nave of Tarragona Cathedral. The survey results prompted archaeological excavations that confirmed the presence of the temple's foundations [1,2]. This earlier project demonstrated the effectiveness of geophysical methods for imaging the subsurface beneath Tarragona Cathedral.

The hypothesis regarding the location of the episcopal complex is primarily based on the historical and urban context of this privileged area of the city [3]. However, no definitive architectural evidence has yet been uncovered, although indirect clues suggest the presence of other characteristic elements of the episcopal seat - such as a possible *Episcopium* and a nearby funerary area. The available archaeological data indicates a significant architectural transformation of the portico surrounding the Roman forum, as well as the dismantling of the former Temple of Augustus.

The current intervention aims to locate and define the layout of the Visigoth cathedral was situated within the axial hall of the former Roman cult precinct (Figure 1).



Figure 1. Location of the Flavian-era cult complex within the context of Tarragona's Upper Part, currently occupied by the cathedral precinct.

II. GEOPHYSICAL SURVEY

The usefulness of geophysical techniques (e.g., ERT, GPR and gravity methods) for archaeological investigation inside historical buildings is well known and has been reported in many papers, for instance [4-8].

Two geophysical techniques have been used: Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR). These complementary methods were used simultaneously to provide high-resolution image of the subsurface and to detect potential archaeological features (Figure 2).



Figure 2. Simultaneous ERT and GPR surveys at the presbytery of Tarragona Cathedral.

GPR data were collected using a GSSI SIR 3000 system with 400 MHz and 1.6 GHz antennas to balance resolution and penetration depth. A total of 51 profiles were acquired—20 in one direction and 31 perpendicularly—with 0.20 m spacing, ensuring dense coverage for 3D modelling. Data acquisition followed straight, parallel lines to maintain uniform distribution.

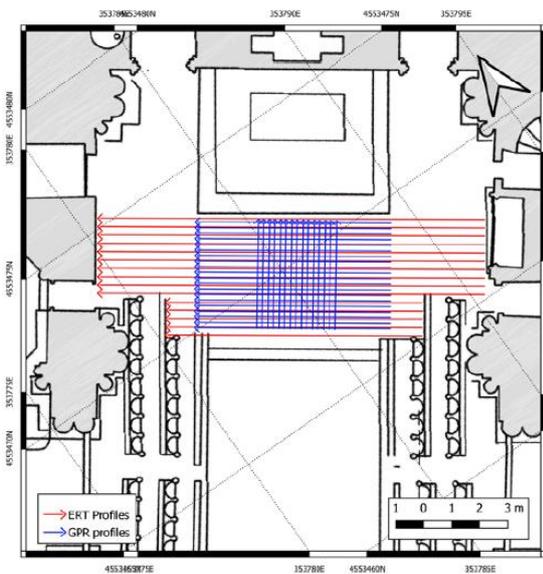


Figure 3. Location of the geophysical profiles: ERT (red lines) and GPR (blue lines).

ERT surveys were conducted with a Syscal Pro system using 48 electrodes spaced 0.30 m apart. Due to the heritage value of the cathedral's stone pavement, electrodes could not be inserted into the ground. Instead, flat stainless-steel electrodes were placed on the surface with an electrically conductive gel to enhance contact without damaging the substrate.

Twenty-one parallel profiles were acquired using a Wenner-Schlumberger array, balancing sensitivity to both lateral and vertical resistivity changes.

Data processing for GPR profiles was performed using Geolix software and included time-zero correction, band-pass filtering, time gain compensation, elevation correction, depth conversion, and time-slice generation to visualize anomalies at different depths.

For ERT data processing and inversion were carried out with RES2DINV software using a Gauss-Newton least-squares inversion method. Robust optimization criteria were applied to minimize RMS error and enhance resolution of subsurface structures [9].

III. RESULTS

A. ERT results

The analysis of the resistivity distribution allowed us to identify two distinct geo-electrical units.

The upper unit is characterized by great heterogeneity, with relatively high resistivity values (150–600 $\Omega \cdot m$). However, in specific areas—particularly at the beginning of the profiles and within the shallowest layers—values exceeding 1500 $\Omega \cdot m$ have been detected. The thickness of this unit remains relatively constant in the first seven profiles (ERT-1 to ERT-7), at approximately 1.20 m. In contrast, in profiles ERT-8, ERT-9, and ERT-10, the thickness decreases significantly, reaching values below 0.50 m.

The lower unit is characterized by lower resistivity values, ranging from 80 to 150 $\Omega \cdot m$, and shows notable homogeneity in the first six profiles (Figure 4). Starting from profile ERT-7, a resistive anomaly is detected in the center of the profiles, with values exceeding 400 $\Omega \cdot m$. This anomaly appears at a consistent location across profiles ERT-7 to ERT-10, approximately 6.20 to 7.20 m from the starting point.

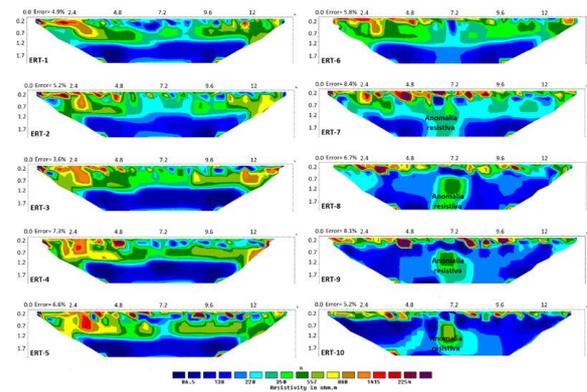


Figure 4. Inverted sections of the ERT-1 to ERT-10.

Based on the full set of profiles, the resistivity values and the X, Y, and Z coordinates of each measurement point were extracted to construct a three-dimensional matrix of electrical resistivity distribution.

Using spatial interpolation techniques, 3D models were generated to visualize resistivity variation with depth. Subsequently, low-resistivity zones were deactivated to highlight only high-resistivity areas. This approach facilitates the identification of potential anthropogenic structures, which may be related to subsurface compositional variations or the presence of materials with distinct electrical properties.

B. GPR results

In some radargrams (e.g., GPR-3), the reflectors are homogeneously distributed along the profile, with no significant anomalies detected (Figure 5 top). However, in other profiles (e.g., GPR-16), zones characterized by high-intensity and discontinuous reflectors have been identified in the subsurface (Figure 5 bottom). These anomalies are consistently located in the central part of the profiles and at depths of approximately 0.50 m. Notably, areas of high resistivity spatially coincide with the presence of strong reflectors observed in some radargrams. The correlation between both geophysical techniques suggests the presence of subsurface discontinuities, possibly associated with a baptismal pool (Figure 6).

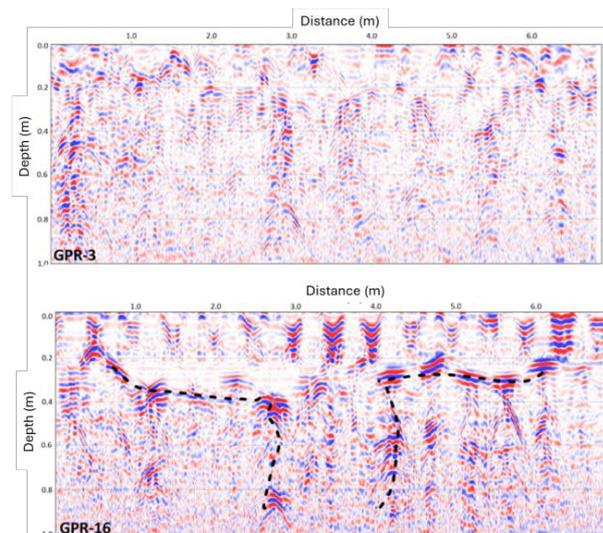


Figure 5. Example of two radargrams showing significant reflections.

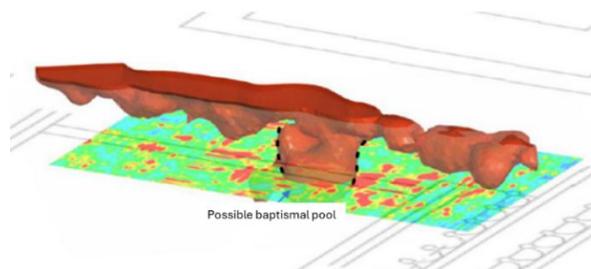


Figure 6. 3D isosurface of the geophysical anomalies.

IV. ARCHAEOLOGICAL ANALYSIS

Based on the results obtained from both geophysical methods, we suggest that the structures responsible for the detected anomalies correspond to the remains of the baptismal pool. This hypothesis is based on a series of factors which, although inconclusive when considered individually, collectively allow us to present this possibility as a plausible scenario.

On the one hand, the anomaly displays dimensions consistent with those of a baptismal pool; on the other, it is located along the same axis of symmetry as the Flavian temple, an axis that was also reproduced in the layout of the medieval cathedral.

These findings lead us to analyze the hypothetical dimensions of the Visigoth church in order to understand the potential location of the baptistery within the architectural development of the building. It is assumed that the baptismal space would be situated at the southern end of the place of worship, with both the church and baptistery possibly forming a single architectural complex. Theodor Hauschild [10] was the first to propose a hypothetical floor plan for the Visigoth cathedral, although his longitudinal measurements appear insufficient. To address this, we have used the theoretical width of the church as a basis to apply the golden ratio in determining its length.

Since the usable width of the Christian temple likely reutilized the width of the Flavian temple — after dismantling the internal perimeter podium — an exterior width of just over 29 meters has been proposed. This total width is currently recognizable between the eastern wall of the Roman temple, preserved up to a height of approximately 10 meters, and the foundation of the funerary church of Santa Tecla la Vella. This distance has allowed us to hypothesize a length of around 47 meters for the nave, based on the golden ratio.

It is important to note that this measurement applies only to the rectangular body of the building and excludes the detached apse, which has a radius of about 6 meters and corresponds to the original sanctuary of the Flavian-period temple.

The projected baptistery has been designed using half the length of the cathedral's nave as a reference.

The use of the golden ratio in compositional schemes is a recurring theme in early Christian architecture, reflecting a continual search for overall harmony rooted in classical tradition. Numerous examples across different time periods and regions support this: San Giovanni in Laterano, St. Peter's Basilica in the Vatican, Saint Paul Outside the Walls, San Lorenzo Maggiore in Milan, and Sant'Apollinare in Ravenna, among others [11-12]. This trend is also evident in Hispania.

This hypothesis is also supported by a broader formal pattern commonly observed in Late Antique Hispania—especially in Tarraconensis—of locating the baptistery at the western end (or "feet") of the church. While this layout is characteristic of the so-called "Hispanic scheme" [13], our limited knowledge of liturgical installations such as the choir and counter-choir within the cathedral prevents us from definitively assigning our proposed structure to this specific architectural model.

The layout of the baptistery suggested by the geophysical survey is also commonly found in much of the Christian West. Without aiming for exhaustiveness, some representative examples of this phenomenon include the cathedral of Sbeitla (Tunisia), the so-called Catholic Cathedral of Tigmad (Batna, Algeria), the see of Aosta (Aosta Valley, Italy), the post-Theodorian phase of the Aquileia complex (Friuli, Italy), Saint John of Poitiers (Nouvelle-Aquitaine, France), Saint-Maximin-la-Sainte-Baume, and the cathedrals of Riez and Fréjus (Provence, France). A more exceptional organizational scheme is that which retains axiality by placing an atrium between the church and the baptistery, as seen in the case of Hammeberg (Carinthia, Austria).

absence of any architectural restructuring. Stratigraphic layers indicate that the area was used as a material extraction zone from the second half of the 5th century onward [14], marked by abundant fragments of decorative architectural elements from the High Imperial period and indicative ceramic refuse from urban dumps.

In the northeastern corner of the former Flavian temenos, structural evidence suggests the presence of official buildings, possibly episcopal in nature [15], while the area between the cathedral complex and this potential *Episcopium* appears to have been used as a burial ground. Supporting this interpretation, a series of historical documents preserved in the *Índex Vell* (1675) also indicate that the eastern exedra was not associated with the Christian basilica established in the Flavian temple.

Finally, the Flavian temple/Visigoth basilica complex was built within a deep man-made cut in the hillside, making it impossible to locate a baptistery to the north of the church, where the terrain remained irregular. Considering the cloister garden as a possible alternative location, archaeological investigations there did not uncover any new architectural structures. Likewise, excavations carried out in 2010 and 2011 in the central nave of the present-day cathedral revealed no new Visigoth-era spaces at the southern end of the proposed baptistery.

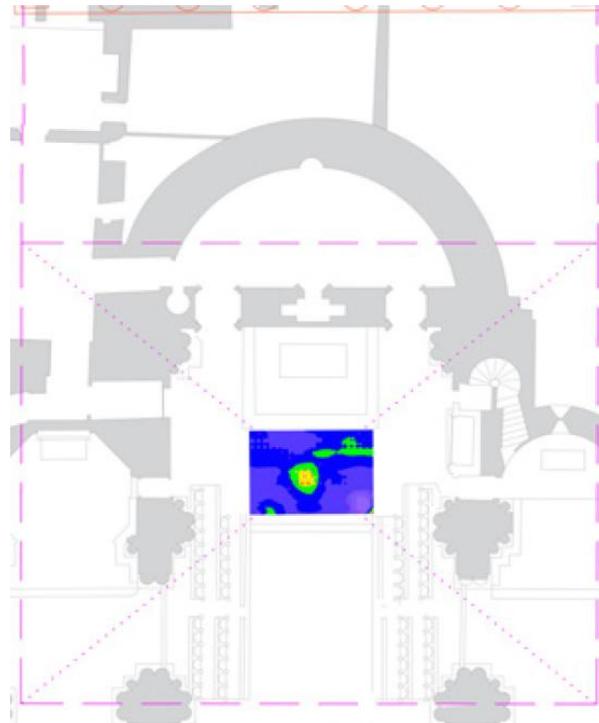


Figure 7. Location of the baptismal pool based on geophysical data.

V. CONCLUSIONS

The use of electrical tomography and 3D interpolation has enabled a detailed understanding of subsurface resistivity, revealing resistive anomalies that correspond with intense GPR reflectors and providing insights into underlying structures.

From these results, we propose a theoretical model reflecting a broader topo-liturgical trend across Hispania, particularly in Tarraconensis, where the studied site functioned as a metropolitan center. From the 6th century onward, the emergence of a structured *Ordo Cathedralis* shaped diocesan churches, raising the question of whether such ritual organization also influenced sacred topography. However, limitations in dating and the scarcity of comparable sites prevent definitive conclusions.

Notably, the traditional Hispanic baptismal rite did not prescribe a fixed baptistery location. Despite well-documented ceremonial practices, the physical positioning of baptisteries varied. This suggests a degree of ritual flexibility within a consistent liturgical framework. Examples from Valencia, Barcelona, and Tarragona illustrate diverse yet functionally coherent models, with proximity to the church serving as the main spatial requirement to accommodate the neophytes' processional route.

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