DIGITAL HERITAGE (2025)
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Survey and Digital Representation of the Statue of San Carlo Borromeo in Arona to Support Conservation Activities

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Abstract

The project aims to create a digital model that supports diagnostic, conservation, restoration, consolidation, and maintenance activities related to the Colossus of San Carlo Borromeo. The first phase focused on the accurate digital documentation of the Colossus's exterior surfaces using digital photogrammetry and laser scanning technology. A subsequent phase—currently in progress—is dedicated to the survey and digital representation of the complex internal and external metal structure that supports the riveted copper plates.

CCS Concepts

• ***Hardware*** → *Emerging technologies;* • ***Information systems*** → *Data management systems;*

1. Introduction

1.1. Framework for an Integrated Digital Documentation and Analysis

This research represents a collaborative effort between the Politecnico di Milano and the Veneranda Biblioteca Ambrosiana, the custodian of the Colossus of San Carlo Borromeo (Figure 1) . The primary objective is the development of a comprehensive digital model to support diagnostic assessments, conservation strategies, restoration interventions, structural consolidation, and the ongoing maintenance of the monument.

The project is structured in two phases. The initial phase focused on the precise documentation of the statue's exterior, achieved through the integration of drone-based photogrammetry and terrestrial laser scanning. This phase resulted in the first complete and accurate digital survey of the Colossus's external surfaces (Figure 2). The second phase—currently in progress—focuses on the internal structural framework, specifically the complex iron system that supports the riveted copper plates. This phase aims to provide the necessary data and tools for the planning of future consolidation and restoration work. A multidisciplinary team of experts carried out an extensive diagnostic campaign on both the materials and structural elements to assess the current condition of the statue [PSV*23]. Their coordinated efforts exemplify the collaborative nature of the project, bringing together diverse expertise to achieve shared conservation objectives.

In parallel with the development of the digital model, bibliographic and archival research was conducted to collect all graphic and textual documentation produced over the centuries, particularly during previous restoration activities. This research yielded valuable insights into the construction techniques employed [OB24] and revealed dimensional inconsistencies in the documented statue's overall proportions and individual components. These discrepancies—attributable to the varying surveying techniques and instruments used across different historical periods—underscored the necessity of accurately defining the dimensions of the Colossus. This has culminated in the creation of a three-dimensional digital twin, which serves as a critical resource for the statue's future restoration and maintenance.

1.2. Historical Framework and Iconographic Evidence

The statue of San Carlo Borromeo was erected in Arona, his birthplace, following his death and canonization. According to the grandiose plan conceived by Cardinal Federico Borromeo, Carlo's cousin, the statue was intended to be the culmination of an ascending path marked by fifty chapels—twenty-five dedicated to the life of San Carlo and twenty-five to the contemplative life. Federico Borromeo, together with the oblate Marco Aurelio Grattarola, supervisor of the Sacro Monte works, envisioned the construction of an enormous statue visible from Lake Maggiore, precisely to honor the greatness of the Archbishop of Milan, whom he repeatedly described in his speeches as a "giant." On this subject, Irene Sozzi [Soz21] writes: "The image of Carlo as a giant, a colossus of sanctity and virtue, reproposed with media hammering insistence in the homilies recited in the cathedral, became a concrete project in Federico Borromeo's mind."

The first proposal for a colossal statue was submitted by the young Giovanni Battista Crespi, known as "il Cerano," to Federico Borromeo on 8 April 1598, in a letter of intent accompanied by a design drawing. Bottari and Ticozzi observe that in 1822 [BT22],

DOI: 10.2312/dh.20253149

Figure 1: *The statue of Saint Charles in Arona (Italy).*

Figure 2: *Documentation through surveying and modelling: overview of the 2022 campaign.*

extraordinary dimensions constituted one of the aesthetic ideals of 16th-century colossus. It is estimated that at least fifty colossal statues were executed in Italy during the 16th century—works that, besides being a classical revival, often carried political and propagandistic significance. No previous example, however, had achieved the monumental scale of the "San Carlone." Cerano, well-versed in Central Italian artistic traditions, emphasized in his letter to Federico the bold challenge this project posed to classical ideals: "As I have depicted elsewhere, in such a large machine it will be enough to have the head and hands cast, which will also be the most magnificent thing that has ever been done since the Romans" [BT22].

Construction of the Colossus began in 1624 but experienced numerous interruptions and delays due to external events, extensively documented by Rejna in 1823 [Rej23] and Adele Buratti Mazzotta in 1984 [BMOT84]. The construction was completed seventy-four years later, culminating in the solemn blessing of the monument by Cardinal Federico Caccia, Archbishop of Milan, on 22 June 1698. The sculptors responsible for executing the work were Siro Zanella of Pavia and Bernardo Falconi of Bissone (Lugano), who slightly modified Cerano's original design: San Carlo is depicted standing in cardinal's robes, wearing a *rocchetto* and *mozzetta*, holding the *Acta Ecclesiae Mediolanensis* in his left hand, with his right arm raised in the act of imparting a blessing.

The image of this colossal monument was frequently described and illustrated during the 19th century by artists and travelers passing through Arona. In 19th-century iconography, the Saint is consistently depicted on his pedestal with the surrounding landscape, as in Figure 3: on one side, the lake; on the other, the town. Human figures are often included to emphasize the statue's immense proportions. Wetzel and Chiara wrote in 1823 [WC23]: "The curious who want to visit the inside of the statue first climb up a ladder to the pedestal, from where another ladder takes them, under a fold of the habit, inside the statue, the interior of which is illuminated by open doors between the folds of the saint's robe. One finally arrives at the head, whose nose is so large that one can comfortably sit in it".

For nearly two centuries, access from the ground to the foot of the Saint—where the entrance to the statue is located—was made via ladders. These were only replaced in 1864 by a fixed staircase with a balustrade surrounding the base of the statue, to facilitate and secure the ascent and visit.

In the black-and-white photographs dated 1930 and preserved at the Archivio Luce (*patrimonio.archivioluce.com/luce-web/detail/IL3000046928/12/la-statua-san-carlo-borromeo-ad-*

Figure 3: *Some iconographies from the first half of the nineteenth century depicting the giant statue of "Saint Carlone" and its context.*

arona-ripresa-frontalmente.html), the statue appears without the balustrade that currently surrounds its base. Although the balustrade is light and not particularly intrusive, its addition altered the perception of the statue's proportions by introducing a visual reference for the height of the human figure.

As is well known, the statue remained the tallest in the world for approximately two centuries, until the construction of the Statue of Liberty in 1886. Designed by Frédéric-Auguste Bartholdi, the Statue of Liberty measures 46 meters from the base to the tip of the torch. Bartholdi stayed in the city of Arona to study the structure of the Colossus—an event commemorated by a plaque at the foot of the statue in New York. He intended to construct a monument significantly taller than the one in Arona, capable of withstanding stronger wind conditions. To achieve this, he enlisted the assistance of his former architecture professor, Eugène Viollet-le-Duc, who designed an internal brick structure. However, Viollet-le-Duc passed away before leaving precise instructions on how to connect the internal framework with the external copper cladding. Consequently, the engineer Gustave Eiffel took over the project and designed the statue's inner structure: a flexible steel skeleton to which approximately three hundred riveted copper sheets were anchored, as illustrated in Figure 4.

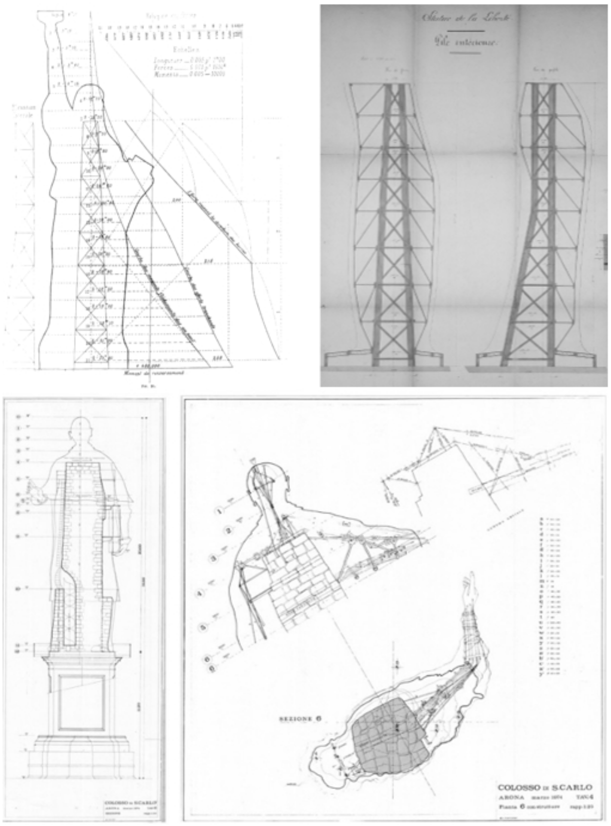


Figure 4: *Comparison of the inner section of: a) above, the Statue of Liberty with its metal structure (source: Musée des arts et métiers, Paris, France); b) below, the "San Carlone" vertical sections (source: Veneranda Biblioteca Ambrosiana).*

Upon entering the statue and ascending the ladder leading to the head, one gains a comprehensive view of the imposing central pillar and the internal metal framework. This structure supports the "cage" composed of flat metal elements, each 4–5 cm wide, which anchor the shaped and riveted copper plates. In 1987, architect Aldo Rossi reflected on this experience, writing: "As in the description of the Homeric horse, the pilgrim enters the body of the Saint, as in a tower or a chariot governed by a skilful technique. Having ascended the external staircase of the pedestal, the steep ascent inside the body reveals the masonry structure and the welds of the large metal sheets" [Ros87], as shown in Figure 5.

Figure 5: *Aldo Rossi architect's drawings, 1979 and 1990 [Pra21].*

2. Geometric Documentation of the Colossus of San Carlo Borromeo

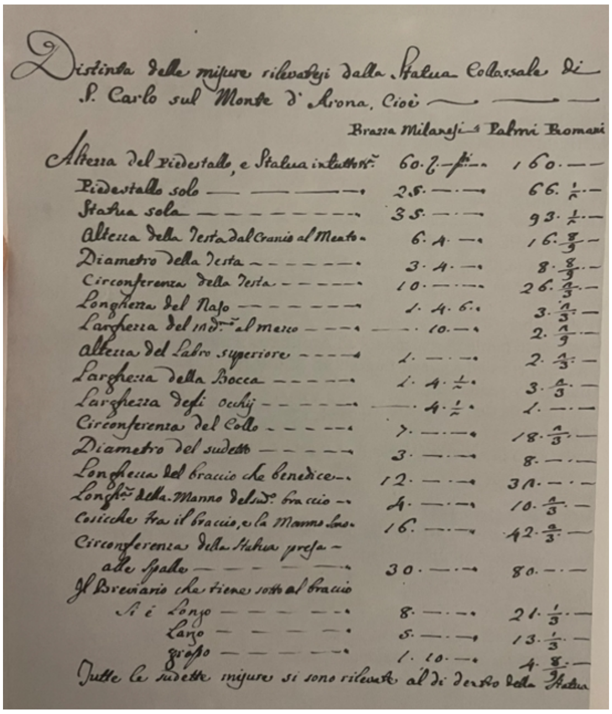
The fact that the statue is a "giant" can be inferred from its dimensions. In particular, the drawings produced during the most recent restoration work—carried out between 1973 and 1975 by Engineer Carlo Ferrari da Passano, director of the Veneranda Fabbrica del Duomo di Milano—indicate the measurements of all structural elements: the granite pedestal stands at 11.20 meters, while the statue itself measures 20.68 meters in height.

Research conducted on archival documents preserved in the Veneranda Biblioteca Ambrosiana in Milan, and partially published in printed texts from the 19th and 20th centuries, has revealed a number of inconsistencies in the recorded dimensions of the statue. These discrepancies are evidently attributable to the use of different measuring instruments over time.

2.1. Measurement and Survey Practices in the Restoration of the Colossus: 18th to 20th Century

The earliest recorded dimensions of the statue, as reported in the archival documentation, appear in a document describing the theft of copper components—prepared in Milan according to a design by Cerano but not yet assembled—stolen in Arona on 4 February 1658 [BMOT84]. However, it is in the plaque affixed for the inauguration of the Colossus that the overall height of the monument, excluding the pedestal, is indicated for the first time. The inscription reads *trigenta tres altam*, meaning 33 *braccia milanesi* (19.63 m) [Mar81], the unit of measurement used at the time of the statue's construction.

Two 18th-century documents provide further descriptions with the principal dimensions of the statue. The first is titled *Misura della Statua di S. Carlo in Arona*, dated 3 March 1741 (Archivio Veneranda Biblioteca Ambrosiana, Colosso di San Carlo). The second, *Distinta delle misure rilevatesi della Statua Colossale di S. Carlo sul Monte di Arona* [BMOT84], reproduced in Figure 6, also dates to the 18th century and contains measurements taken from within the statue. In this second document, dimensions are recorded not only in *braccia milanesi* but also in *palmi romani*. Both descriptions, though lacking accompanying drawings, report specific measurements of major elements such as the arms, head, and hands, again revealing several dimensional discrepancies. Despite these variations, the total height of the statue is reported in both documents as 35 *braccia milanesi*, corresponding to approximately 20.82 meters.



Distinta delle misure rilevatesi dalla Statua Colossale di S. Carlo sul Monte d' Arona, Cioè

	Brazza Milanesi	Palmi Romani
Altezza del Piedestallo, e Statua in tutto	60. 7.	160.
Piedestallo solo	25.	66. ½
Statua sola	35.	93. ½
Altezza della Testa dal Cranio al Mento	6. 4.	16. 8/9
Diametro della Testa	3. 4.	8. 8/9
Circonferenza della Testa	10.	26. 2/3
Longhezza del Naso	1. 4. 6.	3. 1/3
Larghezza del med.mo al mezzo	10.	2. 1/9
Altezza del Labro superiore	1.	2. 1/3
Larghezza della Bocca	1. 4. ½	3. 2/3
Larghezza degli occhi	4. ½	1.
Circonferenza del Collo	7.	18. 2/3
Diametro del sudetto	3.	8.
Longhezza del braccio che benedice	12.	31.
Longh.za della Manno del sud.o braccio	4.	10. 2/3
Cosicche fra il braccio, e la Manno sono	16.	42. 2/3
Circonferenza della Statua presa alle Spalle	30.	80.
Il Breviario che tiene sotto al braccio si è Longo	8.	21. 1/3
Largo	5.	13. 1/3
grosso	1. 10.	4. 8/9

Tutte le sudette misure si sono rilevate al di dentro della Statua

Figure 6: *18th century: "Detailed list of the measurements recorded for the colossal monument of St. Carlo on the Mount of Arona". "Distinta delle misure rilevatesi della statua Colossale di S. Carlo sul Monte di Arona" [BMOT84].*

An important campaign of measurements was conducted in 1816–1817, when scaffolding was erected up to the head of the statue to facilitate restoration work, including the replacement of some copper plates and the application of a bronze-colored coating to protect the structure from the ravages of time [Rej23]. The overall and detailed dimensions were recorded by Battista Cantaluppo, following the directives of Prefect and Rector Zoja. Notably, and of particular historical interest, the measurements in this campaign were expressed in three systems of units: braccia milanesi, meters, and Paris units. In this survey, the total height of the statue was recorded as 36 braccia milanesi, corresponding to 21.42 meters, as shown in Figure 7.

During the 19th century, only limited repairs were carried out on the Colossus, without the support of any new measurement cam-

MISURA DELLA STATUA, DELLE SUE PARTI, E DEL PIEDESTALLO

	MISURA					
	DI MILANO		METRICA	DI PARIGI		
	Brac.	Once		Piedi	Pollici	Lin.
Altezza totale della Statua .	36	—	21, 417. 82.	65	6	1
Circnito della testa	10	—	5, 949. 40.	18	2	3
Larghezza della fronte . . .	3	7	2, 131. 88.	6	3	2
Lunghezza della faccia . . .	3	9	2, 231. 04.	6	5	..
Altezza del naso	1	3 ½	0, 768. 47.	2	4	..
Larghezza del medesimo . .	—	6	0, 297. 97.	—	1	2
Largh.ª di cadauna orecchia .	1	3 ½	0, 768. 47.	2	4	..
Larghezza di ciascun occhio .	—	9	0, 446. 95.	—	10	3
Larghezza della bocca . . .	1	2	0, 694. 10.	1	6	4
Lunghezza di cadaun braccio.	14	—	8, 329. 26.	21	4	..
Altezza del libro	6	6	3, 867. 11.	11	5	3
Larghezza dello stesso . . .	3	3	1, 933. 55.	5	8	8
Grossezza di esso	1	3	0, 743. 67.	2	1	..
Largh.ª del palmo della mano.	2	3	1, 348. 61.	4	2	..
Lunghezza del dito pollice .	2	1	1, 299. 40.	4	—	..
Circuito della vesta	27	—	16, 163. 38.	52	1	..
Larghezza di ciascun piede.	2	—	1, 199. 88.	3	5	..
Piedestallo	18	—	10, 708. 92.	32	9	½

Figure 7: *Measurement of the statue: source "Misura della statua, delle sue parti e del piedistallo" 1816-17 [Rej23].*

Figure 8: *A 1951 photograph of the San Carlone showing a series of dimensions of the statue and its parts: source https://fotografia.cultura.gov.it/fotografiek.text=san 20carlo 20arona.*

paigns. These interventions consisted of punctual replacements of individual elements or structural consolidations, mostly involving the internal metal framework.

Numerous postcards and printed photographs from the 20th century include indications of the statue's dimensions and those of its components (as seen in Figure 8) though all present some differences.

However, the construction of an imposing scaffolding around the statue, as seen in Figure 9, became indispensable in 1974, when a comprehensive restoration of the Colossus was initiated. The statue had been in poor condition for many years and required urgent repair, structural consolidation, and replacement of various elements (Archivio Veneranda Biblioteca Ambrosiana, Colosso di San Carlo, Relazioni per manutenzioni ordinarie, "Relazione 18 dicembre 1983"). On this occasion, a campaign of precise measurements was undertaken under the direction of Engineer Carlo Ferrari da Passano, with the aim of producing the documentation necessary for the restoration work.

Dated 12 February 1974, a letter estimating the scope of surveys and drawings to be performed was sent to Engineer Ferrari da Passano by Carcano Giancarlo (Archivio Veneranda Biblioteca Ambrosiana, Colosso di San Carlo, consulenza tecnica). These surveys and drawings—comprising both vertical and horizontal sections with detailed indications of all structural elements—were scheduled to be completed within 20–25 days, at a final cost of 1,202,000 lire (Archivio Veneranda Biblioteca Ambrosiana, Colosso di San Carlo, Pagamento parcelle, 3 giugno 1974). According to the results of these surveys, the statue measures 20.68 meters in height, while the granite pedestal stands at 11.20 meters, resulting in a total height of 31.88 meters.

2.2. Recent Digital Surveying and Recording Activities (2022–2025)

2.2.1. General workflow

The recent comprehensive documentation of the statue's external surfaces was achieved using digital photogrammetry [LRKB19] and laser scanning [VM10]. The exterior of the statue was digitally

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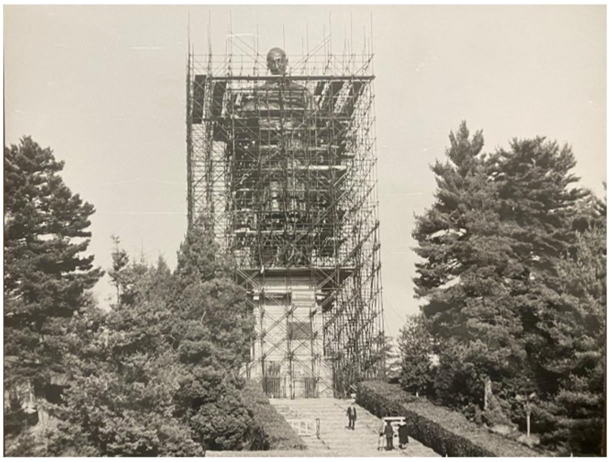

Figure 9: *The imposing scaffolding surrounding the statue during the restoration work carried out between 1973 and 1975 (source: Archivio Veneranda Biblioteca Ambrosiana).*

documented using both laser scanning point clouds and photogrammetric point clouds generated with a drone. The reconstruction of the interior instead mainly focused on the head of the Colossus, leaving the entire body for the second part of the project, which is currently in progress.

The connection between internal and external measurement required the use of a total station network, which allowed the setup of station points around the statue and in the head using measurements through the small windows on top of the Colossus. It is fundamental to underline how the connection of interior and exterior has fundamental importance for the limited thickness of the plates, requiring precise measurements on specific control points to define a common reference system for both drone- and laser-based measurements. Establishing a permanent reference system is therefore mandatory to allow subsequence recapture also considering the need for continuous maintenance over time, which could result in a multi-temporal archive of digital data. The network adjustment using least squares provided 3D point coordinates with associated precisions of approximately 2–3 mm. This level of accuracy is sufficient to establish a stable reference system that can be reused in future measurement campaigns. However, due to the limited thickness of the plates and the expected precision of the laser scanning data—of a similar order of magnitude—the connection between interior and exterior data may not be sufficient to reliably detect the plate thickness. On the other hand, these values are sufficient for comprehensive documentation in accordance with the project's requirements.

2.2.2. Drone-Based Image Acquisition and Processing

The image acquisition process was carried out with a Mavic Air 2S drone, which was manually piloted around the statue. A total of 1,020 images were captured, with the camera oriented at various angles to effectively document horizontal surfaces, such as the statue's arm. The statistics after bundle adjustment resulted in a mean reprojection projection error of $0.62 pixels$, whereas the RMSE values on the 8 control points measured with the total station were less than $5mm$. An image showing the computed camera poses around the statue is shown in Figure 10.

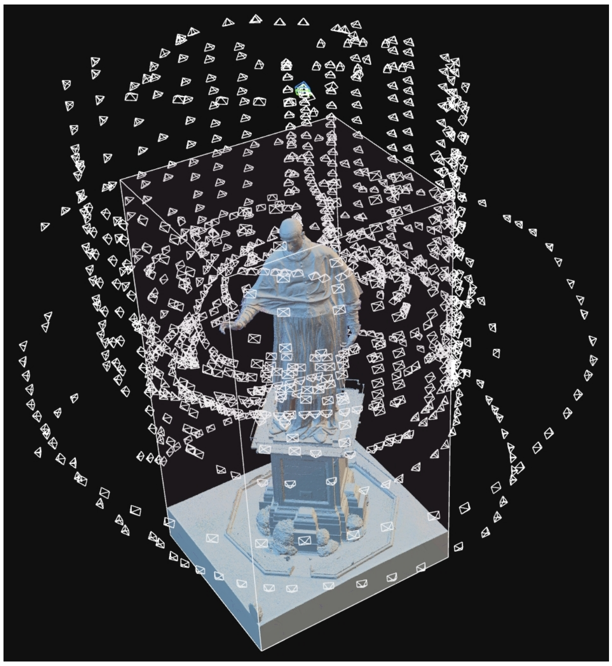

Figure 10: *Visualization of the camera poses.*

To generate the final mesh, a depth mask approach was employed instead of directly interpolating the point cloud, resulting in a model composed of approximately 26 million triangles.

Figure 11 illustrates several views of the final 3D model, displayed both as a shaded and textured mesh, providing an overview of the overall geometry and surface appearance. To further emphasize the level of detail captured during the modeling process, Figure 12 focuses on specific areas of the textured mesh, showing the resolution and fidelity of the surface textures applied to the reconstructed geometry. The final texture resolution is estimated to range between 3 and 8 mm. This variation is due to changes in the camera-to-object distance during image acquisition, which was also constrained by the surrounding vegetation. Nevertheless, the achieved resolution is sufficient for producing the required deliverables. Identifying material deterioration, however, would require a closer inspection, using the generated drawings and orthophotos as mapping support. Overall, the joints between the copper plates are clearly visible, fulfilling one of the key project requirements.

2.2.3. Assessment of the Digital Documentation Approach

Aerial imagery acquired via drone and processed through digital photogrammetry was identified as the most effective method for documenting the complex external geometry of the Colossus. As is typical with photogrammetric reconstructions, external data were necessary to define the scale, position, and orientation of the model in space. This intrinsic ambiguity, which involves a seven-parameter transformation (three for translation, three for rotation,

Figure 11: *Some images of the shaded and textured mesh.*

Figure 12: *Some images of the shaded and textured mesh.*

and one for scale), was resolved using precise measurements obtained with a total station. These measurements enabled the establishment of a stable and accurate reference system into which the photogrammetric model was rigorously registered, thereby providing not only spatial coherence but also valuable insights into the metric accuracy of the dataset.

To complement the external survey, additional scans were conducted inside the statue's head using a Faro Focus HDR 130 laser scanner, along with several scans of the outer surfaces. Targets placed and measured with the total station allowed for the seamless integration of laser scanning and photogrammetry data within the same coordinate framework, ensuring consistency and high metric reliability across all sources. A dedicated set of scans was also carried out around the base of the statue, enabling full documentation of the lower external surfaces using both methods.

The point cloud generated from laser scans captured only the lower part of the Colossus—mainly the base—with good detail and completeness. However, the laser scanner provided only a partial reconstruction of the copper surfaces (i.e., the main body of the Colossus), resulting in a rather noisy and incomplete point cloud, with several outliers caused by incorrect reflections. Therefore, laser scanning proved useful as a complementary method in the digital survey but was insufficient for producing a complete reconstruction of the external surfaces.

The laser scans were primarily used to assess the accuracy of the drone-based results. This approach made it possible to extend the accuracy validation of the final drone-based reconstruction beyond relying solely on control points measured with a total station, as previously described. Figure 13 presents the results for a portion of the base, while Figure 14 shows those for a portion of the body. We chose to isolate specific areas and illustrate the results separately due to the high incompleteness of the laser point cloud, particularly at the top of the Colossus. Additionally, the complex geometry of the surfaces, with several narrow areas, limited the coverage quality.

The overall statistics for the portion of the base indicate a discrepancy of approximately 4 mm, whereas the area corresponding to the copper surfaces revealed a discrepancy of about 7 mm. These results are consistent with the RMSE values obtained from the total station control points and confirm the overall accuracy of the final drone-derived point cloud. The project was carried out using eight control points: four were fixed at ground level, while the remaining four were placed on top of the statue using small apertures at the top and the balcony level. This distribution is relatively homogeneous along the vertical axis and maintains a balance between areas where it is relatively easy to fix targets (such as the ground) and those where installation is more constrained (such as the top).

One component still pending, and planned for future integration, is a comprehensive interior scan of the statue. This remains a technical challenge due to the confined nature of the internal spaces, which include narrow passages and a vertical staircase, complicating both the acquisition and registration processes.

The set of deliverables produced during this initial survey phase includes: point clouds derived from both laser scanning and photogrammetry (coregistered in the same spatial reference system); a high-resolution textured mesh of the external surfaces; and a series of digital orthophotos generated from the textured 3D model. Orthophotos were produced for the four main elevations (front, back, left, right) as well as a top view, all with a ground sampling distance (GSD) of 2 mm, ensuring high detail suitable for documentation and analysis purposes.

Furthermore, a simplified mesh was created to support finite element method (FEM) analysis. Starting from the original high-resolution model, the mesh was decimated to obtain a version com-

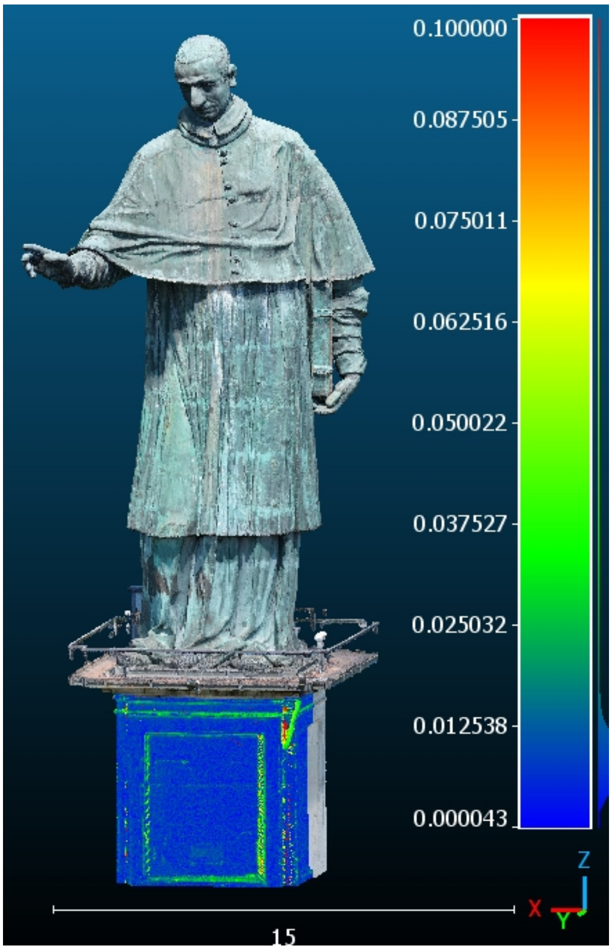

Figure 13: *A comparison between laser scanning and drone-derived point clouds was conducted for a specific section of the base.*

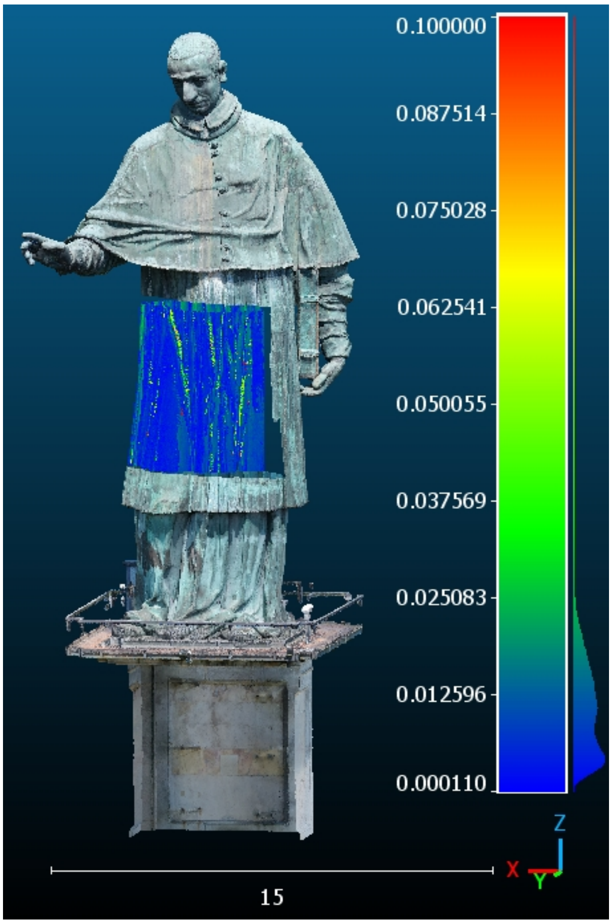

Figure 14: *Comparison between laser scanning and drone-acquired point clouds was carried out for a portion of the statue. A complete comparison was not possible due to the incomplete nature of the ground-based laser scanning point cloud.*

posed a reduced set of faces, balancing the need for geometric fidelity with computational efficiency. This process included a meticulous review and manual correction of geometric and topological issues, such as the presence of holes or intersecting faces, particularly in areas where external surfaces are in close proximity without direct contact. These corrections were crucial to ensure the suitability of the mesh for numerical simulations, as intersecting geometry would compromise the stability and accuracy of FEM results. However, a detailed discussion of the FEM analysis is beyond the scope of this paper, which is primarily focused on digital documentation. It is nonetheless important to note that the proposed work is part of a broader framework involving contributions from various specialists.

Overall, this initial survey phase enabled the creation of a comprehensive digital model of all external copper plates forming the Saint's robes and body. In addition to providing a robust foundation for further structural and material studies, the model serves as a valuable resource for the mapping and monitoring of surface degradation phenomena.

2.3. Comparative Analysis of Measurements from 1974 and 2022

The survey of the statue, conducted using laser scanning and drone photogrammetry, enabled the creation of a three-dimensional point cloud of the entire structure. From this dataset, updated versions of the 1974 plans and vertical sections will be produced. These drawings will serve as a valuable resource for mapping the state of conservation of the statue and for supporting ongoing restoration and maintenance activities.

With today's advanced surveying techniques and instruments, it is now possible to achieve greater accuracy in dimensional analysis and to examine discrepancies with the measurements recorded in 1974, which were based on a complex survey. The current survey indicates that the height of the statue is 20.57 meters, differing by a few centimeters from the 20.68 meters recorded in 1974. The pedestal now measures 11.22 meters in height. The most significant discrepancy is observed in the position of the Saint's right hand: the tip of the index finger was previously recorded at 26.50 meters above ground level, whereas the current measurement is 25.52 meters, as shown in Figure 15.

Figure 15: *Comparison of the point cloud acquired in 2022 with the drawing from 1974. Notable differences can be observed in the inclination of the head and the position of the right hand.*

While this difference may be attributable to understandable measurement error, given the complexity of the earlier survey, it also suggests the need to inspect the internal structure during the upcoming restoration phase. In particular, the structural integrity of the internal elements within the arm should be verified to ensure no deformation or displacement has occurred. It is well established that comparing measurements taken over time can yield valuable insights into the structural condition of monuments, including evidence of deterioration, movement, subsidence, deformation, or material loss. In the context of conservation, it is increasingly recognized that surveying functions as a diagnostic tool in its own right.

The upcoming opportunity to initiate new activities in 2025 will enable the completion of the survey of the Colossus's interior, resulting in a comprehensive record of both internal and external surfaces. The primary challenge associated with interior scanning will be the registration process along the narrow vertical ladder, as shown in Figure 16. To address this, a custom support system will be constructed to secure the scanner to the metal structure, allowing for the acquisition of a series of consecutive scans.

Figure 16: *View of the internal vertical metal ladder equipped with safety hoops.*

The availability of a total station network will facilitate the co-registration of the new scans within the same coordinate system used during the 2022 campaign. In addition, Iterative Closest Point (ICP) [PCS15] methods will be employed to align overlapping areas captured during both years. Both options, and their integrated application, will be leveraged to complete the full scanning of the Colossus and produce a comprehensive set of measured interior sections.

An overall site map will also be produced using a DJI Mavic 3 Enterprise drone equipped with an RTK module for GNSS measurements [LRVS23]. This will enable the generation of a georeferenced orthophoto of the surrounding area, using data from a permanent GNSS network (https://www.spingnss.it/), which provides coordinates in the Italian reference system ETRF2000-RDN [Epoch 2008.0]. The nearest GNSS station, located in Gozzano, is approximately 10 km away. Local topography will also be reconstructed. Elevation values will be corrected (from ellipsoid to geoid) using the Italian geoid [BBCS07].

A new set of images of the Colossus will be acquired using the same drone. These images will be processed in the local reference system to produce a second high-resolution 3D model of the Colossus. Although the resolution and level of detail achieved in 2022 are sufficient for the project's current scope, the opportunity to recapture the Colossus with a drone equipped with a higher-quality camera will yield a complementary dataset. This additional set will be valuable for tracking changes over time, particularly after an interval of approximately three years. As previously mentioned, multi-epoch data acquisition allows for long-term monitoring of the Colossus, and a new full photogrammetric acquisition of the Colossus will be an essential step in that direction.

The new photogrammetric model of the external surfaces will be registered in the local Cartesian reference system, enabled by both the local network and the previous drone flight conducted in 2022. Co-registration can be achieved through various methods, not only limited to ground control points. For example, by processing both image datasets simultaneously while keeping the 2022 exterior orientation parameters fixed during adjustment. The point cloud and textured mesh will then be generated solely from the 2025 images. This approach opens the possibility for diverse processing strategies, including hybrid methods, which will be carefully considered following the 2025 survey campaign.

2.4. Conclusions

The recent digital survey (2022-25) phase made it possible to create a complete external digital model of all the copper plates that make up the Saint's robes and body, also providing support for mapping the areas affected by various pathologies of degradation. The use of a digital recording approach based on multiple non-contact methods (such as drone-based photogrammetry and laser scanning) was essential to capture the complex three-dimensional geometry of the colossus. The integration of a total station network made it possible to control potential deformations during the registration of scans and the orientation of images, while also providing a means to validate the achieved accuracy.

The second phase of the survey (in progress) of the internal iron structures is aimed at providing tools for the planning of consolidation and restoration work on the statue, whose state of conservation will be valuate comparing the actual situation with the one assessed during a careful past campaign of diagnostic investigations [PSV*23] conducted on the materials and structures by a group of experts with different skills, called upon to collaborate to carry out a common project [PPW*22]. A new flight using an improved drone (Mavic 3E) will also be conducted to generate an updated model of the sculpture. Although the new drone offers higher quality, the goal is not to replace the existing model but rather to produce a second model intended for monitoring purposes. In this context, continuous technological advancements in recording equipment make it possible to build a multi-epoch record—creating successive "snapshots" that can be extremely valuable for detecting changes and planning conservation activities.

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