The *Rotonda of San Tomè* in Almenno San Bartolomeo: Rigorous Digital 3D Survey and Data Processing for a Conscious and Sustainable Conservation

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Abstract

The aim of this paper is to examine the crucial role the correct of 3D Survey in the of high-quality conservation projects. A "conscious, sensitive, and controlled" application of digital acquisition systems a reality-based technologies can be particularly beneficial for documentation, conservation, and valorization, provided that these tools are rigorously integrated and combined with direct engagement with the architectural; it is an essential and irreplaceable condition rather than an ancillary one. Drawing on extensive experience in this field, the study reflects a multidisciplinary approach characterized by strong cohesion of intent and shared objectives. It seeks to highlight the advantages of integrating and proactively employing these valuable tools. To this end, the paper presents a highly relevant case study: the recent restoration of the Rotonda di San Tomè, in Almenno; this case exemplifies the adopted survey methodology and illustrates the benefits of an integrated survey program, applied both during the knowledge acquisition phase and throughout the subsequent construction phase.

1. INTRODUCTION

3D surveying represents an indispensable foundation for any intervention on built heritage, whether aimed at understanding the material and technological characteristics of buildings, or at supporting diagnostic analyses to identify potential structural vulnerabilities. A restoration project based on sound methodological principles must necessarily begin with a comprehensive knowledge of the building, obtained through both documentary analysis and direct observation, as well as through indirect metric and material surveys.

3D surveying, therefore, plays a fundamental role not only in the formal representation of architecture but also in understanding its technical and structural essence. It constitutes the first level of investigation, involving draftsmen, restorers, and structural engineers in a multidimensional analysis of the building, from reading proportions and volumes to decoding material stratifications and assessing structural weaknesses. Modern digital surveying technologies, considering both data acquisition and the processing stages involved in creating digital replicas, offer powerful tools for collecting and elaborating three-dimensional data. However, their application must be guided by a rigorous methodological and scientific approach.

The increasing accessibility of such technologies has led to their widespread adoption, often without sufficient awareness of the limitations and conditions necessary to ensure data reliability. The use of contemporary digital survey techniques, based on passive (image-based) and active (range-based) sensors, as well as so-called "drones" (a term often loosely applied to more complex Remotely Piloted Aircraft Systems, or RPAS), if not accompanied by proper topographic calibration and validation, produces virtual models which, although visually effective, lack metric precision and are therefore inadequate for conservation purposes. Only a conscious integration of direct survey methods with digital technologies can provide genuine knowledge of the built environment, which is essential for the preservation and valorisation of architectural heritage.

The research underscores the effectiveness of a multidisciplinary framework that integrates technological innovation with traditional methodological practices, recognising this synergy as essential to the acquisition of reliable and scientifically robust data.

The research focuses on the *Rotonda di San Tomè* (fig. 1), one of the most significant examples of Romanesque architecture in Lombardy, selected as a case study to define a rigorous and methodologically sound practice in the use of RPAS systems. The remarkable historical and architectural importance of the building has attracted numerous studies and surveying campaigns over time. However, many of these surveys were carried out by operators lacking appropriate training, often using approximate or hasty methods.

The poor accuracy of such investigations has led to the production of imprecise three-dimensional models, compromising data reliability and leading to incorrect interpretations regarding the geometry and conservation state of the structure. These errors have had significant consequences, resulting in ineffective or

Figure 1 – The *Rotonda di San Tomè* at Almenno San Bartolomeo, aerial view acquired by UAV (© Corna 2014).

even potentially harmful consolidation proposals. Through a critical analysis of the methodologies employed and the definition of a survey protocol based on scientific rigour and data quality control, this work intends to demonstrate how the conscious and methodologically grounded use of survey technologies can serve as a key element in the knowledge, conservation, and enhancement of built heritage.

2. THE *ROTONDA DI SAN TOMÈ*: HISTORICAL CONTEXT AND EARLY SURVEYS

The *Rotonda di San Tomè,* located in Almenno San Bartolomeo, is a significant example of Lombard Romanesque architecture. It stands in the confluence area between the Imagna Valley and the Brembana Valley, a territory that still preserves traces of ancient Roman centuriation and which, during the Early Middle Ages, became a curtis regia under Lombard control.

The church, with a central plan layout, is a unique case within the Romanesque architectural context, recalling Early Christian models often associated with the liturgical function of baptism or, perhaps, with Templar rituals (fig. 2). The date of the building's original foundation remains uncertain; the first attestation, dating back to the 12th century, mentions a monastic chapel annexed to a monastery. Following the suppression of the convent in the 15th century, the church continued to serve liturgical functions; it is referred to as an ecclesia campestris during the apostolic visit of the Archbishop of Milan, Carlo Borromeo, on October 8, 1575. Subsequent documentation is lacking; chronicles from the 12th century mention its partial abandonment and, like the adjacent convent, its reuse as an agricultural structure.

In the 18th century, the church began to attract scholarly attention, both for its history and for its significance in the context of Romanesque architecture. A key contribution came from the Codex diplomaticus civitatis et ecclesiae bergomatis by Mario Lupo (1784–1789), which included the first detailed surveys of the monument, graphically rendered by Giovanni Francesco Lucchini. Throughout the 18th and 19th centuries, the Rotonda continued to be studied by prominent European scholars, such as Séroux d'Agincourt and Friedrich Osten, followed later by Fernand de Dartein. The early contributions, however, did not introduce elements of particular interest, as they consisted of re-elaborations of the Codex diplomaticus drawings, simplified and geometrically regularised, which "n'ont pas été relevés avec autant de soin" (De Dartein 1865–1882, p. 387).

Fernand de Dartein visited the monument in 1861 and 1863. In his Étude sur l'architecture lombarde, he recognised the high accuracy and precision of Lucchini's drawings, especially appreciating the faithful depiction of the building's irregularities, stating "rendons à ces anciens dessins la justice qu'ils méritent" (De Dartein 1865–1882, p. 387). He conducted a thorough analysis through direct verification on site and a critical approach, as documented in his sketchbooks: those from 1861 focused mainly on the building, while those from 1863 dealt with decorative details. His drawings are often accompanied by handwritten notes regarding geometry, materials, and comparisons with similar solutions observed during his travels in Italy. Dartein's sketches reveal a particular attention to the irrégularités de forme, which he considered a distinctive trait of Romanesque architecture and reproduced faithfully in his notes (Bella 2013).

Dartein's interest in the Rotonda is especially significant because, before his studies, the monument had received limited attention. His research brought to light constructional and historical features that had previously been overlooked, contributing to a greater awareness of the importance of this rural church within the broader context of early medieval European architecture (fig. 3).

A fundamental role in this scholarly development was played

Figure 2 – The *Rotonda di San Tomè*, DALL-E AI-generated conjectural medieval reconstruction (© S.A.B.E. 2025).

by Elia Fornoni, a local researcher with a particular interest in Almenno and the author of several contributions. The relationship between the two scholars is not entirely clear, but some letters preserved in French archives attest to their exchange. In particular, a letter dated June 19, 1889, reveals Fornoni's satisfaction that Dartein had incorporated in his work certain ideas which Fornoni himself had previously developed, albeit with some interpretive differences (Gritti 2012).

It is therefore likely that Dartein's theories influenced subsequent restoration works on the monument, coordinated by Fornoni between 1891 and 1895. During this phase, Fornoni supervised consolidation interventions and carried out exploratory exca-
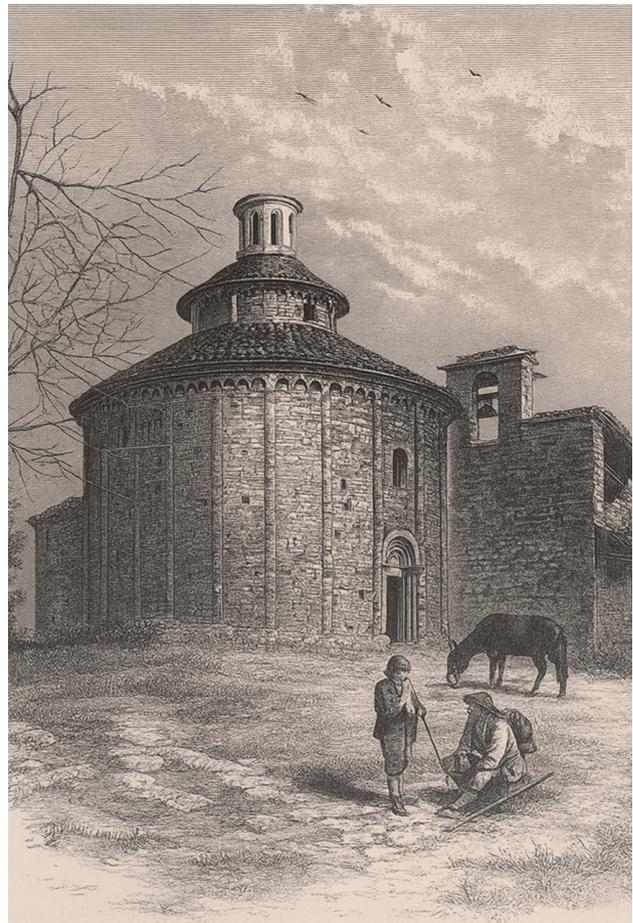

Figure 3 – The *Rotonda di San Tomè* in the 18th century appearance, AI-based photo restoration (© S.A.B.E. 2025).

vations both inside the church and in the north-western area of the site. Within the presbytery zone, three masonry structures were uncovered. The first, the deepest, built in solid quarry stone masonry, was attributed to a small Roman quadrangular structure (possibly a pagan temple).

The second, smaller and built with pebbles, was identified as part of the foundations of the main body of the church and dated to the Early Middle Ages. The third, in regular stone blocks similar to those of the above-ground masonry, was assigned to the Late Middle Ages (Fornoni 1896). However, Fornoni did not adequately document the excavations, which were filled with debris and construction waste, including the ancient terracotta roof tiles replaced with the current slate covering. Archaeological investigations resumed in the 1980s, in conjunction with structural soundness tests of the church's foundations. However, these analyses only confirmed the more recent construction phases, as also suggested by the study of the burial sites, which date to the Late Middle Ages. The masonry remains discovered in the area indicate a progressive elevation of the terrain around the rotunda, more evident in the northern area. This intervention was likely necessary to contain the slope towards the valley of the nearby stream, characterised by steep gradients and landslide risk. These structures also testify to substantial works carried out between the 16th and 17th centuries, perhaps related to the end of the site's funerary use. The connection between the church and the monastery, which until recently was maintained through the adjoining farmhouse (documented in old photographs), occurred through a small door - now walled up - still visible on the southern wall of the presbytery. A clear difference exists in the construction techniques used for the foundations of the nave and those of the

presbytery. However, the significant alterations to the site made by Fornoni do not allow definitive conclusions regarding the early medieval dating, which can only be confirmed through further analysis of possible earlier architectural remains on the site (Vitali 1985). The Rotonda continued to be the subject of study during the 20th century. Noteworthy, though not rigorous, are the drawings by Luigi Angelini (fig. 4).

In 2013 the *Rotonda di San Tomè* underwent a focused conservation campaign aimed at arresting long-standing deterioration and stabilising the monument's external fabric. The work was designed and directed by architects Bruno Cassinelli and Cesare Rota Nodari and carried out by the firms Poloni and Savart, with structural engineering by PierPaolo and Christian Rossi under the Soprintendenza's supervision. Funding was assembled through the local Sistema Culturale Lemine and major philanthropic contributors, notably Fondazione Cariplo, alongside regional partners and private donors. The interventions prioritised roofing repair - a previous intervention was carried out in the early years of the twentieth century (fig. 5) and subsequently, in 1949, by the engineer Angelini -, conservative consolidation of external masonry, and the reinstatement of the tiburio and lantern. A discreet, structural "invisible" armature, consisting of a double steel hoop connected by tie rods and installed beneath the first ring of the roof, was introduced to counteract circumferential cracking and to improve the overall seismic and structural behaviour without compromising the monument's visual integrity.

The removal of the protective scaffolding in late 2013 revealed a markedly improved architectural legibility and reinstated the monument's presence in the landscape; the reopening was celebrated with a formal blessing and community events. Nonethe-
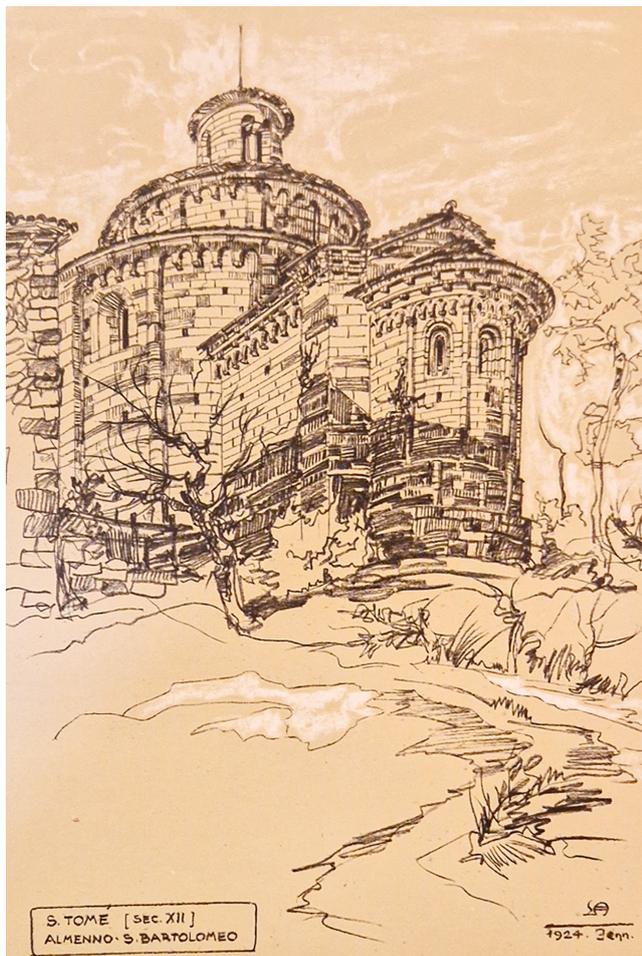

Figure 4 - Comparison between the evocative drawings of the *Rotonda di San Tomè* by Luigi Angelini and the recent survey (© S.A.B.E. 2025).

less, the 2013 phase addressed primarily the external envelope: interior conservation (including frescoes and microclimate management) and long-term monitoring of residual structural stresses have remained priorities for subsequent planning. Continued investment and preventive maintenance will be essential to secure the monument's full preservation for future generations (Cassinelli & Rota Nodari 2013).

Today, the building appears externally compact and austere, with no excessive decoration. Its circular form and the essential use of stone emphasise its symbolic and spiritual character. The main volume is articulated by thin half pilasters, which lighten the mass of the masonry. The semicircular apse is decorated with blind arches and a central single-light window that illuminates the interior. The octagonal drum above the main body has small openings that accentuate the vertical development of the construction. The roofing system reproduces the underlying plan geometry, maintaining full correspondence between structural form and spatial layout, and develops on multiple levels. It is pitched and covered with stone. The interior nave is characterised by a double ring of eight columns; the inner ring supports arches that define an ambulatory around the central space. The upper gallery (matroneum) has large openings facing the nave. Two narrow stairways, built into the thickness of the wall, provide access to the matroneum. The hemispherical dome rests on a tall octagonal drum, which gives vertical momentum to the structure and is crowned by a lantern. The church's orientation is defined by the alignment between the splayed portal and the narrow, elongated apse. The axis does not follow the traditional east–west orientation but is slightly rotated northward. This has led to the hypothesis that the church was built according to specific astronomical criteria, aligned with the sunrise on the winter solstice, symbolising divine light and the resurrection of Christ. However, this theory has not yet been scientifically confirmed.

3. SURVEY AND RECONSTRUCTION WORKFLOW FOR THE DIGITAL TWINS

The development of the latest artificial intelligence systems has transformed the workflow for creating digital copies of the real world. Image-based 3D modelling software uses a sequence of algorithms divided into successive phases, each contributing to the three-dimensional reconstruction. Today, these algorithms use neural networks, enabling faster and more accurate operations while improving the overall efficiency of digitisation processes. 3D survey today is a critical synthesis activity that transforms the complexity of the built environment into a systematic representation using codified relationships of signs and symbols. This process is structured in three main phases:

• 3D Acquisition: involving the objective and neutral collection of data;
• Data Processing: referring to their graphic and geometric processing;
• Analysis: consisting of a critical interpretation based on an intellectual and methodological approach.

Technological innovation has substantially redefined the concept of surveying, making it more efficient and detailed with advanced tools. Automated digital surveying, unlike traditional techniques, ensures both greater objectivity and the detection of details not immediately perceptible to the human eye.

The integration of GNSS systems, terrestrial laser scanners, and photogrammetry has improved acquisition precision, while the use of UAV systems enables high-resolution aerial surveys with reduced costs and time. The use of RTK technology for real-time positioning offers significant advantages, although it does not eliminate the need for topographic references. However, processing point clouds and managing multi-scale data require care-

ful planning to ensure consistent and suitable results for various documentation needs. The documentation of built heritage must therefore rely on an operational protocol capable of calibrating the level of detail according to the adopted scale of analysis.

The S.A.B.E. (Survey and Analysis of Built Environment) research group at the University of Bergamo, in collaboration with restoration professors from the University of Enna Kore, has developed an optimised protocol for producing highly accurate and precise 3D models from aerial images while reducing processing times. This approach is effective even with data from low-cost sensors; the procedure can be applied in most commercially available software. This contribution specifically focuses on the use of Agisoft® Metashape, while clarifying that the described procedures can also be adapted to other platforms, making the method replicable and flexible in different operational contexts.

3.1. Acquisition phase

The data acquisition for the geometric modelling of the *Rotonda di San Tomè* was carried out using a DJI Phantom 4 Pro V2.0 UAV, through approximately one thousand images with a resolution of 5472 × 3648 pixels. The photographs were taken through a series of flights with different operational modes, including nadir shots from various heights, "elevator" flights with orthogonal framing of the wall surfaces, and circular flights with the camera oriented along the longitudinal axis of the church.

During the operations, the position acquisition system was activated, allowing an initial alignment of the images within the WGS 84 reference system. From the collected set of images, a subset of approximately six hundred photographs with more consistent quality was selected. The DJI Phantom 4 Pro V2.0 is a drone equipped with a high-performance camera, featuring a 1-inch
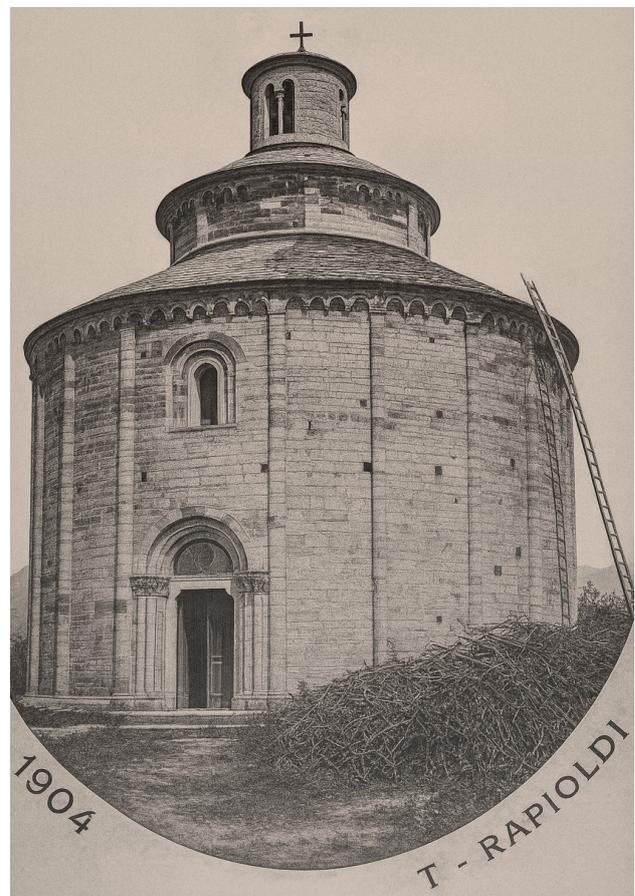

Figure 5 – The *Rotonda di San Tomè* during the restoration of its roof in the early 20th century, AI-based photo restoration (© S.A.B.E. 2025).
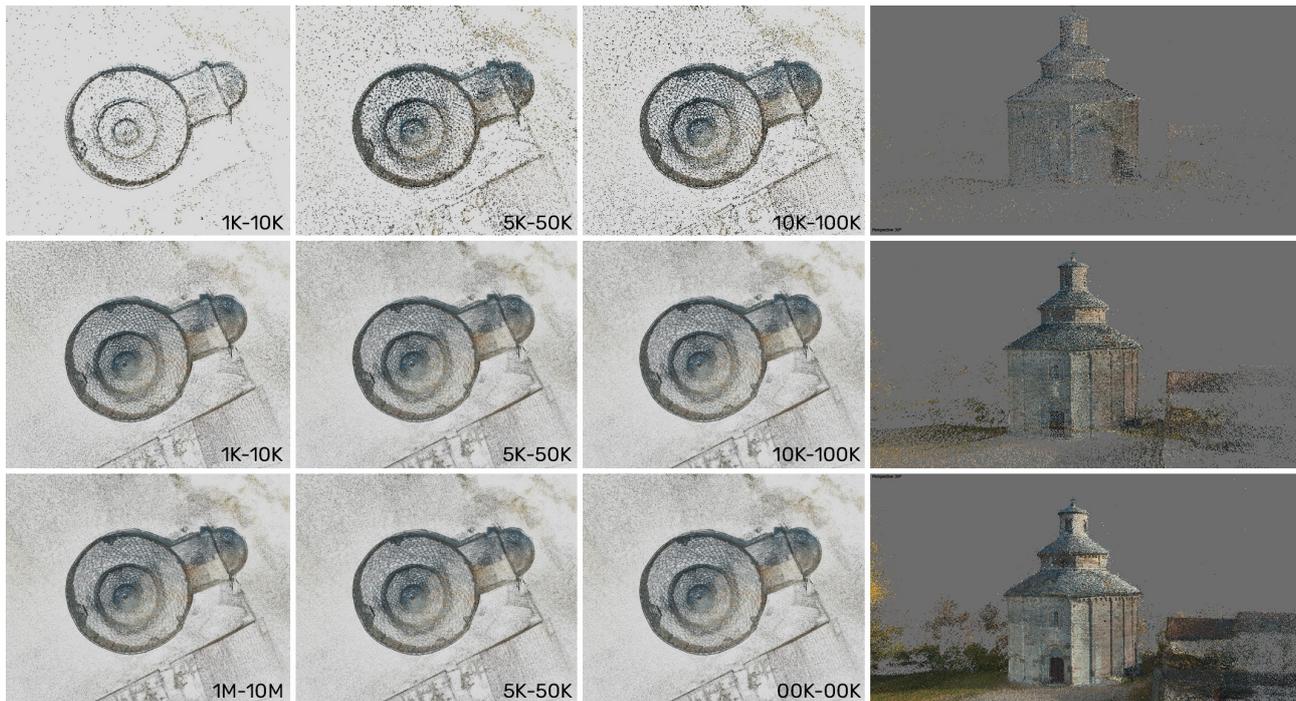
Figure 6 – Different characteristics of the Point Cloud as the ratio between Key Points and Tie Points increases (© S.A.B.E. 2025).

CMOS sensor with a maximum resolution of 20 MP. The images were captured using an aperture priority set to f/2.8 to reduce shutter speeds and ensure proper exposure even under variable lighting conditions. The hyperfocal distance was considered, guaranteed by the 24 mm lens, allowing focus from approximately 1 meter to infinity, which is ideal for detailed outdoor captures. The time-lapse shooting mode enabled the automatic acquisition of images at predefined intervals. The ISO sensitivity was set to 100 to ensure maximum sharpness with minimal noise. Shutter speeds ranged from 1/1600 s to 1/250 s, with images affected by motion blur being discarded. All images were saved in RAW (DNG) format to preserve maximum quality. Vibration reduction was achieved through a three-axis gimbal damping system, ensuring stability even in windy conditions. The mechanical shutter, with a maximum speed of 1/2000 s, eliminated rolling shutter effects typical of CMOS sensors with electronic shutters.

The acquisition operations were not limited to aerial systems but were integrated with a control topographic network. This network, consisting of strategically positioned benchmarks, was measured with high-precision instruments using a methodology based on forced centring and fixed stations to ensure geometric accuracy in subsequent operations. A point cloud acquired using Terrestrial Laser Scanning (TLS) technology was referenced to the topographic network. The integration between the topographic network and TLS data served a dual purpose: it provided consistent geometric support for 3D modelling operations and offered an external verification system for the models reconstructed from the photogrammetric image database.

This integrated approach increased the reliability of metric results and strengthened the scientific validity of the final model.

3.2. Data Processing Phase

The workflow begins with a preparatory phase dedicated to image processing, which is essential to ensure the quality of the visual dataset. This quality is a necessary condition for the subsequent analysis and modelling operations. Artificial intelligence now makes it possible to automate many tasks related to image selection and enhancement. Algorithms work on large datasets and perform two main functions:

• Automatic Selection: neural networks evaluate images based on quality criteria. Blurry, overexposed, or redundant images are removed, resulting in a more coherent and efficient dataset.
• Image Enhancement: operations such as super-resolution, noise reduction, colour correction, and exposure adjustment are applied, even selectively on specific areas. Disturbing elements such as shadows, reflections, or unwanted objects are removed to improve matching and point cloud density.

These algorithms act only on contrast and sharpness without modifying geometry, content, or perspective. This facilitates the following steps and contributes to achieving more accurate results. File format choice is also important. It is recommended to use uncompressed raster images (such as TIFF) generated directly by the sensor. These provide higher quality compared to compressed formats like JPEG or PNG, which degrade data quality and should be avoided.

Not all acquired images were used. Careful dataset processing before photogrammetric processing is essential to achieve optimal results. Quality verification operations, distortion correction, and radiometric homogenization improve dataset consistency and reduce reconstruction errors. The removal of problematic images and the optimisation of acquisition geometry enabled the creation of a 3D model more accurately aligned with the documented reality.

Although not formally part of the processing phase, this preparatory step is essential for obtaining reliable results. The success of photogrammetric processing quality depends on the input images. For this reason, it is necessary to conduct thorough checks, correct any issues, and carefully organise the dataset.

These practices help optimise keypoint recognition, feature matching, and the generation of a dense and reality-faithful point cloud. Most software includes initial quality checks that automatically exclude unsuitable images, ensuring a clean dataset before reconstruction begins.

Artificial intelligence has also transformed the 3D reconstruction process, making the entire workflow more efficient. In the past, the workflow consisted of four phases: image alignment and creation of a sparse cloud, cloud densification, mesh generation, and texture application. The first two phases were based on algori-

thms using collinearity equations in two distinct steps: first, to estimate the position and internal parameters of the cameras, and then to generate a dense point cloud and calculate the spatial position of the images.

Today, traditional densification is often replaced by direct methods that generate dense, georeferenced point clouds in the early stages, avoiding redundant steps. These point clouds can be used directly for mesh generation and texture application. However, generating a point cloud in a single processing step requires a rigorous workflow. It is necessary to optimally calculate the ratio between keypoints (recognisable points) and tie points (corresponding points between images), and to select an appropriate resolution sampling value.

This allows maximum information extraction without overloading computation. An initial comparison (figg. 6-8) shows the results of different processing tests on the same dataset, varying the keypoint/tie point ratios from low values (1:10,000) to very high ones. Data shows that the number of points increases (from 45,000 to over 4 million), the maximum RMS error slightly increases (from 40 to over 70 pixels. However, the average RMS error decreases (from 1.2 to 0.9 pixels). All parameters stabilise around the 10,000:100,000 ratio, which is considered optimal.

The point cloud was generated by analysing all pixels without downsampling, creating a model with over 4 million points and an average error inferior to one pixel.

However, refinement with filtering techniques such as "Gradual Selection" is necessary to remove less reliable points and improve reconstruction quality. This procedure uses diagnostic parameters to remove outlier points:

• Reprojection Error: assesses the geometric consistency between the projected position of a point and its observed position in the image.
• Reconstruction Uncertainty: indicates the uncertainty in spatial triangulation, often due to limited views or unfavourable angles.
• Projection Accuracy: measures the precision of point projection on the image, useful for verifying calibration reliability.

The iterative application of these criteria progressively improves the metric and topological quality of the point cloud, increasing the accuracy of the 3D model. Using "Gradual Selection," it was possible to obtain a point cloud with about 3.5 million points, an average error of 0.35 pixels, and a maximum error below 3 pixels (fig. 9). Two strategies were then compared: the direct generation of the mesh from the point cloud obtained with the new method (M1 and M5) and the generation of the mesh after a traditional densification phase (M2 and M4). Mesh M3 represents the sparse cloud generated using the classic method. Point clouds were also extracted from the mesh model according to both strategies: C1 and C4 for the new method, C2 and C3 for the traditional one (fig. 10). The comparison with the 3D laser scanner model, used as a reference, showed the clear superiority of the new approach, which ensured greater morphological consistency and geometric accuracy in the reconstructed 3D model.

3.3. Analysis Phase

The analytical phase represents the third step in the survey process. In a digital photogrammetric workflow, it plays a central role. It is configured as an interpretative activity. The three-dimensional data, generated from image processing, are subject to critical examination. The analysis is not limited to metric verification. It goes beyond simple quality control of the model. It requires a deeper investigation. It aims to understand the structure, morphology, and formal logic of the surveyed object. The methodology involves a reflection on the meaning of the reconstructed data. Although derived from an automated pipe-
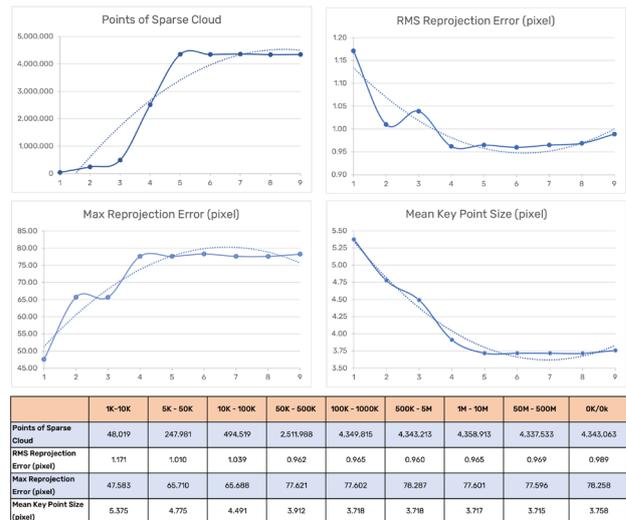

	1K-10K	5K - 50K	10K - 100K	50K - 500K	100K - 1000K	500K - 5M	1M - 10M	50M - 500M	0K/0k
Points of Sparse Cloud	48,019	247,981	494,519	2,511,988	4,349,815	4,343,213	4,358,913	4,337,533	4,343,063
RMS Reprojection Error (pixel)	1.171	1.010	1.039	0.962	0.965	0.960	0.965	0.969	0.989
Max Reprojection Error (pixel)	47.583	65.710	65.688	77.621	77.602	78.287	77.601	77.596	78.258
Mean Key Point Size (pixel)	5.375	4.775	4.491	3.912	3.718	3.718	3.717	3.715	3.758

Figure 7 – Evaluation of the optimal ratio between
Tie Points and Key Points (© S.A.B.E. 2025)

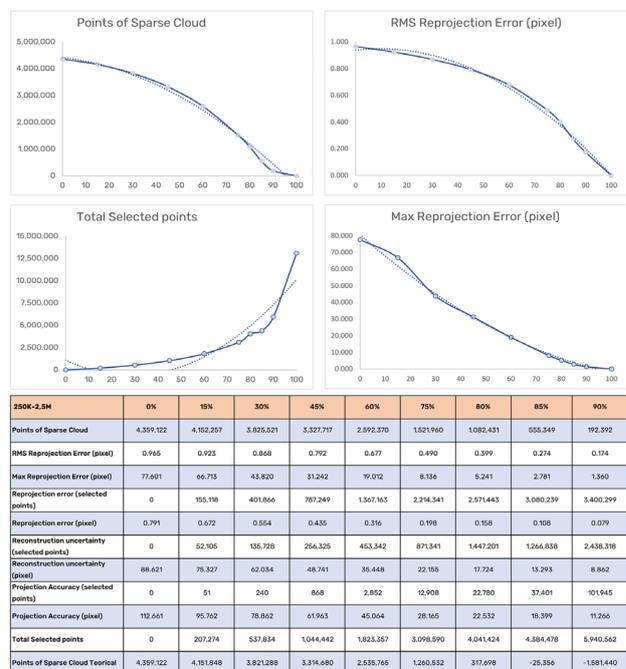| 250K-2,5M	0%	15%	30%	45%	60%	75%	80%	85%	90%
Points of Sparse Cloud	4,359,122	4,152,257	3,825,521	3,327,717	2,592,370	1,521,960	1,082,431	555,349	192,392
RMS Reprojection Error (pixel)	0.965	0.923	0.868	0.792	0.677	0.490	0.399	0.274	0.174
Max Reprojection Error (pixel)	77.601	66.713	43.820	31.242	19.012	8.136	5.241	2.781	1.360
Reprojection error (selected points)	0	155,118	401,866	787,249	1,367,163	2,214,341	2,571,443	3,080,239	3,400,299
Reprojection error (pixel)	0.791	0.672	0.564	0.435	0.316	0.198	0.158	0.108	0.079
Reconstruction uncertainty (selected points)	0	52,105	135,728	256,325	453,342	871,341	1,447,201	1,266,858	2,438,318
Reconstruction uncertainty (pixel)	88.621	75.327	62.034	48.741	35.448	22.155	17.724	13.293	8.862
Projection Accuracy (selected points)	0	51	240	868	2,852	12,908	22,780	37,401	101,945
Projection Accuracy (pixel)	112.661	95.762	78.862	61.963	45.064	28.165	22.532	18.399	11.266
Total Selected points	0	207,274	537,834	1,044,442	1,823,357	3,098,590	4,041,424	4,384,478	5,940,562
Points of Sparse Cloud Teorical	4,359,122	4,151,848	3,821,288	3,314,680	2,535,765	1,260,532	317,698	-25,356	-1,581,440

Figure 8 – Comparison of Point Clouds in relation to the Tie
Point filtering coefficient (© S.A.B.E. 2025).

line, the data cannot be considered objective reproductions of reality. Point cloud density, mesh quality, and texture accuracy are only starting points. A critical evaluation is essential. Perspective distortions, interpretative gaps, and ambiguities must be considered. These issues stem from the limits of the computational process. At this stage, high-resolution orthophotos are produced. These outputs, geometrically corrected and georeferenced, are essential for metric and material analysis. They allow comparison with historical surveys, both graphic and photographic. Current orthophotos can be compared with previous documents. This approach enables the identification of morphological variations, structural transformations, and degradation processes, thereby contributing to the reconstruction of the building's conservation history. Interpretation results from the interaction between technology and disciplinary knowledge. Artificial intelligence and automated processes are support tools. They do not replace methodological awareness and critical judgment. Only an

integrated approach can transform the photogrammetric model. From a mere technical product, it becomes a meaningful representation. Useful for documentation, conservation, and understanding of the built heritage.

CONCLUSIONS

A photogrammetric 3D survey is a knowledge tool. Its effectiveness depends on the ability to link digital results with physical reality and prior documentation. The operator must decode geometric and material complexity. The digital model must be consistent with the research objectives. Digital modelling is not an end. It is part of an analytical process. This process requires critical selection of information. Methodological choices depend on the scale of investigation as well as on the historical and architectural context. The experiment showed the effectiveness of artificial intelligence in the survey workflow. Automated algorithms improve speed and reliability. The use of automatic procedures for image selection and enhancement led to high-quality visual datasets. This is crucial for the success of the modelling phases. A significant result concerns the ability to obtain dense and georeferenced point clouds in the early stages. This reduces redundant steps of traditional methods. It helps to limit time and

Figure 9 – Final Point Cloud derived from the process of Ground Selection Filtering (© S.A.B.E. 2025).

operational costs. Iterative filtering using "Gradual Selection" further improves metric and topological quality. The result is a highly accurate 3D model. The outcomes show high geometric and morphological fidelity. The tested protocol outperforms con-
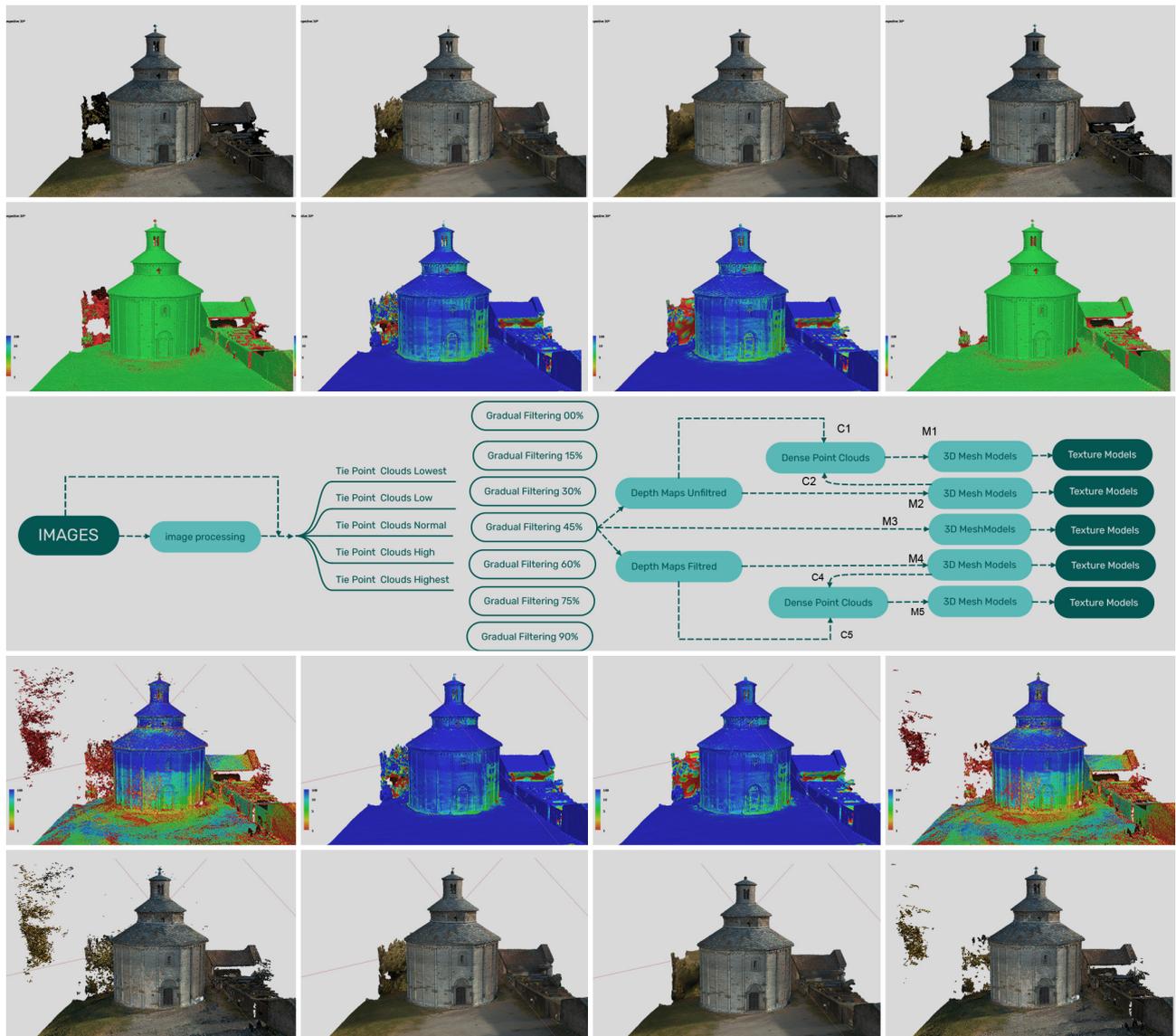

Figure 10 – Pipeline and comparison of result confidence in Point Cloud and Mesh Model generation (© S.A.B.E. 2025).

ventional procedures, even with datasets acquired using low-cost sensors. Another important aspect is the method's replicability. It is compatible with most available processing software. The operational protocol allows the detail level to be adjusted according to the scale. The workflow is flexible and adaptable to various applications. It is suitable for both built heritage documentation and large-scale territorial surveys.

Future developments include the integration of deep learning techniques. These may further automate filtering and mesh reconstruction. Automated pipelines for real-time quality control are also foreseen. The extension of the protocol to multispectral, thermographic, or lidar-integrated datasets could broaden analytical potential. This would provide new tools for heritage and environmental monitoring and conservation.

The presented experiment shows that AI-supported automated survey systems are not just a technical evolution. They represent a methodological transformation. They redefine how data are acquired, processed, and interpreted. They help make the digital copy of reality more objective, accurate, and efficient.

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