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ScienceDirect
Journal of Cultural Heritage 8 (2007) 87–92
Journal of Cultural Heritage
http://france.elsevier.com/direct/CULHER/

Case study

GPR technique as a tool for cultural heritage restoration: *San Miguel de los Reyes* Hieronymite Monastery, 16th century (Valencia, Spain)

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Received 7 June 2006; accepted 11 October 2006

Abstract

This paper describes GPR (ground penetrating radar) surveys performed inside the crypt of the *San Miguel de los Reyes* Monastery (1546–1835) in order to detect the exact location of its founders' remains, the Dukes of Calabria (16th century). This Monastery was erected to house their family mausoleum and the bodies of the founders were buried near the high altar of the church (1645). However, in the 18th century, the tombs were exhumed to provide them with a worthier burial site: the crypt below the high altar. There is no documentation specifying the exact location of the tombs inside the crypt. Therefore, in order to reveal the exact location of the tombs the GPR survey was conducted inside the crypt.

In our specific study, the available historical documentation led us to suppose that the Dukes of Calabria's remains were inside their mausoleums. However, after having performed the GPR analysis, we discovered that the mausoleums were solid and not hollow. The project required data collection on four areas in the crypt: the altar crypt, the *Fernando de Aragón* mausoleum, the *Germana de Foix* mausoleum and the floor between the two mausoleums and the altar.

In this study, we have processed the GPR records in three different ways: the radargrams were processed in a standard manner, a detailed spectral analysis of all anomalous areas was carried out, and finally a 3D representation was generated. After this complete analysis we concluded that the bodies were not located inside their mausoleums, because they were shown to be solid. Besides, a burial site was located in the crypt subsurface near the *Germana de Foix* mausoleum, in which four different elements could be identified. Two of them may well be the tombs of the Dukes of Calabria and the other two the tombs of the *Germana de Foix* sisters.

The results obtained in this survey are a good example of GPR application as an efficient and respectful tool for use in Cultural Heritage restoration studies, providing it with a very useful technique for similar projects such as those carried out in the restoration of historical buildings and those in which the elements to be examined are beneath a shallow coating of material.

Keywords: Ground Penetrating Radar (GPR); Cultural heritage; Restoration and conservation; Hieronymite monastery; Burial element location; Spectral analysis; 3D representation

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doi:10.1016/j.culher.2006.10.005

1. Introduction

Ground penetrating radar (GPR) surveys have proven to be an increasingly useful and non-destructive tool for the identification of burial structures, since with this technique we are able to identify the spatial position of structures of interest such as tombs, cavities and buried elements [1–5]. This paper describes GPR surveys performed inside the *San Miguel de los Reyes Monastery* (Valencia, Spain). The aim of this work was to detect the exact location of its founders' remains, the Dukes of Calabria, *Fernando de Aragón* (1488–1550) and *Germana de Foix* (1488–1536), who founded the Monastery to house their family mausoleum.

There is evidence of buildings from the Roman period and recent archaeological excavations also found evidence of an 11th century Muslim hamlet called *La Rascanya*, which came into the possession of the abbots of *Santa Maria de la Valldigna* after the Christian conquest in 1238. The abbots founded the humble Monastery of *San Bernat de Rascanya* in 1381 [6] and in 1546 it was chosen by the Dukes to found a Monastery under the order of St. Jerome that they could use as a family mausoleum [7]. The building was used as a Monastery until Mendizabal's disentailment in 1835, when it became Government property. After a period of neglect the building was restored and adapted to become the new location of the Valencian Library and nowadays Valencia City Council is in charge of it.

When the Monastery's church was finished in 1645, the bodies of the Dukes were interred near the high altar. However, later on, in the 18th century, the tombs were exhumed and the hieronymite monks decided to provide a worthier burial site for them and for the two *Germana de Foix* sisters. The place chosen was the crypt situated just below the high altar, but there is no documentation showing the exact location of the tombs inside the crypt [8]. Therefore, the main goal of our investigation was to carry out the GPR analysis of the crypt to find out if the Dukes' bodies were located inside their mausoleums, as well as discovering any possible elements that might exist in the subsurface such as funeral remains, before taking any action which could damage them.

2. GPR survey

The GPR study of *San Miguel de los Reyes* Crypt was performed with a SIR-3000 control unit manufactured by GSSI. Three antennas deployed separately and operating at 1.5 GHz, 900 MHz and 400 MHz, were used in the survey. Typically, the lower the frequency, the greater the penetration depth, but a low frequency implies a decrease in resolution. Therefore, to obtain a sufficient depth of penetration the 400 MHz centre frequency antenna was deployed to prospect the crypt floor and the higher frequency antennas were used at the mausoleums to give good resolution at shallow depth.

2.1. Experimental data collection and processing

The project required the collection of data from four areas, in which 80 profiles were collected (Fig. 1, Table 1). The first studied area is located in the altar crypt (five profiles: *A1–A5*); the second is located in the *Fernando de Aragón* mausoleum (six profiles: DC1–DC6) and the third in the *Germana de Foix* mausoleum (six profiles: RG1–RG6). Due to the fact that the first reconnaissance survey carried out in the mausoleums and in the altar crypt showed that it was improbable that the bodies were inside them, a fourth area was also analysed, the crypt floor. It covers the area (5×5 m) between the two mausoleums and the altar, the GPR profiles were performed as follows: longitudinal profiles (P1–P6), transversal profiles (P7–P11) and diagonal profiles (D1–D9). In addition, three profiles were carried out in the walls of the crypt (M1–M3) near the *Fernando de Aragón* mausoleum.

In the mausoleums and the altar the 1.5 GHz and 900 MHz antennas were moved on the surface with 20 ns time window. However, the 400 MHz centre frequency antenna was deployed to prospect the crypt floor with different time windows: 50, 60, and 80 ns.

Subsequent to field acquisition, GPR data were processed using RADAN-NT software (GSSI). The raw data acquired showed directly the presence of some interesting anomalies, however, standard data processing steps were applied to obtain the best imaging. At first, data were horizontally scaled, to be able to compare the radargrams in the X direction. Due to the rapid attenuation of the high frequency GPR signal, it was also necessary to apply some type of gaining function to enhance late reflections. Filtering the GPR data limits the frequency range, suppresses unwanted reverberations, and may suppress noise. A number of band pass filters and Hilbert Transform were applied as necessary to the individual data in order to improve the anomaly identification [9,10].

The dielectric permittivity (ε) of the matrix material at the crypt floor was assumed to be 13, since similar ε values for this kind of clay filled subsurface have been reported by several authors [9–11]. The composition of the subsurface and, hence, its ε could be confirmed thanks to drilling surveys that were carried out in the adjoining rooms.

The dielectric permittivity of the mausoleums and altar were calculated through the in situ measurements of the marble tiles, leading us to estimate the ε to be 9.5.

All the time windows were converted to depth using these dielectric permittivity values in all profiles. To convert time scale to depth, the subsurface electromagnetic wave velocity was obtained from ε [9]. The average velocity of the GPR wave front in the crypt floor was estimated to be 8 cm/ns whereas in the mausoleums and altar 10 cm/ns.

2.2. Results and discussion

The survey performed in the altar and the mausoleums revealed that no bodies were located inside them. Except for the radargrams corresponding to the DC4 and RG4 profiles, all the radargrams obtained in the mausoleums presented similar features and no anomalies were detected.

Fig. 2 shows the GPR sections for the DC4 profile, which presents an anomaly, and the DC3 profile, which can be considered to be representative for the areas of the mausoleums