Digital investigation on the Bridge of Augustus and Tiberius in Rimini: changes in scale over time

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Abstract
Ancient bridges exemplify a domain where the acquisition phase is greatly impacted by the environmental conditions of the surrounds and the level of detail needed for the representation phase, in a sort of from S to XXL framework of documentation. The Bridge of Augustus and Tiberius, or Pons Tiberius, in Rimini, Italy, stands as a testament to the enduring legacy of Roman engineering and the historical significance of ancient infrastructure. Spanning the Marecchia River, this iconic bridge has a rich history that weaves together elements of Roman imperial power, architectural innovation, and cultural heritage. This study is part of a research project that seeks to enhance our understanding of ancient Roman stone bridges in Rome and the Provinces. It involves integrated survey activities, which are conducted to gather data for specific technical, geometric, and metrological analyses. The study utilises advanced technologies such as virtual reconstruction and three-dimensional modelling. The survey exploited conventional approaches such as topographic and GPS, as well as advanced techniques including 3D laser scanning and digital photogrammetry digital. These techniques showed how the bridge's role as a grand entrance to the Roman city can be remembered through several way of representation.

Keywords
digitisation, 3D documentation, point cloud analyses, HBIM, masonry bridge.

Survey of the birdge of Augusts and Tiberius in Rimini. Elaboration by the authors.

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Introduction

The paper aims at highlighting the use of integrated technologies applied on an historical bridge in Rimini in order to create precise three-dimensional models in a process that starts from the initial survey design phase and continues by the acquisition phase, then goes through the data registration and finally ends with the generation of a 3D dataset. While this holds true for any architectural or archaeological artefacts, ancient bridges specifically exemplify a domain where the acquisition phase, particularly, is greatly impacted by the environmental conditions of the surrounds, with environmental considerations carrying substantial importance. Surveying ancient bridges, whether in urban or suburban areas, poses significant challenges due to the unique environmental, morphological, and formal characteristics. These challenges arise from the presence of the underlying waterway and the connection it provides between different parts of the city or territory [Bianchini et al 2022, p. 85]. The essay starts describing the history of the case study, the Tiberius and Augustus bridge, over the Marecchia river, begun in 14 A.D. under Augustus and completed in 21 A.D. under Tiberius, located at the beginning of the Via Emilia (fig. 1).

Fig. 1. Picture of the Augustus and Tiberius bridge, a structure located north-west of the main historic centre that connects the two old areas of Rimini. Picture by Guido Galvani.

This very first part brings short description of the history the bridge, which is useful to understand the importance of this cultural heritage and its role in the Rimini's history. Therefore, the text goes deep into the subject through the analyses and comparison of similar digital investigation approaches on other case studies. Here the paper shows how masonry bridges such as the roman ones remain widely utilised, especially in regions characterised by notable landscape or cultural significance. These centuries-old structures still serve as essential parts of roadways, requiring them to operate under stress conditions that may differ from their original design parameters. Hence, it is imperative to guarantee proper documentation toward their sustainable conservation. The central part of the contribution is focused on the documentation activities carried out on the bridge, describing 3D database consisting of two distinct point clouds that are geometrically consistent but differ based on the type of data. The first point cloud is obtained using a terrestrial 3D laser scanner and coaxial photogrammetry, while the second point cloud is generated by photo modelling techniques. The last part of the contribution highlights how through an integrated approach based on a topographic framework which comprises two closed polygonal structures designed to spatially locate the landmarks the documentation activities was improved in terms of reliability. Furthermore, along with the laser scanner survey, a photographic survey campaign was conducted to capture detailed images of the two side surfaces of the bridge to enhance the description of the bridge's features, including its chromatic aspects, dealing from the extra small scale to the extra-large one.

History of the bridge of Tiberius

The Bridge of Augustus and Tiberius, or Pons Tiberius [Fontemaggi et al. 2022, p. 9], in Rimini, Italy, stands as a testament to the enduring legacy of Roman engineering and the historical significance of ancient infrastructure [Rimondini 2014, p. 14]. Spanning the Marecchia River, this iconic bridge has a rich history that weaves together elements of Roman imperial power, architectural innovation, and cultural heritage. Constructed during the reign of Emperor Tiberius in the early 1st century CE, the Bridge of Tiberius was a response to the growing needs of Rimini and its strategic location in the Roman Empire. The bridge served as a vital link in the Roman road network, connecting the city to the important trade routes and facilitating the movement of goods, troops, and people in a wider strategy carried on by the roman emperors [Ballance, 2013]. The design of the Bridge of Tiberius reflects the engineering mastery of the Romans. Like its predecessor, the Bridge of Tiberius and Augustus, it is a segmental arch bridge, characterized by multiple arches (fig. 2) with a slight rise in the center [Varène 1997, p. 382].
This architectural style not only allowed for better water flow but also provided stability and durability. The builders utilized locally sourced materials, including sandstone and limestone, showcasing the Roman ability to adapt construction methods to the available resources [Foschi 2024, p. 18]. The Romans utilised a combination of these abilities to create "one of the most triumphant, comprehensive, and enduring accomplishments of humanity" [O'Connor 1993, p. 188].

Fig. 2. Detail of a stone arch of Augustus and Tiberius bridge. Picture by Gabriele Giau.

A peculiar feature of the bridge is the piers' orientation: they are inclined with respect to the road axis, because they are oriented towards the ancient mouth of the Marecchia River where the Roman port was located (fig. 3).

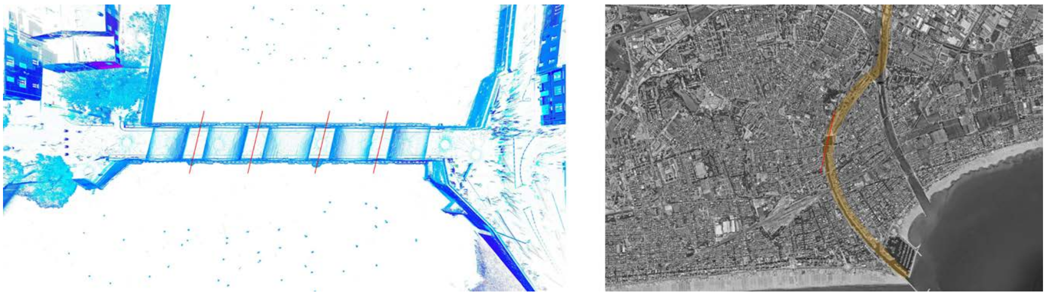

Fig. 3. Point cloud and graphic elaboration (left) that shows the rotation of the piers following the old Marecchia River path (right) that was modified between 1924 and 1930. Elaborations by the authors.

The construction of the Bridge of Tiberius marked a period of expansion and consolidation for the Roman Empire [Fulford 1992]. Tiberius, the second Roman Emperor, sought to strengthen the empire's infrastructure and ensure efficient communication across its vast territories. The addition of this bridge to Rimini's landscape symbolized the empire's commitment to connectivity and served as a visual manifestation of Roman engineering prowess [Hitchner 2012, pp. 225-226]. Throughout its existence, the Bridge of Tiberius has witnessed numerous historical events and transformations [Tassinari et al. 2013]. The fall of the Roman Empire and the subsequent medieval period brought changes to the region, yet the bridge remained a vital crossing point over the Marecchia River. Over the centuries, the structure underwent renovations and repairs, adapting to the evolving needs of the city and its inhabitants [Galliazzo, 1995, pp. 472-474]. The medieval and Renaissance periods saw the Bridge of Tiberius continue its role as a crucial artery for trade and transportation. Its strategic location contributed to Rimini's economic growth, making it a focal point for commerce and cultural exchange. The bridge also found its way into the works of artists and writers, becoming a subject of fascination and inspiration [Empler et al. 2020, pp. 140-141; Bernucci, 2022, pp. 207-235]. Recognizing its historical and cultural significance, restoration efforts were undertaken to ensure the longevity of this ancient structure. These projects aimed to balance the use of modern conservation techniques with a commitment to maintaining the authenticity of the original Roman design. Today, the Bridge of Tiberius stands as a prominent symbol of Rimini's rich history. The bridge not only represents a physical connection between the past and the present but also serves as a living monument to the resilience of Roman engineering [Ferrari 2022, p. 57]. The history of the Bridge of Augustus and Tiberius in Rimini is a captivating journey through the annals of Roman engineering, imperial ambition, and the cultural tapestry of Italy.

3D documentation of historic bridges

Roman road networks consist of paths and bridge structures that vary in design and construction based on the time period and importance of the transportation infrastructure in a certain geographical area of the Empire. (fig. 4). Nowadays masonry bridges continue to be in extensive use, particularly in areas with low urban development and significant landscape or cultural importance [Gazzola, 1963].

These constructions built centuries ago continue to function as integral components of roadways, necessitating their operation under load situations that differ from their original design specifications. Therefore, ensuring the upkeep and conservation of these historic structures is a crucial concern. This situation necessitates the creation of a comprehensive methodology that can address the requirements for understanding the technological and

Fig. 4. Roman bridges in Mediterranean region (from top left corner in clockwise order): Afrin Huri Bridge (Syria), Alte Sauerbrücke (Germany), Roman Bridge of Antalya (Turkey), Puente Romano of Merida (Spain), Baibars Bridge (Israel), Avila Roman bridge (Spain). Pictures available online.

structural characteristics of a bridge, as well as its historical background and present state [Lubowiecka et al. 2011].
This could be carried on by the use of an interdisciplinary strategy, specifically by applying the archaeological analyses method and 3D data management to ancient masonry bridges [Savini et al. 2021]. Several studies with multidisciplinary approaches in the digital documentation of Roman bridges were recently implemented through the application of stratigraphic method and 3D reconstruction [Germano, 2023]. The increased load capacity of contemporary transit might lead to structural damage. Furthermore, due to the antiquity of the structures, the design drawings are typically unavailable. As a result, the geographical positioning of historic bridges becomes more challenging and the preservation of their cultural legacy becomes more intricate (Inglese & Paris, 2020). On roman bridges 3D investigation by different techniques could be conducted to examine the impact of damage on the dynamic response of the structure. In order to simulate the behaviour of ancient masonry materials, a single damage variable could be incorporated into the stress-strain equation. Furthermore, a 3D finite element formulation could be also employed. For instance, the natural frequencies and modal shapes of the bridge can be assessed and compared to the experimental findings [Addessi et al., 2022].

The 3D survey campaign on the Augustus and Tiberius bridge

The purpose of the survey of the Augustus and Tiberius Bridge is the metric, geometric and colorimetric acquisition of the artefact and the elaboration of a point cloud model, a founding element for the constitution of a more complex geometric and informative model, useful for the study of the monument under various aspects, including the historical, geometric-proportional, technical-constructive and state of conservation ones. Integrated survey methodologies were put into practice, based on the application of topographic and GPS techniques, 3D laser scanning and digital photogrammetry (fig. 5). The former were used for the georeferencing of the model and for the topographic net, in order to associate point clouds in a common reference system and in order to control registration errors. The latter were used for the massive acquisition of measurements, both contextual and detailed. The overall model is in fact composed of two point clouds, geometrically coherent but different according to the type of data. The first is a point cloud acquired by terrestrial 3D laser scanner and coaxial photogrammetry, the second derived through photo modelling processes. 3D laser scanner acquisition employed two instruments with different characteristics depending on the size of the spaces to be acquired and the boundary conditions.
Typically, bridges are structures that are difficult to survey from positions located in front of the main surfaces, since they are arranged perpendicular to the element they are intended

Fig. 5. Photo merge of some images of the Augustus and Tiberius bridge used for the 3D reconstruction. Elaboration by the authors.

to cross, which is generally inaccessible. The urban context in which the bridge is positioned, although it does not allow the monument to be approached from less than 20 metres to the south-west and 80 metres to the north-east, presents some anthropic elements that allow to position the laser scanner in front of the two sides of the structure: the quaysides of the XXV Aprile park and a pier that crosses the Marecchia river (fig. 6).

Fig. 6. The three-dimensional dataset of the Marecchia river basin integrates Laser scanner C10 and BLK data and photogrammetry. Elaboration by Guido Galvani.

For this reason, it was decided to use a Leica Scan Station C10 laser scanner, characterised by a medium range (approximately 250m), to acquire the surfaces and external elements of the bridge, as well as the surrounding urban context. For each station, a 360-degree context scan was performed, followed by a detailed scan focused on the bridge, set at a higher resolution, in order to refine the point cloud. In addition, through the coaxial photogrammetry procedure, the colorimetric data of the visible was added to each scan. This acquisition was carried out in exposition conditions of the bridge surfaces as homogeneous and constant as possible among the various scan stations.

Difficulties and challenges faced

The main condition in the approach to surveying a road infrastructure is the maintenance in operation of its functions during the acquisition operations, therefore, adapting to transit flows and maintaining of a low site impact is the key to making sustainable, in general, such a survey.

The additional difficulty of complying with the need to acquire, not only the geometry but also of the colour datum in a continuously changing context, resulted in an operation carried out with a second type of 3D laser scanner that, not having to maintain characteristics of range and measurement accuracy at medium distances, was capable of fulfilling the task of maintaining equivalent accuracy conditions in a much smaller metric range, with high acquisition rates, resulting in reduced set-up times and the possibility of automatic mapping of the colours.
Consequently, given the dimensions of the street, the instrument used was a Leica BLK360, a tool capable of handling metric acquisition at the desired accuracy values in a narrower field and automatically maps the colour data onto the clouds, with high speeds, reduced set-up times and low site impact.
In addition, there is a high risk of inconsistency between the measured point and the RGB data association, the latter being subject to the possibilities of obscuration of the field of view in the different stages of acquisition. Therefore, it was provided for each station a dual acquisition procedure, of the datum metric and colour datum, which resulted in the analysis of inconsistent areas in the post-processing phase of the data, due to the overlapping of the scans made.
With this approach it was possible to cover the shaded areas in the various scans and ensure a correct association of the RGB values with the measured coordinates, eliminating inconsistent areas in the data processing phase.
Three compartments were therefore surveyed: the downstream side of the bridge, the upstream side and its deck with the landings on both sides of the river. These areas constitute three independent substructures, each with its own target network to control the statistical values of the survey as far as possible. These subsets were registered on the general topographic network, consisting of two closed polygonals, aimed at the spatial determination of the targets. Concurrently with the laser scanner survey, a photographic survey was also carried out, aimed at the photo modelling of the two lateral surfaces of the bridge, in order to better describe the detail also from a chromatic point of view.
The acquisition was terrestrial, since the airspace around the site is closed to flight. The point cloud derived from the photogrammetric process was overlaid on the cloud from the laser scanner, by positioning on the same reference system through the same targets, thus completing the overall model of the bridge (fig. 7).

Fig. 7. On the left: The change in perceived scale of the Augustus and Tiberius bridge (A) and the other roman bridge on the Ausa river (B). From monumental scale and main gates of the roman city, to the current state of infrastructure. The bridge on the Ausa (left image letter B) is not visible anymore. (from: Rimini Romana Program Ipa Adriatic - Cross Border Cooperation 2007-2013 project "HERA- TOURISM OF ADRIATIC HERITAGE"), on the right: elaboration by the authors.

Conclusions: from a monumental scale to a contemporary infrastructure

An historical bridge such as the Augustus and Tiberius one evokes the past and serves as a reminder of outdated technologies, such as the horse-drawn waggon. A bridge can also serve as a monument, as demonstrated by the historical and contemporary cultural significance attributed to other roman bridges. These bridges went through an extraordinary time-related transformation as out-of-scale spatial entity into a contemporary infrastructures linked to the urban texture. The temporal dimensions mentioned is just a small part of a more intricate dimensionality that classifies these infrastructures as "super-objects" in the past and that go beyond simple existence (roman bridges were often monumental gate to access the inner city). The time dimension is not merely a linear duration; it is intricately influenced by recollections and juxtapositions of many periods in the existence of an entity or a creation. The Augustus and Tiberius bridge is nowadays part of the historic context of Rimini without having the same important role that it had during the past as it has been engulfed by the urban fabric developed over centuries (fig. 8).

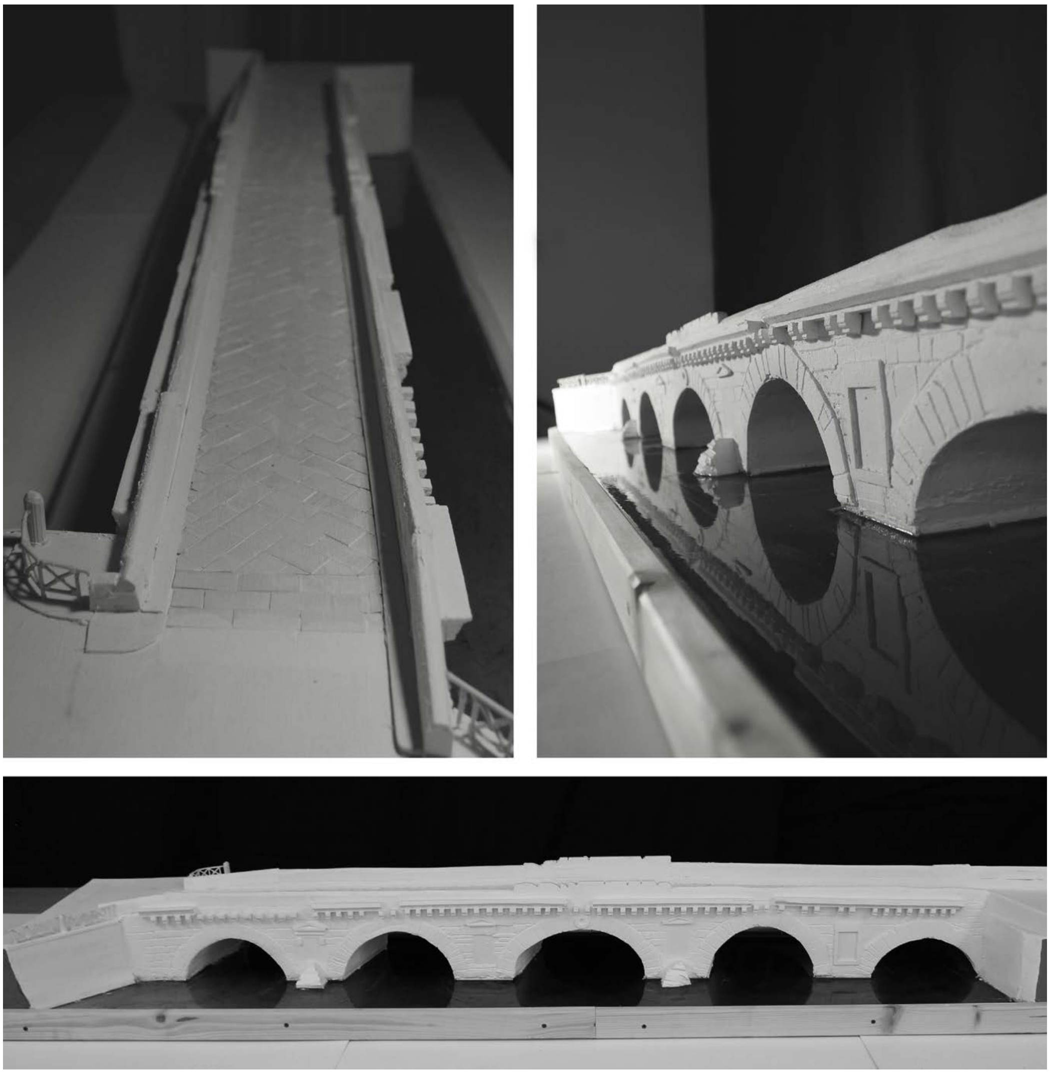

Fig. 8. Image of the physical model of the bridge that shows its monumental aspects isolated from the urban context (images by the authors).

The vision of this bridge as a monumental gate to the roman city can be recalled through both digital images or physical models. The authors of this research wanted to explore also this aspect by the construction of a model able to recreate the bridge isolated from the built environment.
For the construction of the large 1:10 scale model, the point cloud from the laser scanner survey was used as a reliable metric basis. This was then used to build a supporting structure of plywood covered with hand-engraved expanded polystyrene to faithfully recreate the joints. Finally, epoxy resin was used to recreate the effect of water in the basin (fig. 9). Dealing with these old structures means to involve the rhythmic temporality, which encompasses operational and seasonal patterns. This temporality can manifest in both timeless and abrupt ways. It can be perceived both through physical means and through intangible qualities that

cannot be seen. Time is both included and integrated, while also exerting a unifying influence on disparate processes and individuals. A heritage bridge, like the Augustus and Tiberius bridge in Rimini, a super-object in Roman's time, enhances the perception of syncopated temporality by embodying a unique collection of specifically temporal functions and abilities pertaining to the past, present, and future [Schields, 2021].

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