

# High resolution spatial documentation of Renaissance church interiors through multiple non-invasive survey techniques

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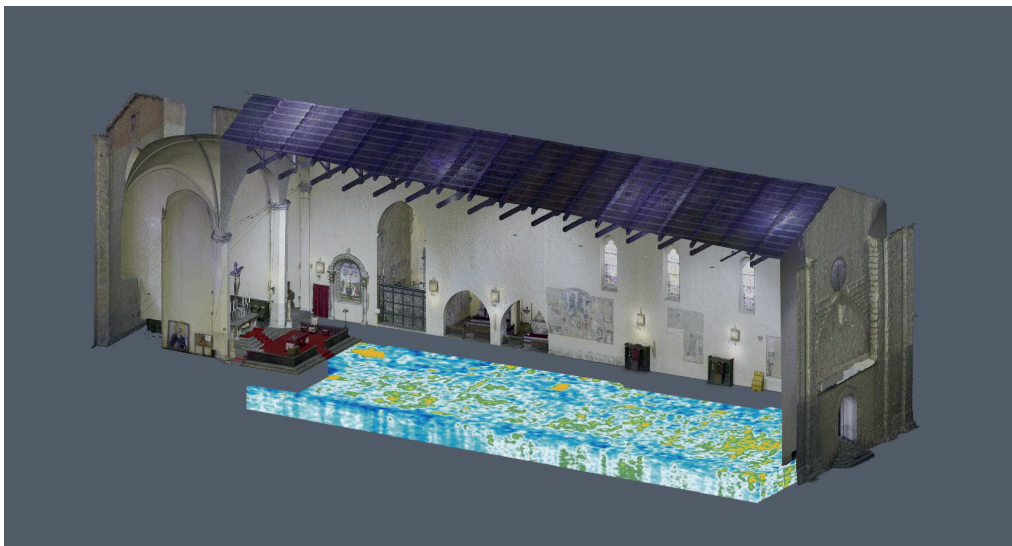
## Abstract

The generation of spatially accurate point clouds through laser scanning, combined with the extraction of high amplitude Ground-Penetrating Radar (GPR) reflections provides a powerful tool to examine both the sub-surface and standing remains in a holistic 3D environment. This preliminary note describes the methodology and results from the examination of two Renaissance churches in central Italy where geophysical prospection and standing building survey have been successfully integrated to support a multidisciplinary study through non-invasive technologies.

## Keywords

Laser scanning, geophysical prospection, ground-penetrating radar, point cloud, visualization

The study draws upon the investigation of two Renaissance churches in central Italy where a non-invasive approach was required to record both architectural elements and to examine the sub-surface of the buildings. The surveys were undertaken at the churches of Sant'Agostino (San Gimignano, Tuscany) and San Domenico (Città di Castello, Umbria) as part of a joint research project between the University of Cambridge and the British School at Rome (Cooper, Kay and Pomar, 2023). The project is addressing questions regarding the artistic and historical background of the investigated churches through the application of non-invasive archaeological survey techniques. Firstly, the study aims to determine the location of rood screens – architectural structures typical of the churches of the 12th and 13th centuries that divided the liturgical space and determined the visibility of artworks. These screens were removed during the Counter Reformation and are therefore poorly documented (Gilardi 2004; Cooper, 2017). Secondly, the study aims to better understand the original positioning of artworks as these would have been closely integrated with their architectural and liturgical settings (including masterpieces such as the 14th century altarpiece of Simone Martini at Sant'Agostino and the *Mond Crucifixion* of Raphael at San Domenico). Finally, the study investigated the potential traces of removed altars and the location of tombs. These questions have arisen as Italian Renaissance church interiors have been radically transformed over the centuries and conventional scholarship has focused upon building analysis and archival



*Figure 1 - Digital representation of the church of San Domenico (Città di Castello) with the GPR dataset in point cloud format.*

documentation to achieve a reconstruction of the original aspect for a specific period. Therefore, the current state of scholarship remains dependent on a small corpus of artistic representations and a few excavations leaving many questions unanswered. In essence, art historical research in this area has reached an impasse. This project was therefore designed to offer an original and interdisciplinary solution to the problem.

Geophysical prospection is routinely used to study standing ecclesiastical buildings, with the majority of applications focused on the investigation of the subsurface for the identification of earlier structures<sup>1</sup>. Likewise, 3D laser scanning has become a conventional method for underpinning research, visualization and restoration projects in cultural heritage. The precise measurements and the highly-detailed graphic restitution achieved in terms of texture and the speed of data collection have made this technique, alongside photogrammetry, one of the most widespread for the documentation and critical analysis of complex architecture such as church interiors<sup>2</sup>. Through the combination of high-resolution Ground-Penetrating Radar (GPR) prospection and 3D recording<sup>3</sup>, a digital environment can be constructed where the datasets can be analyzed in a point-cloud format (Fig. 1). This integrated approach permits a comprehensive assessment of the subsurface features together with the standing architecture<sup>4</sup>.

<sup>1</sup> See for example Bruzelius et al., 2018; Piro et al., 2020; Leucci et al., 2021; Campana et al. 2023.

<sup>2</sup> For examples, see Bosman et al., 2020; Campana et al., 2010; Macher et al., 2015.

<sup>3</sup> For a general bibliography of these techniques applied to archaeology see, among the others, Conyers 2004; Remondino 2011.

<sup>4</sup> See also Bornik and Neubauer 2022 for the application of a similar methodological approach.

## Survey methodology

The architectural complexity and sizable dimensions of the buildings required the investigation to draw upon multiple non-invasive techniques. The project followed the same workflow for the two case-studies. The data acquisition inside the churches was supported by a topographical survey using a robotic total station (Leica TS16). The total station was used to register black and white circular targets recorded in the laser scans and to establish a grid for the GPR survey. In both case studies, the interior total station survey was anchored to a series of exterior GPS points. Five topographical points were recorded outside the churches where there was satellite coverage, by both GPS and total station, to allow the subsequent conversion of the total station local system to real world coordinates. The laser scanning survey was conducted with a Leica RTC 360 with the resolution set at 6 mm at 10 m (35 setups at Sant'Agostino and 67 at San Domenico) to guarantee the generation of an accurate dense cloud as well as a manageable dataset. Data was processed in Cyclone Register 360, Cyclone Core and Cyclone 3DR. After georeferencing and cleaning of the point cloud, a triangular mesh was built with HDR texture<sup>5</sup> to achieve a real colour visualization of the model and a clear image of the detail of the architecture.

The GPR data (recorded with a single channel GSSI 400MHz antenna) was collected with a 0.25m line spacing in regular parallel traverses throughout the full interior of the churches. Data was processed in the software GPR-Slice. The processing included filtering of raw radargrams, slicing and gridding of data and compilation of a GPR volume. For the 2D visualization of the results, horizontal time-slices were exported for interpretation in a Geographic Information System (ESRI ArcMap). For the integration of GPR data within a 3D environment, 3D binary data was extracted from GPR-Slice as ASCII files (.xyzirgb) and imported as point clouds in the software Leica Cyclone 3DR. High amplitude anomalies were then isolated through intensity analysis (using the tool 'inspection value' provided in Cyclone 3DR) in order to visualize the sub-surface recorded features, such as walls and voids, together with the standing architecture.

The study of the church of Sant'Agostino also included photogrammetric documentation of the marble tombstones on the floor of the nave in order to obtain for these features a photographic quality higher than that provided by the laser scanner. The resulting orthophoto, extracted using the software Metashape, was analyzed alongside the GPR dataset to compare the position of the tombstone with the actual location of burials (Fig. 2).

This methodology illustrates how information can be captured using different instrumentation and then combined digitally to answer key research questions. Whilst the GPR survey provided information concerning the sub-surface, the laser scanning allowed the creation of a virtual 3D framework and structure for placing the features in their precise topographical context. The detailed model therefore provided an environment for assisting in the interpretation of the geophysical anomalies in relation to the standing structures.

<sup>5</sup> The instrument used, a Leica RTC360, has integrated cameras which capture High Dynamic Range (HDR) imagery. After the scan acquisition, the instrument captures a sequence of photographs which can later be used for the real-world colour texture of the point cloud.

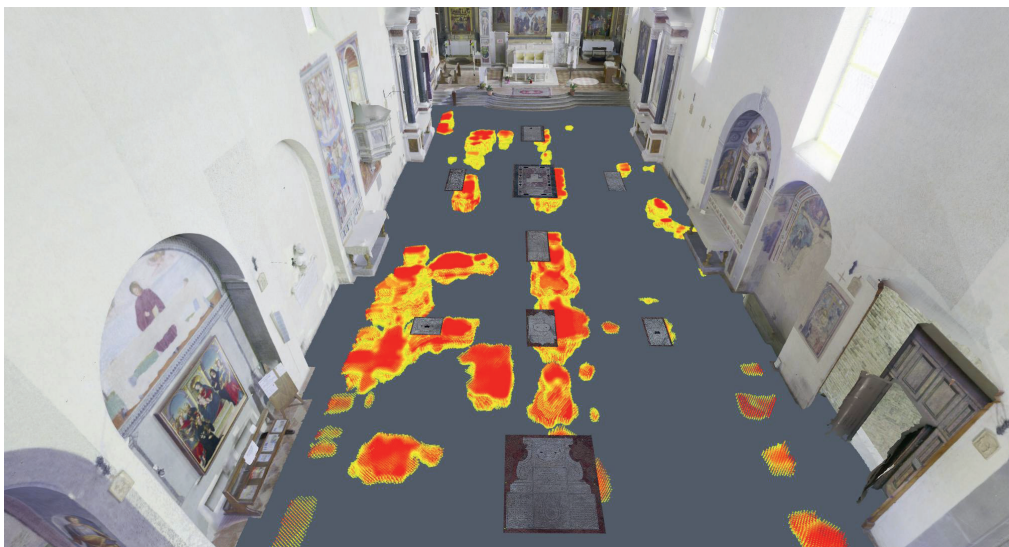


Figure 2 - Digital representation of the interior of the church of Sant'Agostino with high amplitude GPR reflections in point cloud format together with photogrammetric renderings of the tombstones.

### Church of Sant'Agostino, San Gimignano

The Church of Sant'Agostino was built just before 1300 and by the end of the 14th century it was a prestigious ecclesiastical centre (Razzi, 2014). The church has numerous burials in the floor of the nave and cloister, as well as purportedly a cemetery alongside the building. The interior walls of the church are decorated with magnificent frescoes of the 14th and 15th centuries. As previously noted, of importance to the research project is an altarpiece by the Senese artist Simone Martini, three sections of which are preserved at the Fitzwilliam Museum, Cambridge University. The original position of the polyptych - one of Martini's earliest works (c. 1317) - within the church is unknown and its connection with the burial of Beato Bartolo is subject to debate (Barana 2019; Cooper et al. 2024).

The GPR survey in the nave of the church revealed a far higher number of tombs than recorded in the archival record or which are identifiable through the tombstones today (Fig. 3). The survey identified an additional 15 tombs, whilst some of the tombstones were shown to no longer be in their original position due to the absence of underlying voids (Fig. 2). Some tombstones also had small cavities underneath, too small for inhumations and therefore were feasibly small ossuaries inserted into the pavement. Of interest is that whilst the visible tombstones are aligned with the major altar, other recorded tombs are oriented towards side altars. It is reasonable to consider that the greater the number of tombs that were oriented towards specific side altars, the greater the importance of these altars. This hypothesis may also assist in considering the potential location of artworks within the church. Some anomalies recorded along the perimetral wall of the church could indicate altar bases, although the interpretation is uncertain.

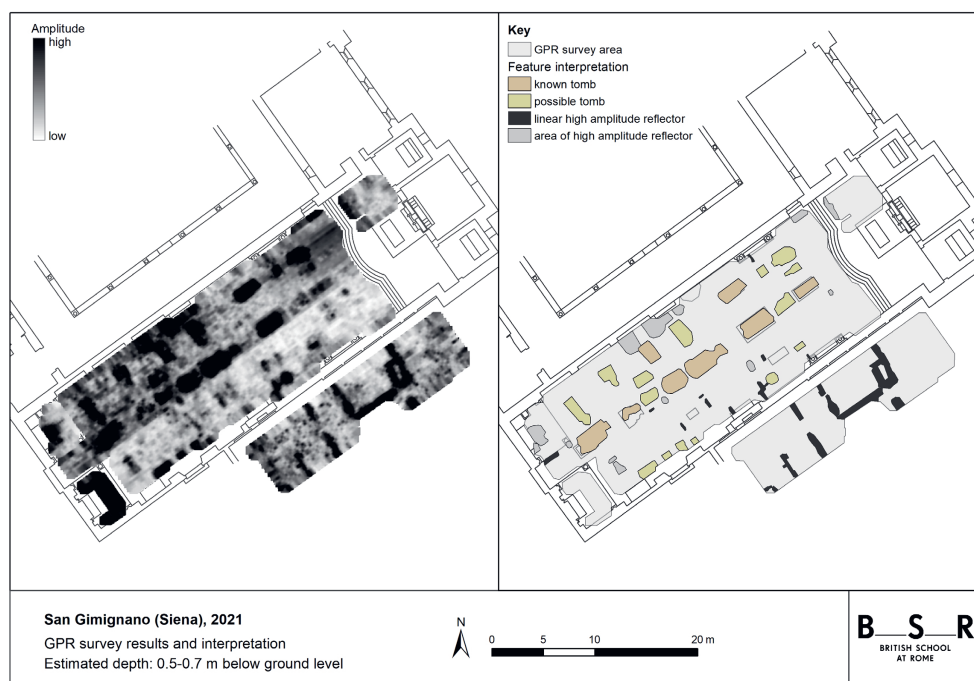


Figure 3 - Results and interpretation of GPR data collected in the church of Sant'Agostino.

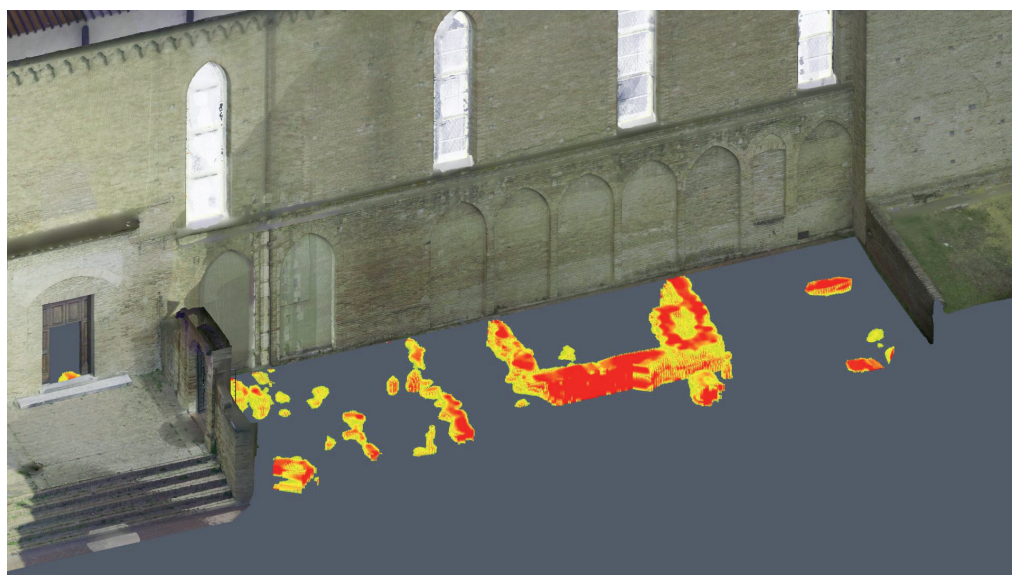


Figure 4 - 3D visualization of linear high amplitude anomalies related to the potential lost chapel of San Martino (Church of Sant'Agostino).

A further question raised by the archival research concerning the church was the existence of a chapel said to have belonged to the brotherhood of San Martino. A previous reconstruction had hypothesized this as an annex on the southern side of the church (Razzi, 2014; 30). The GPR data collected along the external southern wall revealed several interlocking high amplitude anomalies, in a regular rectangular position with a squared feature in the eastern corner which may be interpreted as the chapel (Fig. 3). The possibility of placing the point cloud of the high amplitude features alongside the laser scan data of the church revealed with precision the spatial relationship between the features and the church (Fig. 4).

### **Church of San Domenico, Città di Castello**

The church of San Domenico was built on behalf of the Dominican order and was consecrated in 1426. The church is included in the group of buildings of the *Ordini mendicanti* with a unique nave and roof (Bozzoni 1982). The nave measures 64m in length and 19m in width. The church was home to several important masterpieces including the Martyrdom of S. Sebastiano by Luca Signorelli (today in the Pinacoteca Comunale of Città di Castello) and the Mond Crucifixion by Raphael (today in the National Gallery, London).

Between 1662 and 1667 an internal cloister was added to the south side of the convent, enlarging a pre-existing small cloister, few elements of which are still visible. Several years later the body of Beata Margherita was transferred to the main altar which was rebuilt for the occasion (nowadays the Baroque altar is in the Chiesa delle Grazie, Città di Castello). In the 18th century important structural work occurred inside the church, which significantly altered its aspect. The gothic windows were closed, and the walls whitewashed.

The GPR survey covered the full width and length of the church, and at the eastern end detected a narrow linear anomaly crossing the nave (Fig. 5). When analyzed in a 3D environment, the linear feature (indicated in Fig. 6) can be seen lying off-set at the foot of an arch that divides the twin chapels. The geometry and position of the feature, creating a latitudinal partition of the nave, is compatible with the location of a rood screen that may have divided the space before being removed during the Counter-Reformation. To the east of the potential rood screen, a large area of high amplitude reflections was recorded (circled in Fig. 6). Whilst the recorded reflections indicate an area of disturbance, their proximity to the supposed rood screen suggests a feature of archaeological interest. Indeed, it is known that the areas beyond the screens were often occupied by structures such as choirstalls (Cooper, 2017).

Similarly to the survey at Sant'Agostino, whilst the location of two known tombs was recorded, three further anomalies with similar responses were recorded (Fig. 5). In particular, a probable tomb on a north-south orientation was located on the northern side, possibly aligned to face a removed side altar.

### **Conclusion**

The combination of spatially referenced GPR data with 3D digital models of monuments recorded using laser scanning, as well as high-resolution photogrammetry, provides a unified and simultaneous spatial representation of the visible and hidden reality. In addition, this

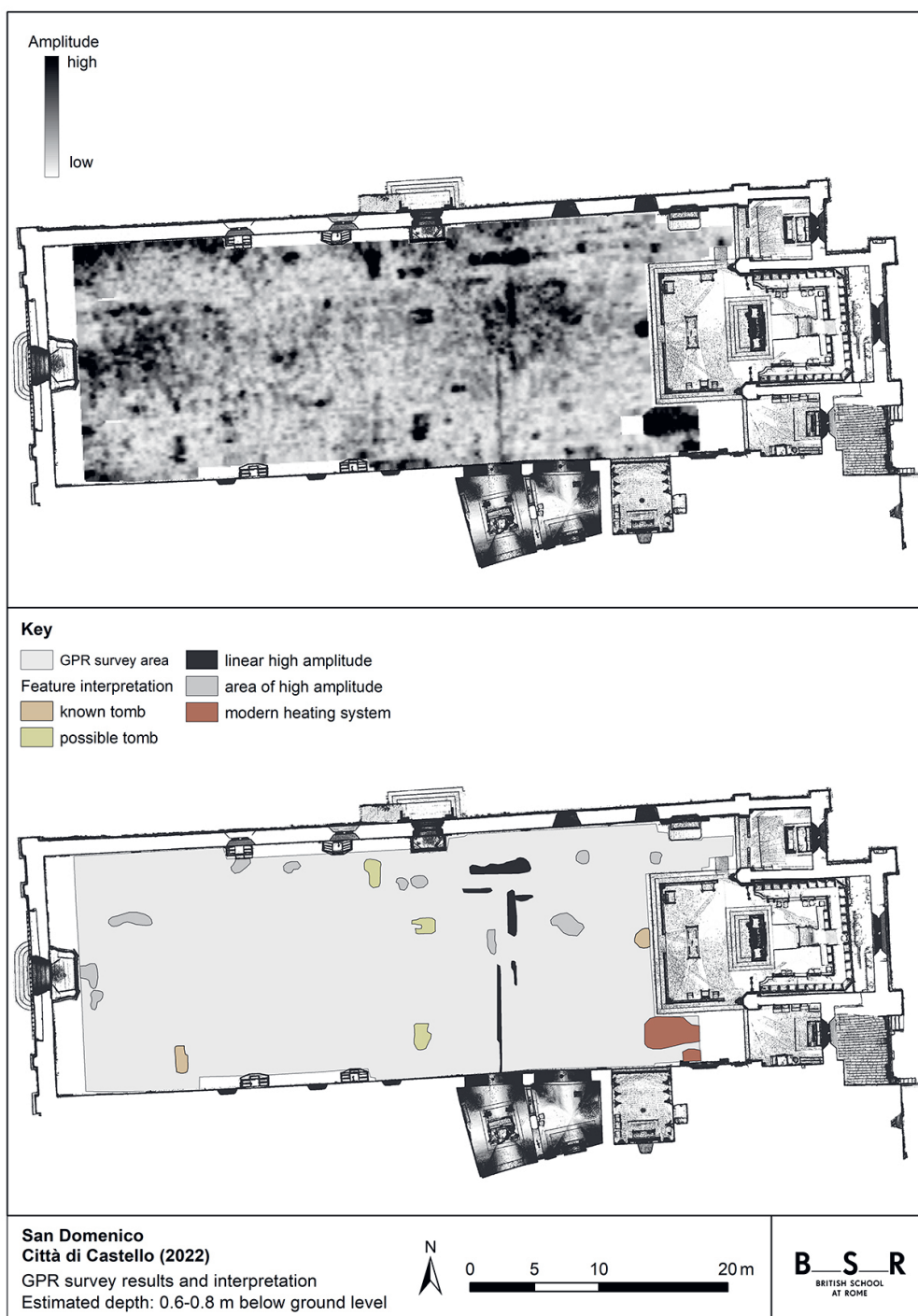
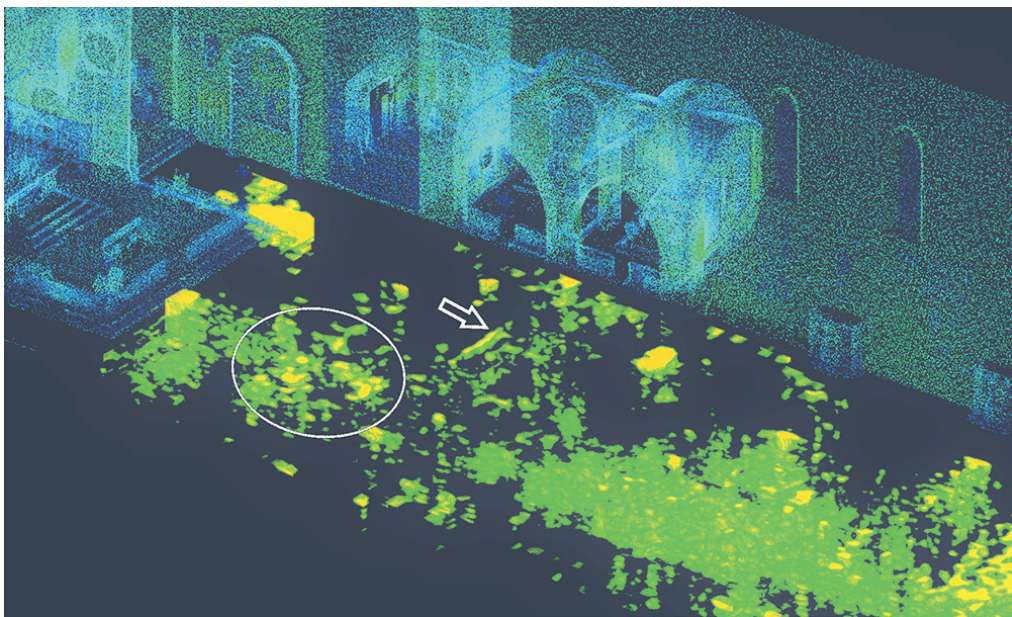


Figure 5 - Plan of the Church of San Domenico extracted from the 3D model with the GPR results and interpretation.



*Figure 6 - 3D visualization of point clouds of the church together with strong GPR reflections. The arrow indicates the linear anomaly that possibly locates the rood-screen, next to which it is circled an area of strong reflections.*

integrated approach permits a direct and diachronic evaluation of the various architectural phases of the buildings.

In these two examples, the multi-method approach to documentation assisted in answering key research questions concerning the original architecture and layout of the Renaissance churches. The GPR survey provided new information regarding previously unknown features, such as altar bases, unmarked tombs in the nave of the churches, as well as linear anomalies consistent with a destroyed chapel at Sant'Agostino and a rood screen in the church of San Domenico.

Managing the high amplitude GPR features as point clouds in a 3D digital environment enables the analysis of sub-surface features in relation to the position of existing architectural elements. For example, it was possible to observe that the hypothesized rood screen in the church of San Domenico was aligned with the pillar dividing the lateral chapels. Furthermore, a potential tomb was discovered in correspondence with a commissioned wall painting.

The documentation of all tombs in the nave of both churches and the accurate digital recording of the architecture will also assist in a holistic comprehension of the original layout and potential viewing positions towards altars, thus their detection can potentially reveal the location of those that no-longer exist. Although not conclusive, the data collected provides significant clues that must be considered when reflecting on the original location of the displaced prestigious artworks made for these churches.

Through the combination of building analysis conducted with multiple techniques combined with an archival study, a much greater understanding has been achieved of these mendicant

Renaissance churches in central Italy. The 3D digital environment generated within Cyclone 3DR has provided a powerful database which stores and manages several georeferenced 3D models and point clouds, where multiple information can be queried by the user. The platform allows for a much greater understanding of the GPR data through both a visual examination and analytical analysis, drawing more deeply on its 3D characteristics.

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