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Evaluating Digital Tool’s Integration for the Preservation of XX century Architectures

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Abstract

This study explores how a mix of digital surveying tools can be integrated to thoroughly document and preserve twentieth-century architectural landmarks, focusing specifically on the Church of Cristo Obrero y Nuestra Señora de Lourdes in Atlántida, Uruguay. Designed by the renowned engineer Eladio Dieste between 1956 and 1960, the church stands as a striking example of structural ingenuity, notably through its use of reinforced brick and signature Gaussian vaults. Now listed as a UNESCO World Heritage Site, it serves as an ideal case study for testing modern documentation techniques.
The research was based on the interoperability, precision, and practicality of several 3D data acquisition methods. By comparing the point clouds these technologies generate, and using data from the highly accurate tool as a benchmark, the study assesses how faithfully each method captures the geometry of the structure.
Findings reveal that although SLAM-based data shows greater deviation, it still holds value, particularly for initial surveys or work in tight, difficult-to-navigate spaces. Photogrammetry, on the other hand, proved indispensable in documenting features that were otherwise unreachable—effectively filling in gaps left by laser scanning. The integration of these data sets required careful alignment and annotation, resulting in a robust 3D model layered with scalar fields to trace both the data sources and their relative reliability.
Ultimately, the research highlights the importance of flexibility and precision in heritage documentation while offering a replicable workflow. The proposed methodology not only enhances data quality but also supports more sustainable conservation practices in the digital age.

1. Subject of the Study

1.1 Introduction

The experimental tools integration carried out on the Church of Cristo Obrero y Nuestra Señora de Lourdes in Atlantida, Uruguay, is the subject of this study. The goal of the tools integration used in the field research is to show how contemporary technologies may be merged and used to create a trustworthy database. The 3D survey used five distinct data sources (terrestrial lidar (2 tools), terrestrial photogrammetry, aerial photogrammetry, and slam technology) to create the digital description. By integrating the currently accessible solutions on the market, the data comparison's outcome seeks to highlight an appropriate and reasonably priced process for data collection. The Leica c10 point cloud was utilised as a metric reference for analysing deviations from other tools in order to assess the geometric-morphological quality of the produced point clouds.
The Church of Cristo Obrero exemplified the effective integration of technologies in producing thorough and dependable digital representations. The proposed workflow and tool evaluation seeks to enhance the sector by providing specific techniques and considerations for professionals engaged in CH documentation, highlighting flexibility, accountability, and reliability.

1.2 The Church

The Church of Cristo Obrero y Nuestra Señora de Lourdes, situated in Atlantida, Uruguay, was conceptualised and designed by engineer Eladio Dieste between 1956 and 1960. The importance of this architectural project arises from the engineer's practical applications in structural design and construction technology (Fig.1).

Figure 1. The Church of Cristo Obrero y Nuestra Señora de Lourdes in Atlantida, Uruguay.

The Church was the first notable implementation of continuous Gaussian vaults in reinforced brickwork utilising thin-shell roof structures by the engineer, together with governed surfaces on its side walls (Melachos & Florio, 2018).
The design and building processes were enhanced by the amalgamation of tradition and innovation, incorporating transportable frames at the site. Alongside these technological and design advancements, both external and interior exceptional architectural spaces were created, highlighting efficiency in the construction process, thereby establishing Eladio Dieste as a structural artist (Ochsendorf, 2004).
The church exhibits Dieste's early professional experimentation, with expansive concrete and reinforced ceramic roofs, as well as high water tanks. Each project, distinguished by diverse

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applications, required considerable creativity in its design (Carbonell, 1987; Torecillas-Perez, 1996). The design of each structure conveys a unique identity, in conjunction with the colours, sizes, and textures of the bricks (Fig. 2). The possibility to construct the parish complex in Atlántida emerged for Dieste during his professional collaboration with Eugenio Montañez, formalised between 1954 and 1956 (Pablo Bonta, 1963). Over the years, it became apparent to the company's colleagues that Montañez epitomised the financial and administrative dimensions, but Dieste personified the creative part, serving as an unrelenting innovator in structural design and building techniques. The visual representation of the Church of Cristo Obrero y Nuestra Señora de Lourdes has been primarily shaped, from its establishment, by the design of the lateral walls of the nave.
The purpose of this design was to construct buttresses that would effectively absorb the thrusts of the vault sequence while maintaining aesthetic and architectural appeal.

Figure 2. Interior space of the the Church of Cristo Obrero y Nuestra Señora de Lourdes in Atlantida, Uruguay, a unique identity in conjunction with textures of the bricks.

The structure is based on a beam, upheld by 30x30 centimetre piles, forming the linear basis for the walls on either side of the church. Following the construction of the church's lateral walls and the formwork for the roof edge beams, steel turnbuckles, approximately 32 millimetres in cross-section, were inserted to mitigate the lateral thrust generated by the vaults. During the construction phase, the tensors aided in stabilising the walls, which had not yet attained equilibrium due to their structural configuration. The roof was built utilising a movable formwork, on which vault segments of six meters each were formed.
In contrast to the temple, which is supported by piles linked to a concrete beam level with the earth fill, the tower's foundation is direct, consisting of a circular base roughly 3 meters in diameter and 30 centimetres thick, situated at a depth of 1.20 meters. The tower was constructed on a circular base with a diameter of roughly 3 meters and a thickness of 30 centimetres at a depth of 1.20 meters. Despite the absence of formal plans for this foundation, it is referenced through the handwritten notes and calculations of Dieste.
On July 27, 2021, the Church of Christ Obrero y Nuestra Señora de Lourdes in Atlantida, Uruguay, designed and constructed by Uruguayan engineer Eladio Dieste (1917 - 2000) between 1956 and 1960, was included on the UNESCO World Heritage List. The UNESCO selection criteria categorise this unique structure as the pinnacle of spatial and aesthetic expression in constructive and technological innovation (World Heritage Convention, 2021). The design methodology leverages tradition, simultaneously reinterpreting and changing it, so unlocking structural and formal possibilities in building that were previously inconceivable and unachievable with conventional brickwork (Melachos et al., 2023).

2. Related Works

Consultation of established academic databases indicates that literature on Eladio Dieste is scarce. The engineer's design and construction principles are exemplified in Carbonell (1987) and Torecillas-Perez (1996), supplemented by writings from Eladio Dieste himself. Pablo-Bonta (1963) is significant for its examination of Dieste’s early works during their creation, whilst Pedreschi (2000) and Anderson (2004) are crucial for modernising the relevance of Dieste’s construction procedures in academic research circles. The Church of Cristo Obrero and Nuestra Señora de Lourdes features a specific portion in each reference, including a floor plan and sections, a comprehensive photographic record, and a physical description and/or introduction pertaining to the architectural design.
The literature pertaining to the Church of Cristo Obrero and Nuestra Señora de Lourdes is mostly guided by the Getty Foundation’s Keeping it Modern report: Iglesia de la Parroquia de Cristo Obrero: Plan de Conservación y Manejo (2018). This comprehensive report delineates a conservation management plan for the subject of study, highlighting the significance of critical construction drawings and the design and construction protocols employed by Dieste and his team in this specific design, along with chapters dedicated to architectural design and the construction process. This report provides the most comprehensive overview of the design and construction process of the subject under investigation in the current state of the art.
Amen and Alvarez (2017) examine the geometry of the Church of Cristo Obrero and Nuestra Señora de Lourdes utilising digital fabrication, creating a 1:20 model and illustrating the significance of physical models in understanding complex geometries such as continuous Gaussian vaults and ruled surface walls. Fritz and Lammers (2016) and Lammers (2017) parametrically modelled the ruled surfaces of the Church of Cristo Obrero and Nuestra Señora de Lourdes, although they did not address the Gaussian vaults and failed to comprehensively illustrate their algorithms. Computational modelling approaches were supplemented by both physical and digital models to enhance understanding of geometry, design, and construction processes.
Melachos and Florio (2018) conducted parametric modelling and evaluated the discontinuous Gaussian vaults of Eladio Dieste, offering a detailed step-by-step account of the procedures employed in the development of the examined architectural geometries. This parametric modelling was supplemented by exploratory polynomial regression in Microsoft Excel utilising the least squares fitting method (Mendenhall, Beaver, Beaver, 2006).
Melachos and Amorim (2022) conducted a Gaussian analysis to assess the developability of Eladio Dieste's discontinuous Gaussian vaults using parametric modelling and Rhinoceros 3D®, but did not employ additional flattening verification procedures as recommended by McNeel (2020). Capone and Lanzara (2018) employed additional flattening approaches to assess the flattening potential of doubly-curved surfaces, establishing a systematic framework through the examination of surface area enlargement and contraction readings.

3. Applied Methodology

3.1 The Equipment's Integration

The use of three-dimensional surveying technology is essential for producing accurate spatial models of complex environments. These methods rely on many devices that must function cohesively to produce high-quality data. The integration of this technology is crucial to provide reliability, efficiency, and accuracy in data collection and processing.
The insufficient integration of 3D surveys may result in inaccuracies, redundancies, and inefficiencies, hence undermining their original purpose (Martinez Espejo Zaragoza et al., 2021).
In the digitisation campaign, executed by a team of three individuals over a span of seven working days, the following equipment was utilised:
- Leica C10 static laser scanner employing topographic registration;
- Leica BLK360 G1 static laser scanner utilising cloud-to-cloud registration;
- Lixel K1 SLAM laser scanner;
- DJI Pro4 UAS drone for digital photogrammetry;
- Canon EOS 90D for digital photogrammetry.

3.2 Acquisition and Registration Approach

The exterior survey was conducted using a Leica C10 laser scanner, an instrument renowned for its superior accuracy and extensive range, despite its age. The scans were registered employing the topographic method, with an average error 2mm on targets. This well-consolidated methodology allowed the optimization of scan positions in relation to the geometry of the building to be surveyed, reducing their position to the ones necessary to acquire the surfaces (Bianchini et al., 2022).
Since, with this method, no high overlapping percentage between adjacent clouds is needed, scan number is reduced, avoiding in-between scans, reducing on-field acquisition time, considering low-speed related to C10 laser scanner, if compared to more update tools. Main hall of the church was acquired with Leica C10 too, in order to provide 4 targets and geometric basis for the registration between exterior and interior point clouds.
The interior detail survey was conducted using a Leica BLK360 laser scanner, which is more quick and efficient in setup and appropriate for capturing tiny to medium-sized areas in reduced time. Furthermore, this instrument was employed externally to conduct a comparison study of the data obtained from all instruments.

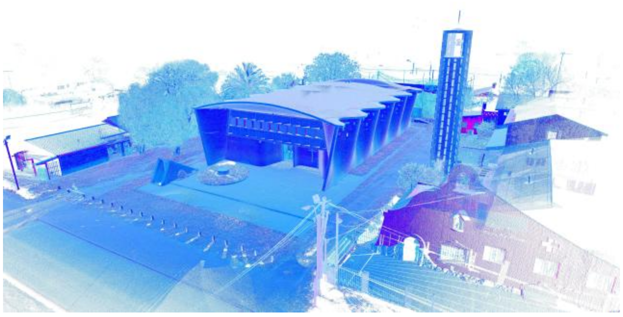

Figure 3. The whole digital database obtained by LIDAR technology.

Both these two BLK sub-models (exterior and interior) were registered internally utilising the cloud-to-cloud approach (average inaccuracy of 5 mm), leveraging considerable overlapping surfaces between adjacent scans, which in this case was sustainable due to tool's high acquisition speed (Pritchard et al., 2017). Later, point clouds obtained from BLK survey were rototranslated onto the Leica C10 one using 14 points (10 external, 4 internal), represented by black and white targets (Fig. 3).
Photogrammetric survey was conducted thorough an aerial campaign, using the camera embedded in Dji Mini 4 Pro drone, and a terrestrial one, using Canon EOS 90D. The aim is twofold: to acquire the hidden geometries in terrestrial laser scanner point clouds, such as of the roof's extrados and the top of the bell tower (i), and to acquire photorealistic external surfaces' colour data (ii). Resulting point cloud is referenced in the same coordinate system of laser scanner ones, through the same targets (Fig. 4).

Figure 4. Data integration by UAS drone.

The SLAM device evaluated in this study was an XGRIDS Lixel K1, utilised to survey both interiors and exteriors via two distinct closed ring pathways.
The registration was conducted utilising the cloud derived from the Leica C10 laser scanner as a reference (Sestras et al., 2025) in order to obtain an interoperable and accurated dataset (Fig. 5).

4. Data Analyses and Main Remarks

The survey methodology resulted in the creation of a database comprising multiple point cloud models derived from four distinct technologies, that can be used for different purposes, according to their quality. The geometric-morphological quality of the point clouds (Suchocki, 2020) was evaluated using the point cloud acquired from C10 instrument as a metric reference for analysing deviations.
The reference cloud was chosen both for having best accuracy among the tools used, and for being registered with a methodology that ensures low errors.

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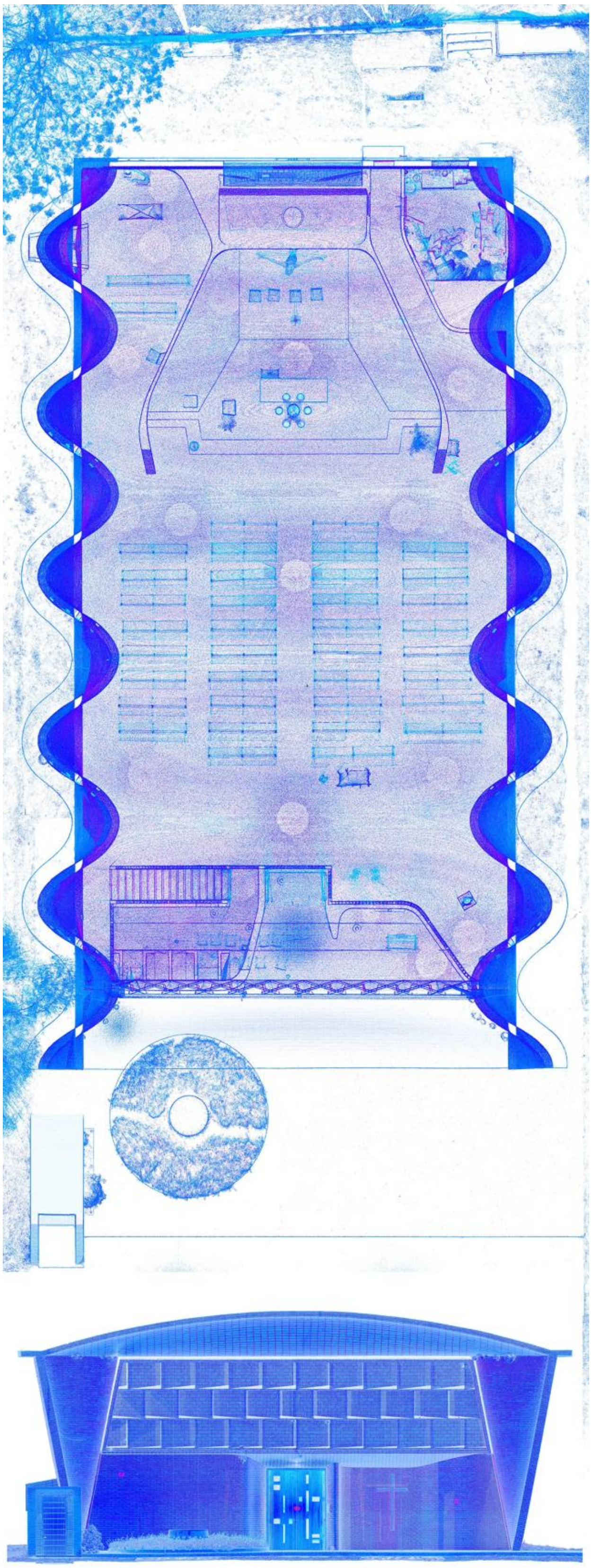

Figure 5. Main façade and plan of the chuch. The digital integrated database can offer several possibilities for data representation through point cloud elaboration.

A first analysis was made by calculating cloud-to-cloud distances of the exterior point clouds (BLK, photogrammetry and K1) to the reference one. Results show point cloud obtained from BLK laser scanning and from digital photogrammetry do not exceed 1cm, which is considered a good geometric accuracy for many purposes (scan-to-bim, surface analysis, etc…). Are exceptions few points in the upper part of the wall in BLK point cloud and, of course, laser scanning shadow cones in photogrammetric one, beyond inconsistent points such as grass and vegetation. Lixel K1 point cloud, as expected, has major deviations and many points exceed 1cm (Fig. 6).

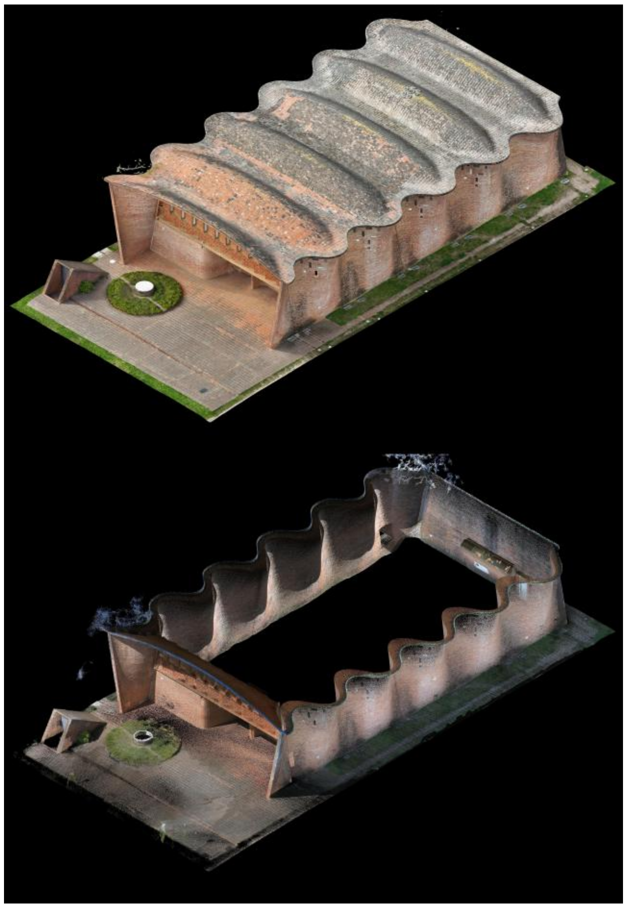

Figure 6. RGB data comparison between Leica BLK (top) and Lixel K1 equipment (down).

The cloud-to-cloud comparison method provided the most direct and accurate measurement of point cloud data (Gharineiat et al., 2024).

In order to deepen the analysis, a horizontal section at an elevation of +5.50m above the floor is taken, where from the previous test emerged major distances. The deviations in the horizontal plane (XY) were analysed and the cloud-to-cloud distance graph extrapolated. The BLK360 and photogrammetry-derived clouds are found to have comparable errors, with modal values around 2mm. The SLAM cloud shows more distributed values, with a modal value of around 1.8cm, which confirms accuracy declared by the manufacturer, but with a considerable number of points with deviations as high as 2.5cm (Fig. 7).

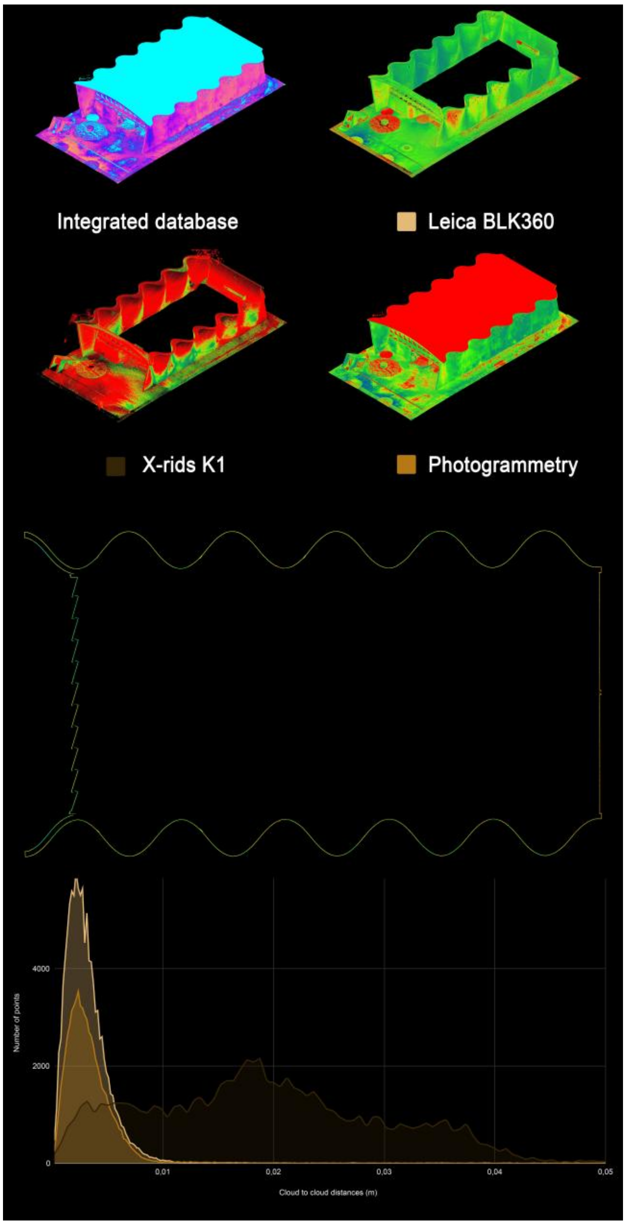

Figure 7. Comparison of the different point clouds with the LeicaC10 cloud: Leica BLK360 (left), SLAM XGRIDS Lixel K1 centre), digital photogrammetry. In red points with distance >1cm. Bottom: section at +5.50m with the deviation graph in the XY plane.

For this reason, this model can be most leveraged for visualization and valorisation purposes, as well as general assessments. K1 colour acquisition, in fact, resulted consistent and adequately faithful, comparable to RGB data surveyed with photogrammetric technique.
In contrast to Lidar techniques, UAS photogrammetry provide swift data acquisition across extensive regions, penetrating difficult terrains that laser scanner may be unable to penetrate. UAS photogrammetry has produced high-resolution images providing it a significant adjunct, especially for capturing intricate structures inside extensive Cultural Heritage contexts that necessitate a cartographic scale approach (Li et al., 2025).
Regarding this case study, but the consideration can be extended to other buildings, the photogrammetric point cloud resulted more complete to the laser scanner ones, since aerial means provide coverage to inaccessible surfaces. However, to reach an adequate quality of the data and a reliable geometric accuracy, in addition to camera performance and shot parameter settings, two further aspects must be considered: a sufficient and well positioned target points must to be measured with other tools (laser scanning or total station) (i), and the shot distance from the surface. Regarding the last point, the survey considers the possibility to carry on surface analysis (materials, state of conservation) on point cloud at 1:50 scale, so, considering camera focal length, it was kept an approximate distance of 4m from the surfaces, where possible. This procedure was guided by the conventions of classical photogrammetry (Docci et al., 2020) and led to the generation of a point cloud with a density, and consequently a resolution, comparable to the laser scanner ones and suitable for detail analysis.
As a result, research in survey methodologies is increasingly moving in the direction of integrating data from different acquisition sources, so the number of cases in which data acquired from different devices is fused has increased (Konstantakis et al., 2024). In this process, it is good to keep track of the source of the data, as it is linked to a certain accuracy. With regard to the survey of the Christo Obrero Church, the elaboration of an integrated final point cloud model was simulated, according to a replicable workflow. It took into consideration best point cloud available for each area. For instance, the exterior consisted in the Leica C10 model, colorized by aligned images of the photogrammetric survey, and the missing parts (roof extrados, occlusions) were automatically segmented from the photogrammetric point cloud, leveraging cloud-to-cloud distances major than 1cm. Then, an additional scalar field reporting source values related to each methodology acquisition is associated to the related area, in order to detect them in subsequent uses of the morphometric model.

5. Conclusion

The integration of heterogeneous 3D data acquisition tools offers significant advantages for the documentation of complex cultural heritage sites. This study not only validates the effectiveness of various tools under real conditions but also introduces a structured approach to integrating and annotating point clouds based on their geometric reliability, proposing a replicable methodology for selecting, integrating, and annotating point clouds. The creation of a composite model, integrating high-resolution areas from different sources and associating scalar fields indicating the origin and precision level, provides a structured and transparent approach for future use of the dataset, including restoration, monitoring, and digital archiving (Fig. 8). Moreover, this research validates the Lixel K1 SLAM scanner as a viable low-cost alternative for preliminary documentation in narrow or inaccessible areas. Although less precise than static systems, its ability to provide consistent colour data and spatial continuity at acceptable tolerances makes it suitable for valorisation tasks, quick assessments, and integration with higher-quality datasets.
The Church of Cristo Obrero served as an effective case study, highlighting the role of combined technologies in achieving comprehensive and reliable digital representations. The proposed workflow and tool evaluation aims to contribute to the field by offering concrete strategies and considerations for professionals involved in CH documentation, emphasizing adaptability, transparency, and replicability.

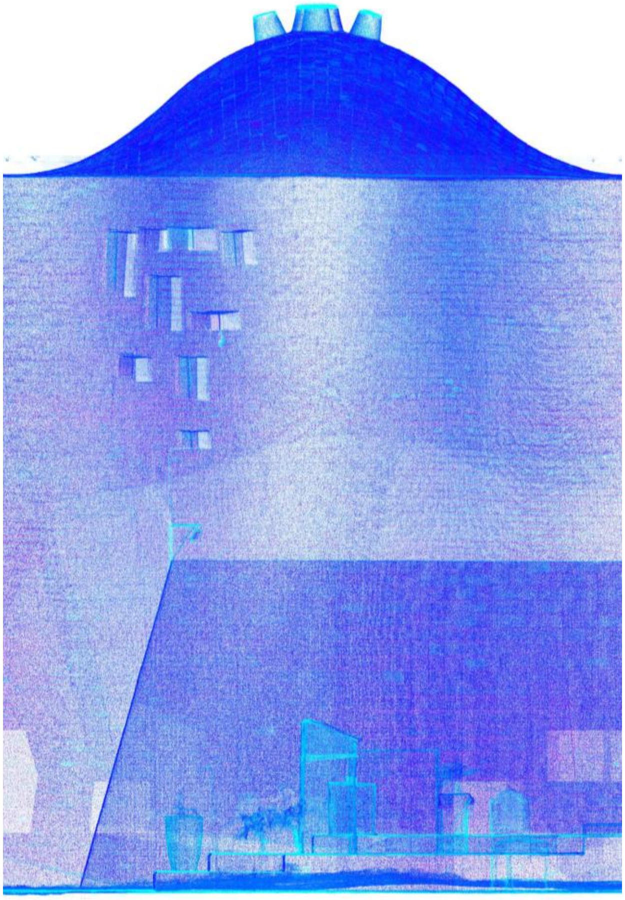

Figure 8. Vertical section of the point cloud highlightin the gaussian vault conceived by Dieste. The final high density dataset obtained by the integration of heterogeneous 3D acquisition tools could enhance the knowledge on these peculiar structures.

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All the authors worked together to conceive this essay, its structure and the final images.
Specifically the authors' contributions are as follows:
Luca Rossato and Theo Zaffagnini wrote chapters 1, 2 and 3
Gabriele Giau and Fabio Planu wrote chapters 4 and 5.

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