

# Ancient metrology in architecture: a new approach in the study of the Roman bridge of Canosa di Puglia (Italy)

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## ABSTRACT

The bridge of Canosa di Puglia (Italy) was originally built in the 2nd century CE to cross the Ofanto river along the *Via Traiana*, the route built at the behest of Emperor Trajan that connected Rome with the port of Brindisi, on the Adriatic Sea. Restorations, collapses and architectural transformations have deeply altered its original structure over the centuries, making it lose the traces of a monumental central arch. Archival and field research, conducted through various surveys, has produced new data that has provided an update of the bridge's history. The aim of this dissertation is to show the results of a research conducted with a new methodological approach to the monument, applying ancient metrology to the interpretation of its architectural evolution. This method has proven to be indispensable to formulate hypotheses about the original configuration of the bridge, whose central arch would result to be one of the widest among the bridges of the Roman architecture.

**Section:** RESEARCH PAPER

**Keywords:** Ancient metrology; heritage; archaeology; roman architecture; bridge

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## 1. INTRODUCTION

A metrological approach is essential when studying ancient monuments, as much as Latin is in the study of Roman civilization. The language of architecture makes use of numbers and measurements that are specific to each culture or geographical area, and their interpretation is key to developing hypotheses about the original look of an artifact and unlocking its meaning. This interpretation is often made difficult by the frequent encounter of gaps in the structural stratigraphy of the monument itself. This difficulty also lies in the use of a different construction vocabulary in the ancient world, made up of measurement systems that cannot be superimposed on the ones used nowadays, globally recognized in the International System of Units.

An interpretative criterion can therefore consist of detecting the recurrence of round numbers or multiples and submultiples of the numeral system of a certain culture, starting from today's metric data, comparing it with known ancient units of measurement and cross-referencing the data to verify the existence of correspondences.

This approach [1] has proven to be useful in the study of a masonry bridge dating back to the time of the Roman emperor Trajan (2<sup>nd</sup> century CE), located along the Ofanto river near Canosa di Puglia, in Southern Italy. Before reaching its present conformation, the bridge is described in ancient documents as having only three arches, of which the central one, wider and higher than the others, gave impressiveness to the whole structure. This characteristic is common to many Roman bridges, such as the nearby Ascoli Satriano bridge, and is due to the intent to obstruct the flow of the river as little as possible. The first (as well as the only) systematic study of the bridge dates back to 1985, when an archaeological excavation was carried out under the scientific direction of Professor Raffaella Cassano of the University of Bari [2], [3]. On that occasion, the archaeological investigation focused in particular on the study of the *platea* and its construction techniques.

After more than thirty years, this research embraces the heritage of those studies, adding new data on the architecture of the bridge and on the basis of this data formulating new hypotheses with the aim of shedding new light on the millennial history of the monument [4].



Figure 1. The route of *Via Appia* (the Appian Way) and *Via Traiana* (the Trajan Way) with the major cities along the road and, in red, the city of *Canusium* (Canosa di Puglia) near the Ofanto river.

## 2. HISTORICAL BACKGROUND

The history of the bridge follows the events of the road network established in this large flat area of Apulia, called *Tavoliere*, which thanks to its geographical characteristics was considered ideal not only for transhumance practices but also for the passage of routes to reach the south of the region and therefore the East.

### 2.1. The bridge in the Roman Age

The original structure was erected on the occasion of the construction of the *Via Traiana* (Trajan Way) ordered by emperor Trajan in 109 CE, starting from the city of Benevento, to create an alternative to the *Via Appia* (Figure 1) that would allow a faster connection between Rome and Brindisi, the main port towards the East. It is not clear if there was already a bridge here prior to the imperial age, for the structure was constructed on a route already in use before, the *Via Minucia* [5]. In any case, the presence of a well-preserved foundation stone paved *platea*, reveals an *ex novo* construction which is consistent with the construction techniques of the imperial age.

The first works of restoration are documented in Roman times through inscriptions [6] that attest to repairs under Septimius Severus and Caracalla, in the Tetrarchic period, between the end of the 3rd century CE and the beginning of the 4th century CE and in the Constantinian age. However, the epigraphs only report these operations in a generic and celebrative way, without providing any useful data to determine measurements.

### 2.2. The bridge in Middle Ages

In the Middle Ages the bridge was still in use, since it was located along the *Via Francigena*, a road through by which Christian pilgrims from all over Europe reached the ports of Puglia to the Holy Land. In the Middle Ages even flocks, herds and shepherds used it when they seasonally migrated from the altitudes of Abruzzo and Molise to the plains of the *Tavoliere* with a milder climate, through the so called *tratturi* (drover's roads), one of which was passing right through here.

During this long period new works were certainly necessary, but these were not documented until 1521, as the fragment of an inscription, reused in the Mausoleum of Boemondo d'Altavilla in Canosa, would evidence.

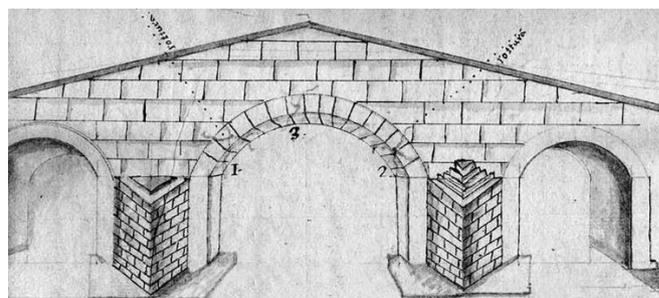


Figure 2. Drawing of the bridge by Francesco Delfino, 1749, detail. (Archivio di Stato di Foggia)

In 1541 a Polish traveller described it as *altissimum pontem muratum* ("a very high masonry bridge") [7], while the first known information on its dimensions has been provided by an Italian traveler who at the end of the 16th century, in addition to describing the bridge as *ponte bellissimo fatto* ("a very well-made bridge"), reported the size of the central arch: 128 palms long and 40 palms high [8].

### 2.3. 18<sup>th</sup> century: first survey, the collapse and the reconstruction

More than a century later, earthquakes, floods and wear and tear would weaken the structure of the bridge, making further restoration work necessary. The institution in charge of its maintenance, as belonging to the area of its domain, was the *Regia Dogana delle Pecore* (Sheep Customs Office), established in nearby Foggia in 1480. The documents relating to the interventions of the eighteenth century are still preserved in its archives.

In these archives it is stated that in 1749 a technical expert's report was commissioned to Francesco Delfino in which he warned of the dangers of stability. Attached to it, he schematically drew an architectural representation of the bridge in which he indicated the possible breaking points (Figure 2). In the same document [9] he also reported the exact measurements of the arches:

"[...] the main arch (is) 112 palms wide, high from the floor to the top (of) 44 palms, with a front of 5 palms, (while) the two lateral arches are wide 50 palms each, and high 25 palms".

Due to the stalling of a targeted action that inevitably would have involved large costs, which none of the parties involved wanted to bear (the *Dogana*, the Crown, local administrators and landowners), the central arch collapsed on 11 February 1751.

Several considerations were made by technical experts who immediately intervened after the matter, among which, in the end, the proposal of a safer reconstruction prevailed, but which would have definitively changed the millenary aspect of the bridge. In fact, it was decided not to rebuild the central arch but instead to put two smaller ones in its place resting on a newly built central pillar, thus lowering the profile of the bridge to a height similar to that visible today.

### 2.4. The bridge today

The latter, however, does not date back to these interventions because the current structure is the result of a reconstruction carried out in the mid-twentieth century, particularly concerning the central arches, after the retreating German troops in World War II bombed the bridge [10], of which only the piers and the abutments were saved.

The bridge today (Figure 3) features five arches of different sizes and morphology (starting from the East: 6.50 m, 13 m, 12.10 m, 12.10 m, 13 m) based on four piers of different sizes, ranging from a minimum of 6.2 m to a maximum of 8.4 m. These



Figure 3. The bridge of Canosa di Puglia. View from West.

are composed of square blocks in isodomic work and equipped with triangular starlings and prismatic cones, upstream and downstream. The walkway above is developed for a length of 170 m and a width of 4.5 m, its trend is not straight and nor in correspondence with the abutments. The piers, the abutments, and the foundation *platea* are the only surviving elements of the original structure [3]. When the river is dry, it is also possible to see the concrete walkway built for the passage of American tanks in the last phase of World War II [10] (Figure 4).

Today, the bridge is only accessible on foot, so as not to overburden the structure with the passage of vehicles, for which instead was built a bridge in the 20th century a few hundred meters further upriver.

### 3. METHOD

Thanks to the diffusion of new digital technology and the constant decrease of its cost it has been possible to develop



Figure 4. The bridge during the dry season, when the paving blocks of the roman *platea* and the concrete boardwalk built in the first half of the 20th century are visible.

methodologies able to detect, interpret and preserve very important data regarding works of archaeological and architectural heritage [11], [12].

All these operations have been a fundamental support to the global process of knowledge and analysis, revealing the need for multidisciplinary expertise, both theoretical and technical, in the approach to archaeological and architectural heritage.

Once the research aim has been set up and the parts of the artefact considered to be original had been ascertained, the following steps were taken:

- archival research, through published sources and unstudied documents,
- comparison with historical photographs,
- on-site survey with manual and drone technology,
- photogrammetry operations,
- identification and recording of the different SSU (Structural Stratigraphic Units) [13], [14],
- 3D modeling,
- graphic restitution and reconstruction hypotheses.

Leaving aside the part about archival research, which has been dealt with in detail elsewhere [15], all the on-site operations highlighted the complexity of data collection in a context such as the fluvial one. In particular, the photographic campaign and the acquisition of the metric data with the integrated survey were found to be difficult due to the high flow of the river and the dense vegetation. For this reason, survey operations must take into account the natural context in which they are carried out and must also be appropriately planned according to the season.

#### 3.1. Survey with drone technology and photogrammetry

Thanks to drone technology, it was possible to overcome some of the obstacles described above and record a set of data useful for the creation of the virtual model.

The drone used is a Dji Mavic 2 Pro equipped with a high resolution camera with 78.8° shooting angle of 26.6 mm and 1/2.3" CMOS sensor of 12.7 Megapixel and GLONASS GPS system with vertical accuracy error of  $\pm 0.1$  m and  $\pm 0.3$  m

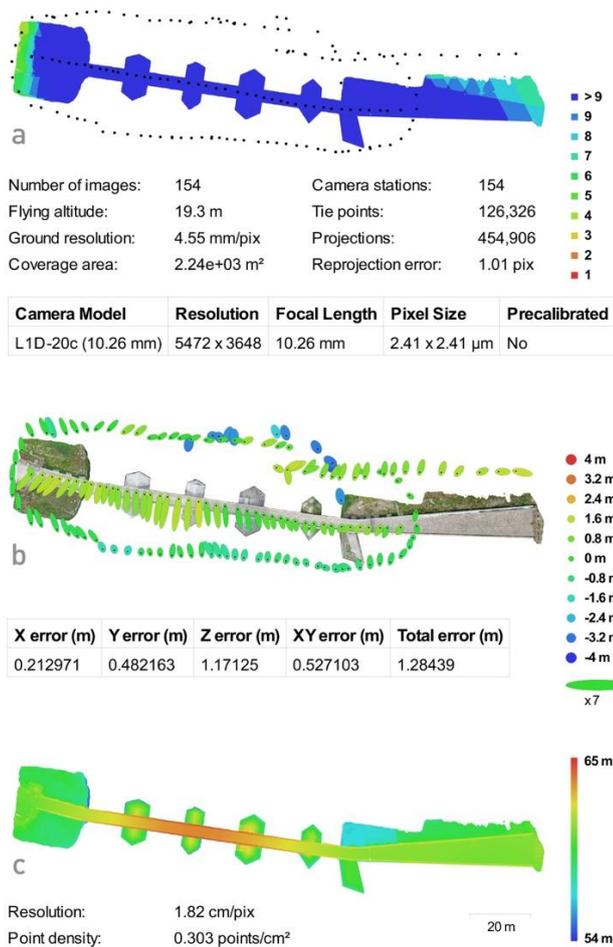


Figure 5. a) Survey report: Camera locations and image overlap; b) Camera locations and error estimates. Z error is represented by ellipse colour. X,Y errors are represented by ellipse shape. Estimated camera locations are marked with a black dot; c) Survey report. Reconstructed digital elevation model.

horizontal. Proceeding with an aerial photo acquisition in manual flight, 3 photo acquisitions were made, of which 2 in rotation around the artifact at an altitude of 5 m and 15 m and one top view at an altitude of 25 m.

The rotation photographic acquisition was made with a camera inclination of 0° (the one at 5 m), then with a view perpendicular to the building in order to reduce the aberrations during data processing, the one at 15 m with a camera inclination of 45° for a photo acquisition necessary to receive data of the

intersection node between the vertical and horizontal surfaces, and finally the one above 25 m with nadir camera inclination for the acquisition of data from the upper part of the bridge, producing a total of 154 photographs with GSD (ground simple distance) of 4.55mm/pix.

Even if Ground Control Points (GCPs) are usually necessary to guarantee that the shape of the model is geometrically correct in all three dimensions, during the acquisitions it was not necessary to use GCPs for a subsequent scaling of the model, as the measurements were taken using the architectural elements present in the structure such as the widths of the spans and the width of its the extrados, through direct survey operations and the use of laser level and laser rangefinder.

The photogrammetry operations [16] were carried out with the help of Agisoft Photoscan software, through which a dense point cloud composed of 12,490,415 points was generated, on which a textured mesh composed of 396,783 polygons and 396,783 vertices was produced (Figure 5). The model was scaled according to the points detected in the campaign phases.

The combined use of the survey methodologies constituted a system of verification of the overall process in the acquisition of the monument's dimensional information and its interpretation. In addition to the textured model (Figure 6) generated by the photogrammetry software, a simplified model has been elaborated for the virtual reconstruction operations [17]. The former then served as a comparison and verification of the latter, and vice versa.

### 3.2. Ancient metrology and data analysis

A metrological approach has been adopted in the interpretation of data resulting from the survey, comparing it with dimensional measures mentioned in ancient sources and cross-referencing them by synchronic or diachronic conversion of numerical data. The first case applies for historically and culturally related contexts, while the second case implements a multi-layered reading of different ages.

Discarding the parts ascertained as added or reconstructed, only the original elements still *in situ* were taken into consideration. Finally, a reconstructive hypothesis of the original morphology of the monument has been formulated, based on Roman construction and measurement methods.

A certain degree of approximation is to be expected both in reporting the measures and, consequently, in converting them to reconstructive hypotheses. However, the margin of error is limited enough to consider the data as valid for the purpose of the research.



Figure 6. Axonometric view of the bridge elaborated using drone technology and aerial photogrammetry.

Table 1. Ancient units and their mutual correspondence.

Unit	Roman Feet	Neapolitan Palms	Meters
<i>Pes</i>	1	1.1225	0.2960
<i>Palmo</i>	0.8909	1	0.2637
<i>Canna</i>	7.1270	8	2.1096
Meter	3.3784	3.7922	1

While the fundamental unit of measurement used during the Roman age was the foot (*pes*) and followed closely the measures of its Greek counterpart, the Attic foot, corresponding to 0.296 m [18], the authors of the two reports describe the bridge using the same unit of measurement, i.e. the *palmo* (Table 1).

As the two cases, 1584 and 1749, fall within the time span of the dominion of the Kingdom of Naples, which included the whole of southern Italy, we have therefore to assume that they were referring to the Neapolitan palm, corresponding to 0.26367 m [19], calculated on the basis of the measurement of an oxidized bar kept in Castel Capuano in Naples used as the governmental standard [20], according to an edict (lost) issued on 6 April 1480 by Ferdinand I of Aragon and in force until 1840. By applying a metrological approach, it is possible to derive different hypotheses about the construction phases of the bridge.

### 3.3. Synchronic conversion: what happened between the two key dates (1584 - 1749)?

A first conversion, of synchronic type, is made within the same measurement system to hypothesize the changes between the two sources key dates: it is interesting to note that both measurements are a multiple of 8. In the Kingdom of Naples, the unit of measurement that follows that of the *palmo* is the *canna*, which measures exactly 8 palms. Reading it in multiples, the 1749 survey describes an arch span reduced from 16 to 14 *canna*, exactly one *canna* per side (2.1 m). A margin of error of 4.2 m appears too large for a width of about 30 m.

One possibility is that consolidation works were necessary following one or both of the devastating earthquakes, the first in 1627 and the second in 1731 [21], which struck the Capitanata area and in particular Canosa. In this sense, the work may have involved the overlaying or covering of the inner part of the pillars with a masonry reinforcement designed on the basis of a standard building measure, i.e. one *canna*.

Within Delfino's design there are two elements protruding from the piers (Figure 7), an unusual fact that supports this

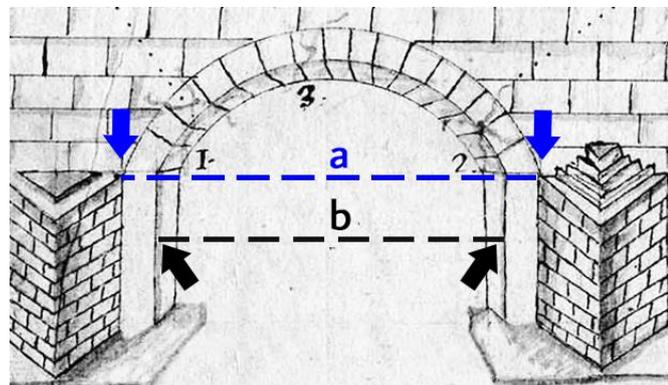


Figure 7. Drawing of the bridge by Francesco Delfino, 1749, detail of the central arch (Archivio di Stato di Foggia). Possible traces of structural changes between 1584 (a) and 1749 (b) which would explain the different dimensional data of the two reports mentioned in the text.

Table 2. Diachronic measures conversion chart.

Element of the bridge	Palms	Meters	Roman feet
Main arch (span)	112	29.53	99.78 $\approx$ 100
Main arch (height)	44	11.60	39.20 $\approx$ 40
Lateral arches (span)	50	13.19	44.54 $\approx$ 45
Lateral arches (height)	25	6.59	22.27
Front	5	1.31	4.45

hypothesis, as an expert surveyor would hardly have invented or exaggerated, despite the evident schematization of the work.

### 3.4. Diachronic conversion: reconstruction hypothesis

On the other side, through a diachronic conversion of the units of measurement (Table 2) it is possible to read the dimensions of the monument with the same measuring standards of the Roman builders. As previously said, the central arch was imposing and larger than the other two, as shown by Delfino's drawing and, even if with a more simplified style, other graphic sources preserved in the archives.

Therefore, if we accept the dimensions reported in the document (112 palms) and hypothesize that they are unchanged from the Roman age, having assumed the lateral piers as dating back to the imperial age, we obtain a measure (29.49 m) that is, with the due margin of error, exactly corresponding to 100 Roman feet.

This measurement is an architectural constant of the monumental Roman architecture [22], present in one of the most famous monuments of the Emperor Trajan in Rome, the column called "*centenaria*" for its height, and then in the Aurelian column, but also verifiable in the diameter of many monuments such as mausoleums (emperor Augustus, Cecilia Metella, L. M. Plancus and Sempronius Atratinus and the most famous pyramid tomb of Caius Cestius, whose side measures exactly 100 Roman feet), public buildings (the hall of the palatine basilica of Constantine in Trier), theater orchestras (Aquilaia), bridges (Narni, Alcantara) and many others, just to mention a few [23]-[26].

Also the height, 44 palms, would correspond to about 40 Roman feet, still a multiple decimal number, but this data is subject to more variables since in the case of restoration or collapse the section of the arches is the part most exposed to sensitive alterations.

Moreover, it must be considered that it is not indicated in the sources whether the measurements were taken at the height of the water or the foundation *platea*.

Given these measurements, therefore the arc of the circle tangent was traced to the ideal segment at the level of the piers, about 3 m high, obtaining a figure that outlines a double-inclined slopes profile, based on a comparison with similar bridges, such as that of Ascoli Satriano on the Carapelle river (2nd century CE) and the Pont Julien at Bonnieux, in France (Augustan age).

The inclination of this profile corresponds to that found in the joints of the abutments (Figure 8), especially on the western side, which would confirm the presence of the original outline of the bridge (Figure 9).

Further information comes from some inscribed slabs found in Cerignola [27] that could belong to the bridge. This type of inscribed slab bore the inscription relating to the work, exalting its completion, and was part of the construction program of the *Via Traiana*. Also in this case, even if we do not have any information on what the original parapet looked like, the metric data relative to the "front" (5 Neapolitan palms, that is 132 cm)

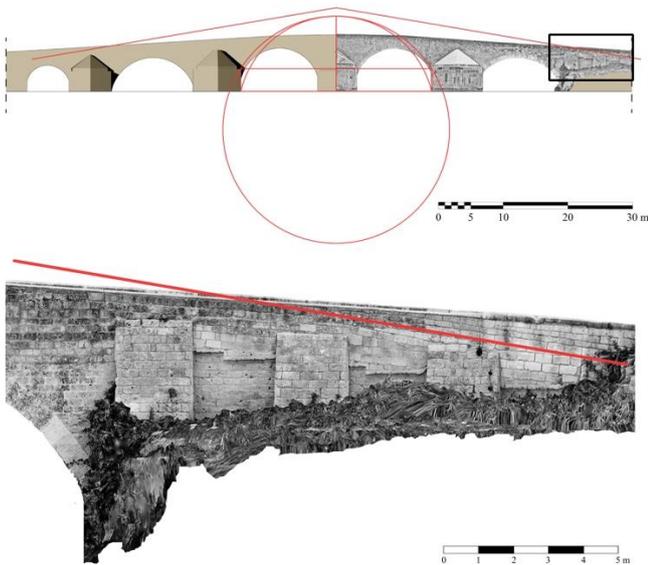


Figure 8. Upper, the bridge with the geometrical construction of the hypothesized shape. Lower, northwest front of the bridge, abutment. The red line shows the probable original incline still identifiable in the grade of the rows of blocks.

corresponds exactly to the height of the slab of Cerignola, so is possible that it was set along the balustrade that delimited the passage on the bridge. Thanks to this large amount of details, the reconstructive hypothesis of the bridge during the original phase of the structure and the subsequent ones has been elaborated, according to a representation technique that, combining technical drawing with watercolor effects, was both consistent with the data and useful for dissemination (Figure 10).

This phase of representation, based on processing and elaboration of raw data obtained from the previous survey, requires a logical process [28] that can lead us to reconstruct an accurate and complete 3D model in order to be used as a support for the research.

In order for the representation to be complete and intelligible, it is necessary indeed to understand the geometry and shape of the elements to be represented, as well as their reciprocal relationships [29].

#### 4. CONCLUSIONS

In an impervious context such as that of a river, challenging due to the frequent lack of sources and archaeological data, the research has shown how useful metrology has proved to be in formulating the reconstructive hypothesis with a high degree of

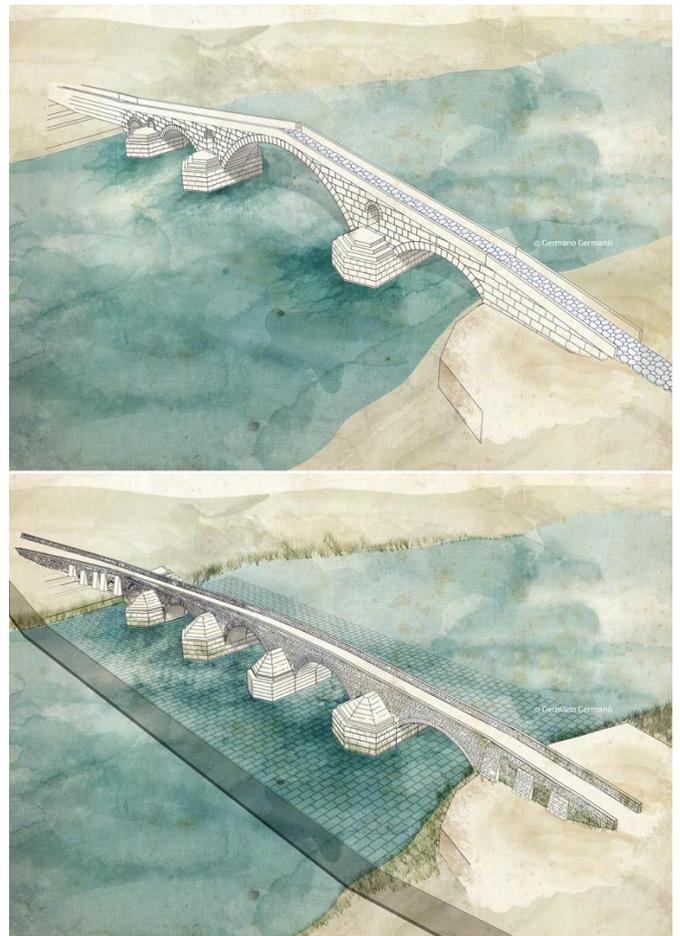


Figure 10. Illustration of the two main phases: the Roman bridge (top); the bridge nowadays showing the foundation *platea* (bottom).

reliability on a monument that has been strongly compromised over the centuries.

Beyond the theories on the exact morphology of the bridge, the research brings to light an architectural reality whose scope has been unfairly underestimated, and which places the bridge back in the history of ancient architecture, counting it among those with a central span among the longest in Roman times, according to a comparison with the monumental study carried out by Professor Vittorio Galliazzo [30], which is the most important work on Roman bridges, together with those of Colin O'Connor [31] and Piero Gazzola [32].

The results of this study would confirm the tendency in Roman monumental architecture to use a 100-foot module,

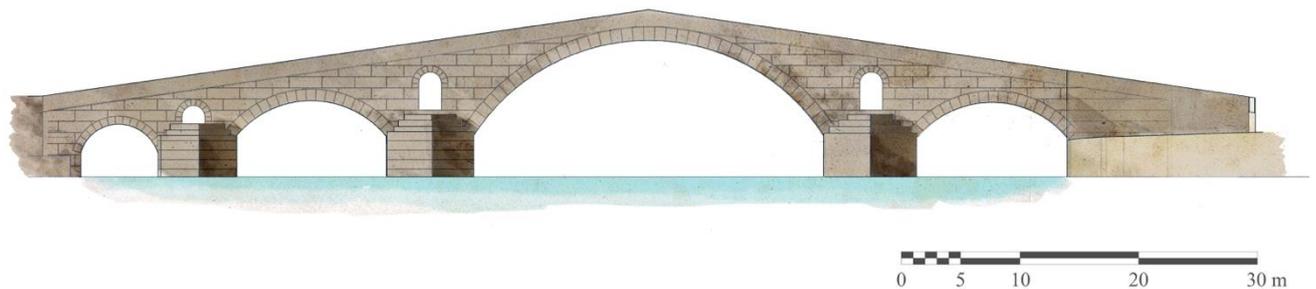


Figure 9. Graphical reconstruction of the bridge of Canosa in Roman times.

although the variables involved encourage a careful approach, in order to prevent the temptation of a “metrological pareidolia”.

## REFERENCES

- [1] G. Germano, The Roman bridge of Canosa di Puglia: a metrological approach, Proc. of the 2020 IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage, Trento, Italy, 22-24 October 2020, pp. 605-610. Online [Accessed 20 March 2022] <https://www.imeko.org/publications/tc4-Archaeo-2020/IMEKO-TC4-MetroArchaeo2020-115.pdf>
- [2] R. Cassano, Canosa. Campagna di scavo 1985: il ponte romano sull'Ofanto, in: *Le Rassegne archeologiche in Puglia. Atti del XXV Convegno di Studi sulla Magna Grecia*, Taranto, 3-7 ottobre 1985, Napoli 1986, pp. 408-142. [In Italian]
- [3] R. Cassano, Il ponte sull'Ofanto, in: *Principi, Imperatori, Vescovi, Duemila anni di Storia a Canosa*. R. Cassano (editor). Marsilio, Venezia, 1992, ISBN: 8-8317-5377-0, pp. 708-711. [In Italian]
- [4] G. Germano, Il ponte romano sull'Ofanto: analisi delle tecniche costruttive, ipotesi di restituzione e valorizzazione, Tesi di specializzazione in Beni Architettonici e del Paesaggio, Bari, Italy, 2019 (Unpublished results). [In Italian]
- [5] G. Ceraudo, Via Gellia: una strada 'fantasma' in Puglia centrale, *Studi di Antichità* 12 (2008), pp. 187-203. [In Italian]
- [6] M. Chelotti, V. Morizio, M. Silvestrini, *Le epigrafi romane di Canosa II, Edipuglia*, Bari, 1990, ISBN: 978-88-7228-065-2. [In Italian]
- [7] B. Bilinski, La Puglia e Bari nel "Diario di viaggio" di Jan Ocieski, ambasciatore polacco nel 1541, in: *La regina Bona Sforza tra Puglia e Polonia, Atti del Convegno (Bari 27/4/1980)*. Ossolinum, Leopoli, 1987, pp. 16-40. [In Italian]
- [8] P. Ieva, La sepultura di Re Boamundo in una inedita breve descrizione tardo-cinquecentesca, in: "Unde boat mundus quanti fuerit Boamundus": Boemondo I di Altavilla, un normanno tra Occidente e Oriente: atti del Convegno internazionale di studio per il IX centenario della morte, Canosa di Puglia, 5-6-7 maggio 2011. C.D. Fonseca, P. Ieva (editors). Società di storia patria per la Puglia, Bari, 2015, pp. 301-335. [In Italian]
- [9] M. R. Tritto, I restauri settecenteschi del ponte romano di Canosa di Puglia, in: *Canosa. Ricerche Storiche 2004*. L. Bertoldi Lenoci (editor). Schena Editore, Fasano, 2005, pp. 71-100. [In Italian]
- [10] G. Germano, Bridges at war and conservation of cultural heritage: a case study from Italy, in: *Antiquities, Sites and Museums Under Threat: Cultural Heritage and Communities in a State of War (1939-45)*, Proceedings of the International Conference at University of Ghent (Belgium 15-16/10/2020). A. Crisà, J. Bourgeois (editors). Brill, Leiden, 2022.
- [11] J. McCarthy, Multi-image photogrammetry as a practical tool for cultural heritage survey and community engagement, *Journal of Archaeological Science* 43 (2014), pp. 175-185. DOI: [10.1016/j.jas.2014.01.010](https://doi.org/10.1016/j.jas.2014.01.010)
- [12] E. Stylianidis, *Photogrammetric Survey for the Recording and Documentation of Historic Buildings*, Springer, Cham, 2020.
- [13] E. Fentress, C. J. Goodson, Patricians, monks, and nuns: the abbey of S. Sebastiano, Alatri, During the Middle Ages, *Archeologia Medievale*, XXX, 2003, pp. 67-105.
- [14] R. Parenti, Le tecniche di documentazione per una lettura stratigrafica dell'elevato, in: *Archeologia e restauro dei monumenti*. R. Francovich, R. Parenti (editors). All'Insegna del Giglio, Firenze, 1988, pp. 249-279. [In Italian]
- [15] G. Germano, The role of archives in the graphic restitution of monuments: the case of the Roman bridge over the Ofanto river in Canosa di Puglia, *Bitàcora Arquitectura* 45 (2020), pp. 4-11. DOI: [10.22201/fa.14058901p.2020.45.77630](https://doi.org/10.22201/fa.14058901p.2020.45.77630)
- [16] F. Remondino, Heritage recording and 3D modeling with photogrammetry and 3D scanning, *Remote Sens.* 3 (2011) pp. 1104-1138. DOI: [10.3390/rs3061104](https://doi.org/10.3390/rs3061104)
- [17] G. Germano, 3D Reconstruction of a Roman Bridge in Canosa di Puglia (Italy), in: *Studies in Digital Heritage* 5(1) (2021), pp. 75-87. DOI: [10.14434/sdh.v5i1.30812](https://doi.org/10.14434/sdh.v5i1.30812)
- [18] A. Mazzi, Nota metrologica, in: *Archivio Storico Lombardo. Società Storica Lombarda*, Milano, 1901, p. 354. [In Italian]
- [19] C. Salvati, *Misure e pesi nella documentazione storica dell'Italia del Mezzogiorno, L'arte tipografica*, Napoli, 1970, pp. 34-35. [In Italian]
- [20] E. Lugli, *The Making of Measure and the Promise of Sameness*, University of Chicago Press, Chicago, 2019, p. 20.
- [21] A. Rovida, R. Camassi, P. Gasperini, M. Stucchi, *Italian Parametric Earthquake Catalogue (CPTI11)*. Istituto Nazionale di Geofisica e Vulcanologia (INGV), Milano, Bologna, 2001. DOI: [10.6092/INGV.IT-CPTI11](https://doi.org/10.6092/INGV.IT-CPTI11)
- [22] M. S. De Rossi, *Analisi geologica ed architettonica delle catacombe romane*, Roma, 1864, p. 75. [In Italian]
- [23] A. Carandini, *La Roma di Augusto in 100 monumenti*, UTET, Roma, 2019, ISBN: 9788851169909. [In Italian]
- [24] C. Inglese, L. Paris (editors), *Arte e tecnica dei ponti romani in pietra*, Sapienza Università Editrice, Roma, 2020, ISBN: 978-88-9377-150-4. [In Italian]
- [25] J.-P. Brun, P. Munzi, S. Girardot, A. R. Congès, M. Pierobon, Un mausoleo a tumulo di età tardo-repubblicana nella necropoli settentrionale di Cuma, in: *Dall'immagine alla storia. Studi per ricordare Stefania Adamo Muscettola*. C. Gasparri, R. Pierobon Benoit (editors). Naus Editoria, Pozzuoli, 2010, ISBN 978-88-7478-017-4. pp. 279-302. Online [Accessed 20 March 2022] [In Italian] <https://hal.archives-ouvertes.fr/hal-01435853/document>
- [26] A. R. Ghiotto, G. Fioratto, G. Furlan, Il teatro romano di Aquileia: lo scavo dell'aditus maximus settentrionale e dell'edificio scenico, *FOLD&R*, 495, 2021. Online [Accessed 20 March 2022] [In Italian] <http://www.fastionline.org/docs/FOLDER-it-2021-495.pdf>
- [27] G. Ceraudo, A proposito delle lastre iscritte dei ponti della Via Traiana, in: *Atlante Tematico di Topografia Antica* 22. L. Quilici, S. Quilici Gigli (editors). L'Erma di Bretschneider, Roma, 2013, ISBN: 978-88-8265-772-7, pp. 143-153. [In Italian]
- [28] V. Croce, G. Caroti, A. Piemonte, M. G. Bevilacqua, From survey to semantic representation for Cultural Heritage: the 3D modeling of recurring architectural elements, *Acta IMEKO* 10(1) (2021), pp. 98-108. DOI: [10.21014/acta\\_imeko.v10i1.842](https://doi.org/10.21014/acta_imeko.v10i1.842)
- [29] L. De Luca, Methods, formalisms and tools for the semantic-based surveying and representation of architectural heritage, *Applied Geomatics* 6 (2014) pp. 115-139. DOI: [10.1007/s12518-011-0076-7](https://doi.org/10.1007/s12518-011-0076-7)
- [30] V. Galliazzo, *I ponti romani*. Canova, Treviso, 1995, ISBN 10: 88-85066-66-6. [In Italian]
- [31] C. O'Connor, *Roman bridges*, Cambridge University Press, 1993.
- [32] P. Gazzola, *Ponti romani*, Leo Olschki, Firenze, 1963. [In Italian]