The Photogrammetric Survey of an Historical Map

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Abstract

This study investigated the effectiveness of photogrammetric surveying for the digital reproduction of historical documents unsuited to traditional scanning techniques due to their fragility or large dimensions. The experiment focused on a mid-18th-century territorial map, known as the “Calcato”, that in Italian means ‘trodden’, in the sense of a landscape that has been explored and described through walking it on foot. The objective was to obtain high-resolution, metrically accurate digital outputs by designing a specific acquisition protocol, including a tailored flight plan and the use of a metric camera. Image acquisition was conducted indoors through oblique photography from external positions. To address surface irregularities caused by the semi-rigid support, a high-precision digital surface model (DSM) was generated to enable accurate orthorectification. Geometric reliability was ensured by establishing a topographic control network, defining the coordinates of six ground control points with sub-millimetric precision. The resulting orthophoto validated both the methodological approach and its implementation, providing a reliable and detailed representation suitable for territorial analysis. The outcomes contribute to the objectives of the PRIN project and offer a replicable methodological reference for the digital reproduction of large-format historical documents, supporting the safeguarding of documentary heritage and the dissemination of its informational content.

1. Introduction

In this era, characterised by the transition from analogue to digital, the concepts of digitisation and digital copy are no longer confined to highly technical fields but have become an integral part of all areas of work and research. In the field of architecture, the notion of the digital copy has become an inevitable development and it is no longer restricted solely to newly constructed buildings, which have traditionally been associated with BIM systems. Digitisation has, in fact, become an essential aspect of the built environment and historic architectural heritage. This broadening of scope has led to a significant wave of experimentation, aimed at testing new approaches and software tools across various research and professional contexts, using the specific requirements of individual case studies to inform the development of systems with broader applicability.

In light of changing patterns in public engagement, one of the earliest and most widespread applications of digitisation has been the large-scale dissemination of information, particularly in relation to the public’s interaction with the architectural heritage. In this context, the digitisation of information, drawing from developments in ICT (Information and Communication Technologies), has given rise to numerous experiments involving virtual reality (VR) (Banfi, 2021), augmented reality (AR) (Maietti et al., 2021; Merchàn et al., 2021), and mixed reality (MR) (Ioannides et al., 2017). Within this extensive and varied field of experimentation, there has also been significant work of a technical and methodological nature, particularly in relation to the modelling of complex buildings, as explored through Scan-to-BIM or H-BIM approaches (Banfi et al., 2022; Bolognesi and Fiorillo, 2023). Another strand of research has focused more specifically on the management of information concerning buildings or the built environment, calling upon GIS software (Huesca Tortosa et al., 2017; Santos et al., 2020), or seeking to establish links between GIS platforms and 3D modelling environments (Colucci et al., 2023; Matrone et al., 2023; Xu et al., 2023, Pozzoni et al., 2024).

This movement, fostered and catalysed by national and international policy frameworks such as the 2030 Agenda, has found ample opportunity for growth, yielding stimulating and relevant outcomes even in less technologically driven fields, such as the study and valorisation of historical archival documentation. This archival legacy, often accumulated over decades or centuries, is now increasingly recognised as an integral component of the heritage asset itself and, as such, occupies an important position within this domain of investigation (Biolo et al., 2023). Numerous studies have examined the potential of integrating historical cartography within GIS environments for various purposes: to support well-informed urban planning (Cazzani et al., 2019; Jovanović and Oreni, 2021), to develop tools and systems for territorial analysis that encompass both geographic and historical coordinates (Iarossi, 2014; Piovan, 2019). The capacity of these systems for large-scale data management has also been explored as a potential response to widespread challenges in organising the dispersed archival heritage held across different regions (Bitelli et al., 2019). All these research branches, however, presuppose the digitisation of historical documents, a process which, despite its centrality, has received relatively little direct attention in the literature. Digitisation is often treated as a preliminary or implicit stage within broader workflows, rather than as a subject of study. Sometimes, however, this process is not always straightforward, and in many cases calls for careful consideration and the development of alternative approaches (Tsioukas and Daniil, 2006; Roggero and Soleti, 2015). It is precisely in this gap that the work described in this text falls.

The opportunity arose within the framework of the PRIN (Project of Relevant National Interest) initiative *Crafted in Stone / Recorded on Paper*, which aims to collect and promote knowledge of buildings and archival heritage related to the “good” governance of cities. The main objective is the creation of a Built Heritage Database (DBPC) (Guzzetti et al., 2024), accessible through a WebGIS platform, allowing consultation of the digitalised documents.

In the course of this work, and specifically during the study of historical materials held in the Historical Municipal Archives of Gandino, a particularly noteworthy and unusual historical map was identified: the “Calcato” of Gandino. This discovery led to an experimental study focused on adapting land surveying techniques to the digitisation of fragile and large-format historical documents.The work aimed to complete the digitisation of the “Calcato” map, safeguarding a document of notable historical value and the wealth of information it contains. At the same time, it sought to develop and test a working method capable of producing results comparable in quality to standard direct scanning, while also being applicable in situations where conventional scanning is not feasible, thus ensuring the map’s legibility and usability in digital format. Finally, the occasion also offered an opportunity to test an interdisciplinary approach, combining expertise from the fields of geomatics and the study of the history of architecture and construction. The project thus served to highlight the potential of such collaborations in supporting the preservation of archival heritage and the enhancement of the information it holds.

2. The case study: the map of the “Calcato” of Gandino

The town of Gandino is the county seat of the valley that bears its name, Val Gandino, situated along the eastern edge of Valle Seriana, in the province of Bergamo (Italy) (Progetto Civita, 1999). As early as the 15th century, municipal statutes provided for the presence of five (later four) representatives of the local quarters, who were in charge of measuring and controlling the municipal boundaries. These figures were referred to as “calcatori” (or “chalcatores”), as they physically ‘trodden’ the land, measuring it using a medieval technique based on traversing the terrain and identifying physically recognisable markers in the landscape (Marchetti, 1996). This method differed significantly both from ancient land surveying techniques, by then evidently lost, and from those employed by modern surveyors in Lombardy (Sandri, 1983). The act of treading was performed along an ideally circular path which, in practice, formed a closed broken line, referred to as a “serada” (that means ‘closed’)[(1)]. The line’s vertices were defined by “termini”: stone markers, building corners, path intersections, and natural features like streams and puddles. Regular and detailed verification of these boundaries was imposed upon the rural districts by the city of Bergamo, likely for legal and juridical purposes, and quite possibly for mercantile and fiscal ones as well. The “calcatori” were required to produce written documents recording the linear measurements of the boundaries of public land, documents known as “calcati”. Only a limited number of these have survived, now preserved in the archives of a few municipalities in Valle Seriana, including Alzano Lombardo (Nicefori et al., 1999), Clusone, and Oneta[(2)].

Figure 1. The map belonging to the “Calcato” of 1747.

The Historical Municipal Archives of Gandino preserves three versions, dating at least from 1435–1523, 1567, and 1747[(3)]. The one from the mid-eighteenth century stands out, in contrast to all other known documents of this type, for its inclusion of two elements: a 139-page register and a large cartographic map (Figure 1), while normally only the written document is present[(4)]. The eighteenth-century register is divided into eighty chapters, each describing a different location. The sequence of chapters follows the actual path taken during the new surveying operations, and the measurements are recorded using the agrarian unit known as the “cavezzo” (conventionally equivalent to 2,626603 metres, or six “braccia” of approximately 0,53 metres each). The register was written by notary Bernardino Gregorio of Gandino, active in Bergamo, while the town council assigned the measurement to Pietro Antonio Ferrari “de’ Domo D’Ossola Status Novariae“[(5)], with the aim of producing a second document: a drawing, referred to as “Typum” (Bianchi, 1993). The new and definitive measurements were to be based on the observation of existing reference points (“termini”), the examination of historical documents, and the acquisition of new data. The operations began on 31 July of the same year and concluded on 15 January 1750 with the production of a “novum ichnograficum universalem Typum”[(6)].

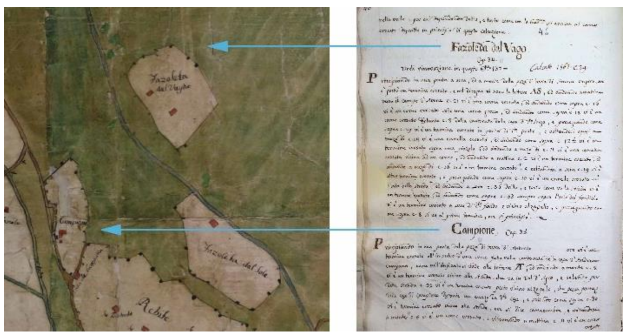

Figure 2. Comparison of a portion of the map with its corresponding description in the register.

Ferrari’s work likely began with sheets documenting the measurement process, which were later combined to create the composite object studied in this research. A direct relationship between Ferrari’s map and the register (Figure 2) is evidenced by capital letters (e.g., A; AB) appearing in both documents, corresponding to the actual route taken during his three-year survey of the territory. Further symbols are used to denote the “termini” (represented by black-filled rectangles or squares) and the “crosati” (crosses of varying size), which served as reference points during the measurement operations.

The work culminated in a topographic map measuring 1,83 metres in width and 3,10 metres in height, composed of 25 sheets of paper of varying dimensions, joined together and glued on a canvas, an operation probably dating to the twentieth century. The map is now stiffened by two rods and resembles a kind of large banner[(7)]. It is therefore plausible that the representatives of the Municipality of Gandino originally intended to produce a significant and emblematic object, one that would serve as a

1 For “serada”, see: https://www.lombardiabeniculturali.it/archivi/complessi-archivistici/MIBA002E8B/.

2 https://www.lombardiabeniculturali.it/archivi/complessi-archivistici/MIBA002E8B/.

3 https://www.archiviedocumenti.it/archivi/?str=109&prg=31; ASCG - Archivio Storico Comunale Gandino (Bg), 107, 113, 115.

4 *Calcato de’ Beni tutti della Spett.le Communità di Gandino 1747*, “Omnia Gandini arvorum confinia, Lector / Nec non mensuras iste libellus est”, ASCG, 115.

5 Ferrari is named as “national milanese essercitante la Geometria ed agrimensore già ed in Bergamo e nel Distretto sperimentato perfetto in tale arte …”, ASCG, 115, c. 106.

6 ASCG, 115, c.2.

7 ASCG, 115.1.

reference model for the local community. The elaborate multicoloured compass rose, and above all the prominent city coat of arms bearing the inscription "MISURA E PIANTA DELLA SPETTABILE COMUNITÀ DI GANDINO" ('measure and plan of the estimable community of Gandino') in the lower left-hand corner of the map (Figure 8) further support the hypothesis of a consciously political project. For the administrators of the time, the detailed municipal map served both to assess the actual extent of the land assets and to guide local governance policies (Selva, 2013).
From the perspective of historical research, the "Calcato" map of Gandino raises several questions that merit future investigation (Pederzani, 2023). This cartographic document stands out not only for its historical significance but also as a nearly unique example in Lombardy and possibly Italy, given its considerable size (Zappa, 1991/1992; Pagani, 2021). Due to the PRIN project's goals and the urgent need to safeguard this singular artefact and its information, digitisation was prioritized. This study presents the development and testing of an alternative digital reproduction method for the "Calcato" map, designed to be replicable in similar cases and to support both heritage preservation and information dissemination.

3. The digitisation of the historical map

The aim is to digitise the map at a resolution comparable to that achievable with traditional scanners. Due to its format, the map requires an aerial photogrammetric approach, as if surveying a territory from above, ensuring a ground sampling distance (GSD) (Verhoeven, 2018) equivalent to a 300-dpi scan, namely, a GSD in the order of 0,10 mm. The boundary conditions impose certain specific requirements, some highly restrictive, others which, to a degree, simplify the methodology.
The "Calcato" is preserved in an enclosed space with relatively low lighting levels. As is well known, ground illumination is a quantitative factor influencing the diaphragm's aperture settings and, consequently, depth of field (DoF), both critical in close-range photogrammetry (Luhmann et al., 2020) applications. The brighter the maps can be illuminated, the better. Since moving the map outdoors without exposing it to direct sunlight (which could damage the original) is practically impossible, artificial lighting was carefully arranged to avoid any reflective effects, which would otherwise compromise the quality of the digital output.
Once unrolled, the big document retains a degree of non-planarity that is not negligible in relation to the digitisation process. During the survey, it was placed on a perfectly level floor and tensioned appropriately using the wooden supports to which it is affixed. Nonetheless, undulations in the order of a few centimetres were observed. This necessitated the use of a high-resolution digital orthophoto, rendering controlled mosaic techniques unsuitable. Again, the issue of non-planarity required meticulous lighting management to eliminate both shadows and reflections.
As is often the case when digitising non-rigid materials, the process of laying the "Calcato" flat is not repeatable, each attempt produces slightly different geometries. Through the rigorous determination of control points, described in detail below, it was possible to assess those variations between successive layouts are in the order of a few millimetres, more than an order of magnitude greater than the desired GSD of 0,10 mm. This finding provides reassurance for the digitisation process, which only needs to ensure accuracy intrinsic to the scanning procedure itself, as is the case with conventional digitisation of paper documents; the result will never constitute a metrically rigorous source, since the map lacks cartographic parameters such as kilometre grids or geographic referencing frameworks. This constraint also defines the limitations of the digitised representation, which can never be used for precise metric comparison with modern cartography.

3.1 The flight plan

The task involves preparing a flight plan equivalent to a photogrammetric flight over a slightly undulated terrain, with the constraint that, due to the impossibility of setting up a scaffolding in the premises where the tracing is laid out, the work must be carried out using oblique strips captured from the sides of the map.
The photogrammetric camera available is a Canon EOS 700D, equipped with a 5184 x 3456-pixel sensor. The first design parameter, with a target GSD of 0,10 mm, is that the ground coverage of a single frame in nadiral configuration is 518,40 x 345,60 mm. To cover the entire map with the required longitudinal and lateral overlap, numerous images is necessary. The pixel size of the sensor is p = 4,38 microns; for each pixel to correspond to a GSD of 0,10 mm (Equation 1), the resulting average image scale 1/m is approximately 1:23.

$$1/m = f/H = p/GSD, \tag{1}$$

Based on the nadiral acquisition parameters just calculated, it is possible to estimate the number of images required per strip while ensuring 70% overlap within it. Approximately 20 images are required, with slightly more than 10 cm between consecutive photographic shooting points. This first fundamental parameter for flight planning can correspond to different acquisition geometries thanks to the availability of a variable focal length camera. With a 44 mm focal length, images are captured at a distance of 1000 mm from the document, while a 55 mm focal length corresponds to a distance of 1255 mm. This initial nadiral flight configuration must, however, be revised to account for the need to carry out an oblique acquisition, due to the impossibility of performing images perpendicular to the object. Still under the nadiral imaging hypothesis, considering the object width of 1800 mm, and adding a 20 mm safety margin on each side, bringing the total to 1840 mm (Wtot), the strip width of 518 mm (Ws) allows for a proposal of four parallel strips (Ns). This configuration (Equation 2) yields a lateral overlap band of approximately 8 cm (77 mm).

$$(((Ws \times Ns) - Wtot))/((Ns - 1)), \tag{2}$$

This initial hypothesis of four parallel nadiral strips must now be reinterpreted as two pairs of oblique strips acquired from outside the tracing, each at different flying heights (Figure 3). The resulting geometry must then be tested using the parameters governing achievable DoF in the acquisition setup. It is important to emphasise that having two different flight altitudes per side is essential to ensure an optimal acquisition geometry, thereby avoiding the risk of capturing images from the same position with only a change in the camera angle, an approach that would significantly weaken the metric content of the automatic aerial triangulation.
The two image sets acquired at a flying height H1 = 1000 mm using a 44 mm focal length, while maintaining a 20 mm safety margin beyond the tracing edges, define a camera-to-target distance D1 = 1100 mm, which results in an average GSD of 0,11 mm, still within acceptable limits. The corresponding strip width is 627 mm, thereby improving lateral overlap parameters. The GSD at the outermost edge of the tracing remains 0,10 mm; in the farthest area of each image, the GSD reaches 0,13 mm. This too is acceptable, particularly as the high longitudinal overlap in

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that zone allows the use of the GSD derived from the second strip acquired with a different focal length at a higher altitude.

Proceeding with the checks for the second flight height H2 = 1255 mm using the maximum focal length available on the camera (55 mm), the distance D2 from the tracing becomes 1533 mm. This results in an average GSD of 0,12 mm. The strip coverage is 789 mm, further improving lateral overlap. In the area closest to the camera, which overlaps with the previously detailed strip, the GSD returns to 0,11 mm; at the farthest part of the strip, though highly overlapped with the strip acquired at the same height from the opposite side of the map, the GSD exceeds 0,14 mm. At the midline of the tracing, the GSD slightly exceeds 0,13 mm. In conclusion, the GSD substantially meets the digitisation objectives.

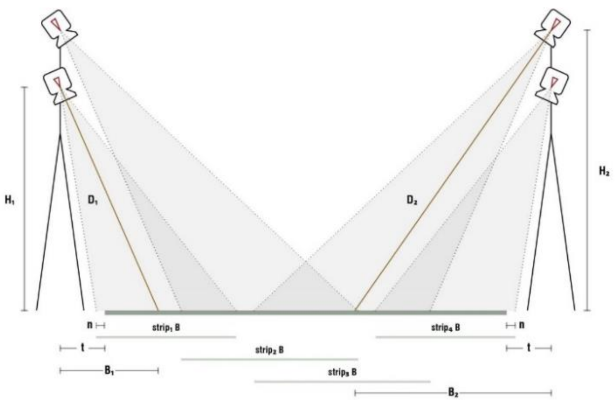

Figure 3. Scheme of the position of the four strips.

The final aspect to verify is the DoF, given that neither of the two proposed flight heights corresponds to the hyperfocal distance. In photogrammetric documentation of flat archival materials, such as the "Calcato" map, ensuring consistent image sharpness is crucial, particularly when using oblique (inclined) shots. The DoF refers to the range of distances within which objects appear acceptably sharp in a photograph. When the sensor is tilted, parts of the document fall at different distances from the lens, potentially exceeding this sharpness range if depth of field is too shallow. Three main factors influence this aspect:

- Focal length (f): Longer focal lengths decrease DoF.
- Aperture (N): Higher f-stop values (smaller apertures) increase DoF.
- Focusing distance (D): Greater focusing distances increase DoF.

The circle of confusion c for the Canon EOS 700D is 0,019 mm. The acquisition is planned in diaphragm's aperture-priority mode, using value of N equal to 16, and working on a photographic tripod to ensure perfect camera stability.

For the lower strip, we consider the focal length (f) to be 44 mm and the flight distance (D) to be 1092,20 mm.

The hyperfocal distance (hp1) is 6368,42 mm using Equation 3.

$$hp1 = f\hat{}2/(N * c), \quad (3)$$

Based on this, it is possible to calculate (Equations 4 and 5) the effective DoF for the actual flight distance (Figure 4).

$$(hp1 * D)/(hp1 + (D + F)), \quad (4)$$

$$(hp1 * D)/(hp1 - (D - F)), \quad (5)$$

In this case, the range is from 937,84 mm to 1307,39 mm. Since D falls within the DoF range, the image wills stay focused across the inclinated surface, including at the closer and further edges of the cone projection. In the case of the higher flight, the parameters change, but the result remains satisfactory. The DoF ranges from 1334 mm to 1801 mm. In both cases, the inclination of the image acquisition ensures that the entire image remains in focus under the working assumption of photographing with an aperture of N = 16.

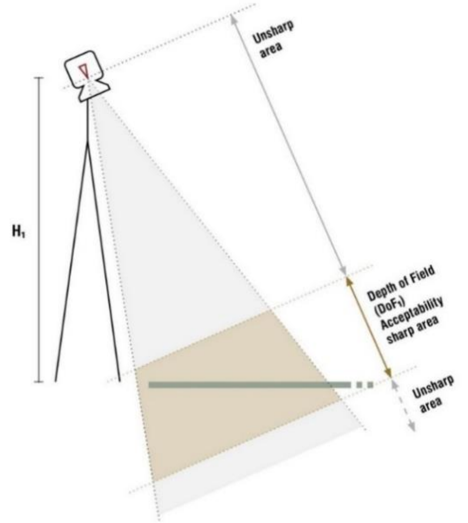

Figure 4. Representation of the DoF and its areas.

3.2 Field operations and data acquisition

The survey campaign was carried out as closely as possible in accordance with the planned design. The camera was moved between successive images with centimetre-level precision, guided by a meterstick carefully placed along the edge of the tracing. In addition to the two pairs of lateral strips captured along the long side of the tracing, two transverse strips were also acquired, mirroring the same geometry as the strips flown at a relative height of 1 metre, positioned alongside the short side of the map. In total, the block comprises 178 images across 6 strips (Figure 5); the photogrammetric camera used operated with two different focal lengths.

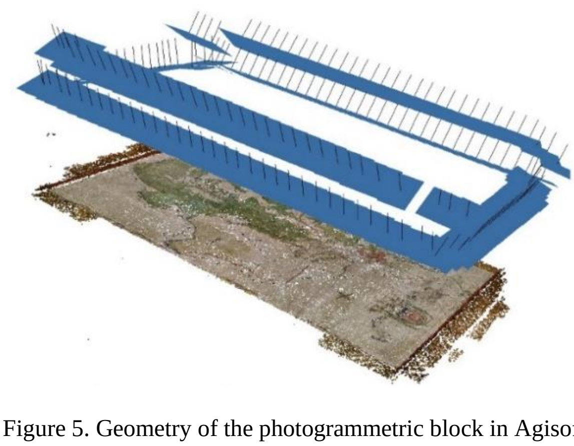

Figure 5. Geometry of the photogrammetric block in Agisoft Metashape ("tie points" visible below).

To ensure accurate orientation of the entire block, six ground control points (Cabo et al., 2021) were measured on distinctive features within the map's drawing (Figure 6). The precision in determining these control points must be consistent with the GSD. In order to achieve an RMS (Root Mean Square) error of

±0,10 mm, it was considered appropriate to use the method of forward intersection from two total station setups. The only distance measured was the planar distance between the two instrument stations, which primarily serves to define the scale factor for the entire block. All other observations consisted of angular measurements, taken using a Topcon ES series total station. At such short working distances, the angular measurement accuracy is sufficient to ensure, through variance propagation, that the RMS error in the resulting control point coordinates meets the required specification. This redundant measurement scheme enabled the calculation of an RMS error for each coordinate of the six control points, none of which exceeded 0,10 mm in absolute value.

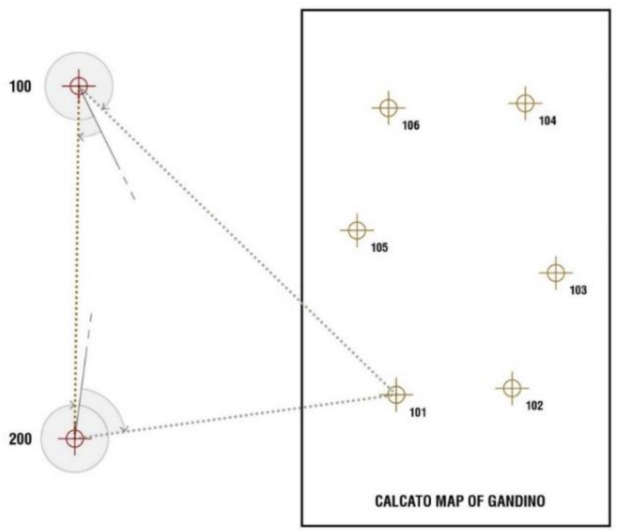

Figure 6. Distribution of the six control points on the “Calcato”.

3.3 Photogrammetric processing and orthophoto development

The photogrammetric block was subsequently processed using Agisoft Metashape software. The mean residual error on the six ground control points was 0,80 mm; the average value for the reprojected pixels was 0,67 pixels, noting that the average pixel size across the entire document is 0,13 mm. Each support point is visible on a number of frames that varies from 6 to 12, therefore with a strong redundancy. The georeferencing and external orientation of the automated aerial triangulation yielded excellent results.
The dense cloud, generated in “high” mode, consisted of 143.976.699 points, with an average density over the 3 × 1,80 m² area of the tracing equivalent to 27 points per mm². Already this intermediate product showed a very high level of legibility. To generate the orthophoto, a 3D mesh was created with 23.317.704 faces. The final orthomosaic, produced according to the software’s suggested parameters based on the mesh density, was generated at a resolution of 0,114 mm, fully consistent with the target GSD of 0,10 mm. The resulting image measures 19.249 × 32.211 pixels. This image was then rigorously cropped along the edges of the tracing, removing the outer margins initially recorded as a safety buffer.
Of particular interest is the precision of the overlap achieved in the photogrammetric coverage. Figure 7 displays the number of images covering each portion of the historical cartographic document under examination. As shown, there are only very narrow bands covered by three images, while vast areas are covered by more than nine images. This confirms that the photogrammetric block is highly rigid, also thanks to the inclusion of the two transverse strips, which further validate the low residuals achieved on the control points.

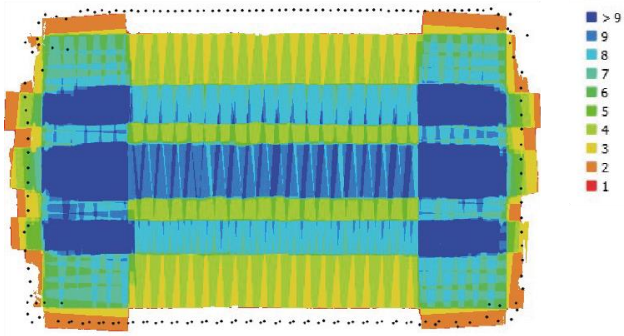

Figure 7. Diagram of the frames overlapping.

3.4 Results and evaluation

The photogrammetric survey of the mid-18th-century “Calcato” map of Gandino has demonstrated that high-resolution and metrically accurate digitization of large, fragile archival documents is entirely achievable, even under significant physical constraints such as limited indoor space and the impossibility of using overhead scanning systems. Through the careful integration of topographic and photogrammetric methods, supported by an intense planning phase and high-quality processing in Agisoft Metashape, the project successfully produced an orthophoto with a resolution of 0,11 mm per pixel, closely aligned with the original objective of 0,10 mm.
The use of forward intersection for the 3D positioning of ground control points proved to be a valuable strategy. It allowed for sub-millimetre accuracy without relying on EDM measurements, which would have introduced greater errors due to the short working distances and the characteristics of the instrument used. From the acquisition strategy, based on inclined imagery taken at multiple heights, to the final orthophoto export, every stage was designed to preserve the map’s historical and graphic integrity. The project delivered a high-quality digital product suitable for archival and analytical use. It contributed to the PRIN project’s broader goals, *Crafted in Stone/Recorded on Paper*, by enhancing the digital accessibility of historically significant but often overlooked materials from smaller Italian municipalities.
Furthermore, an interesting qualitative result can be observed in Figure 8 where some details of the final orthophoto are shown.
The methodology developed here is highly replicable and can be applied to similar cases involving sensitive or large-scale historical documents. It offers a practical model of interdisciplinary collaboration between survey, photogrammetry, and archival studies, opening up new possibilities for heritage conservation and digital research.

4. The digital copy of the “Calcato” and initial study

4.1 Comparison of maps and evolution of the territory

Thanks to the ground sampling distance of the resulting orthophoto, the document is fully appreciable in its digital form, enabling new opportunities for research no longer tied to physical archive access. Its availability on digital devices supports software-based analyses and direct comparisons with digitally native datasets.Within this research, preliminary analyses were undertaken to compare the Municipality of Gandino at the time of the map with its present state, an operation made feasible only by the document’s digital transposition.

Figure 8. The digital copy of the map and a zoom.

The investigation relied on superimposing the "Calcato" with the regional technical map (Carta Tecnica Regionale – CTR, 1:10.000 scale). These analyses were purely qualitative, aiming to identify enduring territorial features in Gandino after roughly 250 years. Quantitative results were not pursued due to several limiting factors: the original surveying methods remain unknown; the document also suffers from age-related deformations and lacks cartographic graticules. Additionally, the mountainous terrain, ranging from 300 to over 1.500 metres above sea level, likely impacted the original survey's accuracy.

The investigation employed QGIS, an open-source GIS software. After importing already georeferenced modern data, the historical map was georeferenced using QGIS's "Georeferencer" plug-in. Twelve well-distributed, clearly recognisable points were selected across both maps. The chosen configuration minimised the mean total error without introducing geometric distortions, using a basic Helmert transformation (translation, rotation, uniform scaling). Discrepancies between the "Calcato" and the CTR reached several tens of metres but still allowed for meaningful interpretation.

Key findings relate to territorial continuity, not only of the historic urban core but also of typically unstable or non-anthropogenic features. These include isolated structures and secondary infrastructure (e.g., mountain paths) in high-altitude zones. The municipal boundary, largely unchanged, and minor buildings such as the Church of San Gottardo, are also consistent between maps. Most notably, surface water features (Figure 9) shown on the eighteenth-century map, small bodies of water in higher elevations, remain visible today and are still recorded in current maps. Their modest size (historically referred to as "pozze", that means puddles) makes this continuity especially striking.

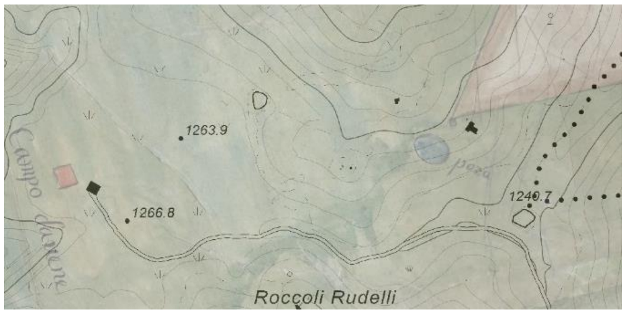

Figure 9. Overlap between the "Calcato" and the CTR. In both, the same elements can be seen (a building on the left; the stretch of water and the municipal boundary on the right).

This phase of the work highlights the substantial analytical potential of the document's digital version. The observations stem from an initial visual investigation of the digitised "Calcato", yet further analytical work, beyond traditional archival practices, could deepen understanding of such historical sources and the layered information they offer.

4.2 The "Calcato" and Artificial Intelligence

A second line of investigation explored the potential of artificial intelligence in cartography and the study of historical graphic documents. This test stemmed from the observation that only the 18th-century version of the "Calcato" includes a map, an essential tool for interpreting the register. The idea was to verify whether AI could generate a territorial representation based solely on property descriptions in the text. If successful, this approach could be extended to other versions held in municipal archives, such as those from 1435 and 1567 preserved in Gandino.

The test used a conversational AI model developed by OpenAI, ChatGPT (o4-mini-high version). A moderately complex, manageable chapter of the register was selected for this initial trial, the "Bagotto" area. The AI was first tasked with reading and transcribing the text from an image. Notably, it received no visual input of the "Calcato" map, a deliberate choice aimed at evaluating the model's intrinsic processing abilities. The only external reference provided was the unit of measurement, the "cavezzo", abbreviated as "c." in the text. The next phase involved asking the AI to calculate a set of vectors defined by length and angle (direction and orientation) based on the transcribed content. The register describes land parcels through perimeter lines, defined by segment lengths and angles relative to cardinal directions. Using these vectors, the AI generated a table of vertex coordinates within a relative system, with the first point fixed as the origin. Initial results produced open polylines with intersecting segments, due to the AI’s difficulty handling slight directional variations implied but not explicitly stated in the register, variations that would have been evident to historical surveyors. By permitting limited angular adjustments (up to five degrees) and forbidding intersections, a valid result was achieved. The final shape closely resembles the area shown in the eighteenth-century map (Figure 10).

Though limited to a small portion of land, the outcome demonstrates the method’s potential. A promising next step would be to provide the AI with the “Calcato” map, allowing it to learn from the historical representation and apply that knowledge to registers without accompanying maps.

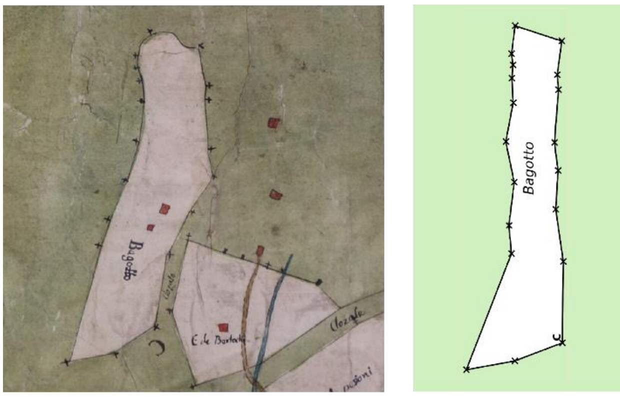

Figure 10. Area of “Bagotto”, comparison between the “Calcato” and the representation obtained with the AI.

5. Conclusions

The work carried out on the “Calcato” of Gandino represents, first and foremost, a significant contribution to the advancement of the PRIN project *Crafted in Store / Recorded on Paper*, and more broadly, to ongoing historical research. The outcome of the project has enabled the safeguarding of an important fragment of the local history and of the society of that time. It is worth recalling that this cartographic document, besides currently being a unicum, was not conceived as an operative tool, but rather as a political and representative artefact. Through the digitisation process, and given the high quality of the resulting output, the project has succeeded, as a first and essential result, in preserving a valuable example of the documentary heritage of this territory.

Secondly, the results obtained through this experimental procedure have validated the effectiveness of the proposed approach. The methodology developed has proven to be highly replicable and may be applied to comparable cases involving fragile or oversized historical documents, or in contexts where conditions do not permit the use of traditional direct-scanning techniques. Naturally, for a successful reapplication of this method, one that ensures an output meeting both quantitative standards (ground sampling distance) and qualitative ones (legibility and usability of the digital copy), it is essential to consider the factors discussed in the previous sections, such as for example light management and surface planarity. The work has also highlighted a nowadays key aspect, namely the importance of interdisciplinarity. The study and enhancement of historical knowledge, as well as of the documentary and informational heritage it encompasses, should no longer remain confined to a single discipline but should emerge as the outcome of integrated activities. The methodology proposed here offers a practical model for interdisciplinary collaboration between topography, photogrammetry, and archival studies, thereby opening new perspectives for heritage preservation and digital research.

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