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Survey, semantics, and H-BrIM modeling for health assessment of masonry railroad bridges

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Abstract

Masonry arch bridges are an important part of Europe's road and railway heritage due to their integration with the environment, relatively low costs-maintenance, and high durability. However, lack of preservation and inherent obsolescence threatens this heritage, resulting in structural weaknesses and reduced functionality or total unviability. Developing effective and integrated procedures for characterizing the structural conditions, identifying potential vulnerabilities, and studying their geometric configurations, construction techniques, and documentary heritage is essential to preserve both the heritage value and infrastructural functionality.

The present work focuses on the development of innovative methodologies for the knowledge and documentation of historic masonry arch bridges, with the ultimate goal of preserving their historical and engineering value. The research is undertaken in the context of the significant number of masonry arch bridges that have been abandoned or threatened by inherent obsolescence and lack of maintenance.

The research project involves the analysis of established and emerging Scan-to-HBrIM (Historical/heritage bridge information modelling) procedures for masonry arch bridges, to develop effective procedures for characterizing the structural conditions of the bridges and identifying potential vulnerabilities, including the creation of a knowledge framework (ontology) that can be used for bridge modeling. The research goals include the formulation of operational protocols for surveying and modeling masonry bridges, the development of a knowledge system for providing an organized and easily applicable framework for data management, and the creation of a semantic structures for improving interoperability between models and information management systems.

The chosen case study for this research is the system of bridges of the Circumetnea railway in Sicily, Italy. The railway connects Catania to Riposto, almost encircling Mount Etna. The Circumetnea bridges are important heritage assets at risk and hence offer a suitable study subject for the research objectives. Moreover, these bridges hold significant historical value as it serves as a testament to the industrialization period of the Sicilian territory.

The proposed methodology is structured in three phases: a cognitive phase for knowing and documenting the case studies, a semantic phase for designing the bridge computational ontology, a segmentation phase for organically extracting information from the point cloud, and an information modeling phase for creating parametric components. The innovation of the present work lies in proposing a methodical and consistent application of surveying paradigms revisited from the perspective of surveying masonry arch bridges. Additionally, a complete bridges semantic structure, including structural, architectural, and design aspects, is proposed and described. The work also proposes an automated and expeditious method for providing a quick assessment of the geometrical characteristics of the bridge starting from point clouds obtained by field surveys.

Abstract (italiano)

I ponti ad arco in muratura sono una parte importante del patrimonio stradale e ferroviario europeo grazie alla loro integrazione con l'ambiente, ai costi di manutenzione relativamente bassi e all'elevata durabilità. Tuttavia, la mancanza di interventi di conservazione e l'obsolescenza intrinseca di tali manufatti, minacciano questo patrimonio, con conseguenti criticità strutturali e una ridotta funzionalità o la totale inagibilità. Lo sviluppo di procedure efficaci e integrate per la caratterizzazione delle condizioni strutturali, l'identificazione delle potenziali vulnerabilità e lo studio delle configurazioni geometriche, delle tecniche costruttive e del patrimonio documentale è essenziale per preservare il valore del patrimonio e la funzionalità delle infrastrutture.

Il presente lavoro si concentra sullo sviluppo di metodologie innovative per la conoscenza e la documentazione dei ponti storici ad arco in muratura, con l'obiettivo finale di preservarne il valore storico e ingegneristico.

Il progetto di ricerca prevede l'analisi delle procedure Scan-to-HBrIM (Historical/Heritage Bridge Information Modelling) consolidate ed emergenti per i ponti ad arco in muratura, al fine di sviluppare procedure efficaci per la caratterizzazione delle condizioni strutturali dei ponti e l'identificazione delle potenziali vulnerabilità, compresa la creazione di una base di conoscenze (ontologia). Gli obiettivi della ricerca includono la formulazione di protocolli operativi per il rilievo, lo sviluppo di un sistema di conoscenza per fornire un quadro organizzato e facilmente applicabile per la gestione dei dati e la creazione di strutture semantiche per migliorare l'interoperabilità tra modelli e sistemi di gestione delle informazioni.

Il caso di studio scelto è il sistema di ponti della Ferrovia Circumetnea in Sicilia, Italia. La ferrovia collega Catania a Riposto, quasi circondando l'Etna. I ponti della Circumetnea sono un importante patrimonio a rischio e rappresentano quindi un oggetto di studio adatto agli obiettivi della ricerca. Inoltre, questi ponti hanno un valore storico significativo, in quanto testimoniano il periodo di industrializzazione del territorio siciliano.

La metodologia proposta è strutturata in diverse fasi: una fase cognitiva per la conoscenza e la documentazione dei casi di studio, una fase semantica per la progettazione dell'ontologia computazionale dei ponti, una fase di segmentazione per l'estrazione delle informazioni dalla nuvola di punti e una fase di modellazione delle informazioni per la creazione di componenti parametrici. L'innovazione del presente lavoro consiste nel proporre un'applicazione metodica e coerente dei paradigmi di rilievo rivisitati per l'applicazione nei ponti ad arco in muratura. Inoltre, viene proposta e descritta una struttura semantica completa dei ponti, che comprende aspetti strutturali, architettonici e progettuali. Il lavoro propone anche un metodo automatizzato e veloce per fornire una rapida valutazione delle caratteristiche geometriche del ponte a partire dalle nuvole di punti ottenute dai rilievi sul campo, oltre alla creazione di schede specifiche per la classificazione dei ponti e la catalogazione del relativo materiale storico-documentale.

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Chap. 1 Introduction

1.1 Problem statement

Masonry arch bridges are a significant part of Europe's road and railway heritage, both in numerical consistency and valuable integration with the environment. Their construction techniques are nowadays considered a legacy of the past that often support today's communication networks.

In the second half of the 19th century, stone and masonry arch bridges had an enormous development in Europe and Italy, due to the expansion of railway networks. Although they are quite prototypical structures, as they were built following the nineteenth-century guidelines for designing masonry arch bridges, these artworks use local construction techniques and materials, reflecting the *modus costruendi* of the time as an historical persistency of the past. Furthermore, these works have relatively modest maintenance costs other than, having higher durability in comparison with concrete and metal bridges. However, inherent obsolescence and lack or improper maintenance may threaten this heritage. Due to the disuse of several railway networks, which have been replaced by road transportation, a significant number of these masonry bridges have been abandoned and neglected. In this regard, a substantial number of masonry bridges have collapsed over the past years.

As a critical component of the road and railways infrastructure, masonry arch bridges require special treatment. It is crucial to develop effective and integrated procedures to characterise their structural conditions, identify and prevent potential vulnerabilities, also by studying their geometric configurations, construction techniques, and documentary heritage.

In this direction, the Italian guidelines for monitoring and management of existing bridges (MIT, 2020) suggest that knowledge is a crucial step in the comprehensive approach to understanding the constructions' behaviour.

Italy has a large and widely diversified heritage of bridges, built with different materials (masonry, reinforced concrete, steel), many of which were designed with technical standards that are quite different from the current ones. Safeguarding these structures, i.e., ensuring their efficiency, durability, and reliability, is important from a social, economic and safety perspective and can be pursued through a proper maintenance planning. Obviously, to define an improvement intervention or maintenance, detailed knowledge of the structure is essential. Visual inspections are a first step towards the knowledge of these artefacts. They are aimed at verifying the reliability of the data collected in census, gathering further information about the actual geometric and structural characteristics of the work under examination and the construction site, and assessing, albeit in a cursory and summary manner, the degree of preservation of the structures.

The digital survey acts as a mean of understanding the artefact, connecting the fundamental aspects of observing the asset (visual inspection) with the possibility of recording the state of the bridge at a given moment, adding a further dimension (time) to those that define its spatiality and the materials. These techniques provide an objective description of the actual condition of the work and its surroundings, by means of accurate photographic, geometric, and main deterioration phenomena investigation.

To this aim, a multi-level approach for the management of existing bridges is recommended. Indeed, the complex aspects behind the inspections, investigations and monitoring of these structures require a homogeneous and structured framework methodology to support, in a quantitative and/or qualitative manner, maintenance operations towards the preservation of functionality and heritage value of these works.

1.2 Definition of the research

1.2.1 Research questions

Based on the aforementioned scenario, this research is centred around the following questions:

- What are the most suitable and expeditious spatial data acquisition protocols for masonry bridges, aimed both at the preservation and at the studying of this works?
- Which terms and what vocabulary are needed by domain experts to define masonry bridges and their components?
- Which ontology structure is best suited to describe the different aspects necessary to investigate and to get a more complete understanding of masonry arch bridges?
- How this knowledge domain could be exploited for a scan-to-BrIM semi-aided modeling with a focus on vulnerability assessment?
- Can structures such as masonry bridges serving an infrastructure be considered cultural heritage? If so, in what terms?

1.2.2 Research aim and goals

The research project is focused on the development of an innovative methodology for the knowledge and documentation of historic masonry bridges. The objective is to develop effective procedures for characterizing the structural conditions of these assets and identifying potential bridges vulnerabilities. This also includes the creation of a knowledge base (ontology) that can be used for various purposes, such as bridge modeling. In this regard, the project involves the thorough analysis of well-established and emerging Scan-to-HBrIM procedures for masonry arch bridges. In the light of the above, the research goals of the present work are:

- The formulation of operational protocols for the surveying and modelling of masonry arch bridges, to support the appropriate combination of survey techniques to adopt depending on the structural and geometrical features of the work;
- The setup and development of a knowledge system that includes the fundamental aspects of masonry arch bridges, in order to provide an organized and easily applicable framework to support quick data management of the surveyed works;

- The creation of a semantic structure regarding the masonry arch bridges and the characterization of their structural/geometrical components, in the vision of improving interoperability between models and information management systems.

1.3 Applied case study

To pursue the above objectives, the bridges of the Circumetnea (Catania, Italy) were chosen as case study. Circumetnea is a still-in-service railway connecting Catania to Riposto, almost encircling Mount Etna and passing through several towns in the slopes of the volcano. It is the last narrow - gauge railway in Sicily still in service, as other similar railways are no longer used. Built in a very short period (1889-1895) on the impulse of the 19th century commercial growth of the area, Circumetnea is supported by several masonry arch bridges, reflecting the typologies described in the technical manuals of the period. It is worth noticing that these bridges are heterogeneous in terms of materials, geometry, and number of arches, as well as there is a recurrence in typology. Moreover, Circumetnea bridges are heritage works at risk: as an example, traffic rearrangements and requirements have led to demolition of some of them. All these abovementioned aspects make the Circumetnea bridges a suitable study subject for the discussed research objectives.

1.4 Methodology

The proposed methodology (Figure 1) is herein presented and is structured as follows:

- **Cognitive phase**, aimed at knowing and documenting the case studies. It was developed according to the following steps:
    - documentary research allows the understanding of the design idea and provides important indications on the artefact, especially regarding the geometric configuration and the relationship with the pre-existing structures at the time of construction;
    - several integrated digital survey campaigns (laser scanning + Structure from Motion (SfM) aerial and terrestrial photogrammetry + mobile scanning + videogrammetry) aimed at acquiring the actual configuration of the bridges;
    - the census brings together all the information acquired during the cognitive phase on all the bridges under study.
- **Semantic phase**, aimed at designing a masonry arched bridge computational ontology that can be used as a knowledge base for deep neural network training, according to the following steps:
    - conceptualisation: which provides an in-depth survey of existing vocabularies and taxonomies. Then, identifying relationships and hierarchies between parts to choose the proper classes, subclasses, and property of the developing ontology is required. To do this it is crucial to conduct in-depth research into technical manuals and treatises, as it is analysing several case studies and their typologies, as that reported in;

- overview of existing ontologies: useful to understand whether it is better to link to an existing ontology or create a new one;
- ontology development: as an extension from the existing standards, particular attention is given to the level of granularity. Some levels of information to be added, for instance, are related to the semantic structure, construction techniques, and typical defects.

- **Segmentation phase**, aimed at speeding up the Scan-to-HBrIM (Historical Bridge Information Modelling) procedure, extracting useful information from the point cloud in a automatic and semi-automatic way:
  - semi-automatic point cloud segmentation: developing a code to extract useful information from point clouds for the creation of informative models.
    - application of categorization algorithms to segment the different components of the bridge based on their functional characteristics (e.g. vault, abutments, spandrels etc.);
    - extraction of the vault point cloud to compute geometrical information (e.g. arch arrow, vault span etc.) and identify the arch typology that generates the vault;
  - automatic point cloud segmentation
    - Creation of a two-level GAN (Generative Adversarial Network): a first GAN that generates or synthesizes isolated objects corresponding to each ontology concept, then a second one combines the generated objects according to the spatial information provided by the ontology, to generate realistic scenes and create a synthetic dataset. To create a synthetic dataset, it is necessary to start from real images. For this reason, a massive acquisition of pictures of the same typology as the case study is necessary.
    - Training of the CNN (Convolutional Neural Network) with real and previously mentioned synthetic datasets.
  - Test the effectiveness of the proposed approaches on point clouds obtained by digital surveying.
- **Information Modelling phase**, aimed at creating parametric components, starting from the segmented point clouds.
- **First evaluations of the integrated H-BrIM and InfraBIM approach**.

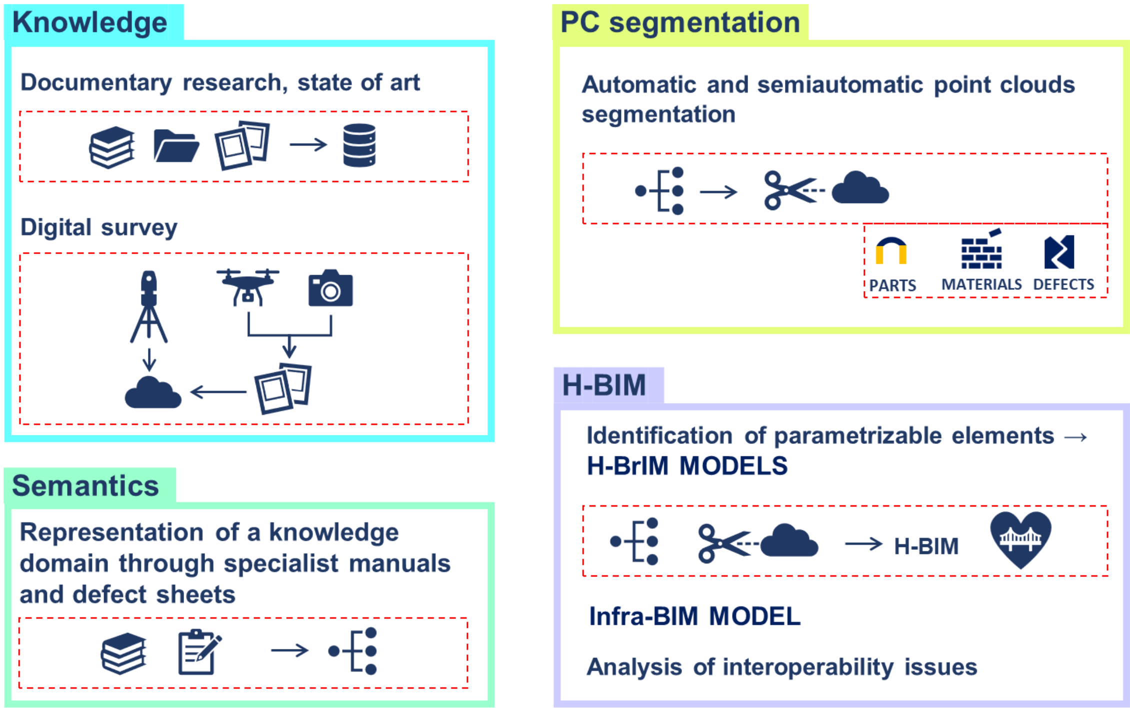


Figure 1 – Scheme of the methodology

1.4.1 *Innovative contribution*

In the light of the abovementioned discussion, an ensemble of research endeavours was carried out by means of multi-disciplinary approach to the goals of the present work. The activities included the thorough collection, analysis and comparative study of archive documentation, historical cartography, and digital surveys, reconnecting the past and present of the chosen case study.

The present research work advocates for a methodical and consistent application of surveying paradigms revisited from the perspective of surveying masonry arch bridges.

The work proposes an innovative work scheme which involves a diversified range of survey techniques and spatial information analysis methods, and through, a comparative analysis of their performance and the suitability of their use within the specific case, provides a framework to choose in a quick and accurate manner the most proper survey techniques.

Furthermore, a complete masonry arch bridges ontology, including structural, architectural, design and defective aspects, is proposed and thoroughly described. In the knowledge of the author, this omni-comprehensive approach has never been attempted in literature.

Moreover, an automatized and expeditious method to provide a quick assessment of the geometrical characteristics of the bridge starting from the point cloud obtained by survey is developed within MATLAB environment.

Although some attempts in literature do exists proposing this type of methods, the proposed method provide a more complete assessment of the bridge by providing a complete scheme of the dimensional, geometric, architectural features of the bridge.

The research investigates and deepens the surveying methodologies, defining operational protocols that take into consideration the characteristics of bridges. In particular, the following characteristics have been investigated: size, environmental context, cultural instance, accessibility, and types of expected interventions.

The classification of the acquired archival material has also seen the elaboration of novel specific sheets, referring to different cataloguing standards. In this way, it was possible to obtain cards that classify the bridge along its line and connect it to any acquired documentary material. To achieve this, the peculiarities of masonry arch bridge, elements at the border between the architectural/cultural and the structural domain, were considered.

Moreover, the knowledge system adopted in the present work to catalogue the bridges involves the inclusion and classification of not only the bridges intended as infrastructures, including structural and strictly engineering features of the work, but also information regarding cultural heritage value and purposes. Such an informative and complete database provide the basis for a more structured and integrate approach to the management and maintenance of bridges, in which both their functionality and their historical value must be preserved.

Another innovative aspect of the present work is the comprehensive approach, which includes the knowledge phase, the inspection phase, and, finally, lays the foundation for three-dimensional and informative modeling, based on a structured domain of knowledge (ontology). The bridge is considered a starting point for point cloud classification systems (both automatic and semi-automatic) and for three-dimensional modeling in the BIM context, with interoperability as a constant guiding principle.

1.5 Thesis structure

The work is divided into five parts. Considering the heterogeneous nature of the topic being explored, each section begins with a specific overview of the state of the art related to the respective theme. Subsequently, the obtained results of the specific tasks are presented. In this way, this manuscript is a collection of four parts, resulting from the application of the proposed methodology to the case study.

Chapter 2 describes the applicative case study, which encloses the Circumetnea, and its masonry arched bridges, contextualizing them within their historical and territorial framework.

Chapter 3 reports the methodology and the results of the archival research, which allowed to deepen the knowledge about the Circumetnea infrastructure system and provided insights on the motivations and the reasoning behind the development of the project.

Chapter 4 illustrates the survey campaigns, focusing on strengths, weaknesses, and context of application of each employed survey technique. For each survey a different combination of techniques was employed, depending on the specific characteristic of the bridge.

Chapter 5 shows the results of an in-depth analysis conducted on masonry arched bridges computational ontologies; following this, a semantic conceptualization in the masonry bridge domain is proposed. The conceptualisation is structured in three group of key concepts needed in the process of knowledge: bridge elements, materials, and defects.

Chapter 6 presents a discussion about the potential of Artificial Intelligence approaches to speed up the Scan-to-BrIM procedures, extracting information from the point cloud through an automatic or semi-automatic manner. A proposed methodology and preliminary results are presented.

Chapter 7 discusses possible applicative scenarios of Scan-to-BriM approaches and the possibilities of an InfraBIM approach, in which the single informative models are included and integrated into a larger infrastructure-system level model.

A conclusive chapter closes the work.

Chap. 2 The Circumetnea and its bridge artworks

In this chapter, the Circumetnea railway line is delved into, contextualizing it within its historical and territorial surroundings. By doing so, the vast potential of this railway line within the diverse and varied landscape of the Etna region is discussed. This region is known for its complex and multifaceted nature, with a rich history and culture that has shaped its landscape and people. The railway line, with its unique infrastructure and capabilities, has the potential to greatly benefit the region and its inhabitants, connecting different communities and fostering economic growth and development. As the case study is further explored, the various ways in which the railway line can contribute to the growth and well-being of the Etna area are highlighted.

2.1 Territorial framework

The Circumetnea railway was constructed between 1889 and 1895 to improve the economic activity of the agricultural and manufacturing industries in the area around Mount Etna. The construction of the Circumetnea (Figure 2), which was completed relatively quickly, made it possible to connect the port areas of Catania and Riposto to villages that were previously difficult to reach by other means of transportation. This facilitated the growth of manufacturing and agricultural trade in the region.

As the line's role as a means of transportation for productivity has been abandoned in favour of transportation by wheels, it is now mainly used by students and commuters. Additionally, the Circumetnea is a popular and picturesque way to discover the area around Mount Etna and the peculiarities of the villages it passes through, as it travels at a leisurely pace through towns, villages, and vineyards, in a succession of coastal, hilly, and mountainous landscapes framed by lava stone (Figure 3).

Running from Catania to Riposto, it passes through towns and villages located in the foothills surrounding Etna (Catania, 2014). Although being a single line, Circumetnea is divided into two branches, with an interchange point at the Randazzo station. The first stretch runs from Catania to Randazzo, and the second one runs from Randazzo to Riposto. The first section passes through the following towns in order: Catania, Misterbianco, Camporotondo Etneo, Belpasso, Paternò, Santa Maria di Licodia, Biancavilla, Adrano, Bronte, Maletto, and Randazzo. This part of the railway line has undergone significant changes over time, which have altered its course to better adapted to the needs of the growing towns it passes through, for example by building tunnels and by demolishing and reconstructing with reinforced concrete some of its historical bridges.

The second section of the rail line, on the other hand, still preserves most of its original design features, such as its historical masonry arch bridges and galleries.

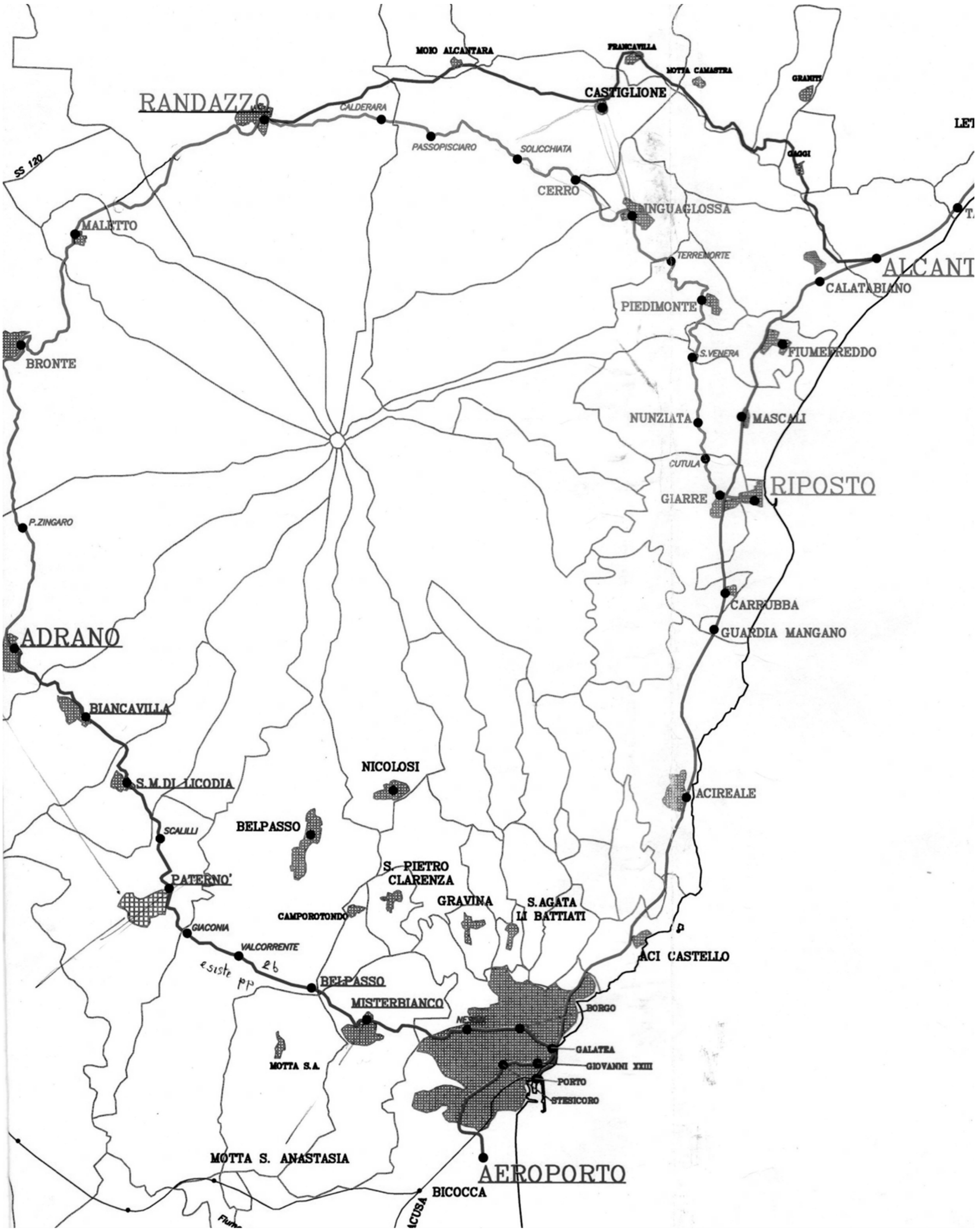


Figure 2 - The distribution of the line along the slopes of Mount Etna - Ref: Circumetnea archive

Figure 3 - One of the Circumetnea's lava stone bridges in Maletto (CT) – Ref: Circumetnea archive

Starting from Randazzo, this branch crosses Castiglione di Sicilia, Linguaglossa, Piedimonte Etneo, Mascali, Giarre and Riposto. Thus, the line constitutes the natural boundary of the Etna Park, framing its variety and its thousand landscape facets.

Rivers and streams are important factors to consider when designing and building railway bridges. The location and size of a river or stream must be taken into account to ensure the bridge is able to withstand the forces of the water and any potential flooding. The alignment of the railway line in relation to the river or stream is also an important consideration, as the bridge must be able to connect the two properly. In the case of the Circumetnea, the relationship with waterways is particularly significant. Many of the bridges along the Circumetnea exist precisely because of what were once watercourses and are, to this day, identified with them. For this reason, a focus on the hydrogeological aspect of the railway line is deemed necessary.

2.2 Hydrogeological framework

The territory served by the Circumetnea railway line is hydrologically part of the basins of the Simeto river and the Alcantara river (MATTM, 2023). The geological province within which the railway ring is located is identified with the Etna volcanic complex, bounded to the south by the Catania Plain and to the north by the Peloritani-Nebrodi ridge. In general, the railway track intersects several water courses during its development.

The **Misterbianco-Paternò** section of the railway is located within the Simeto River basin, which covers an area over 4186 km^2. The Simeto River is 116 kilometres long, originates downstream the town of Maniace and receives several tributaries along its way to the coast. The eastern part of the basin, which is mostly covered by volcanic rocks from Mount Etna, lacks a surface hydrographic network due to the high permeability of the volcanic substrate. This means that rainwater is easily absorbed and feeds into underground aquifers and sources.

In the Misterbianco-Paternò section, the railway track runs almost parallel to the SS 121 road and is in an urbanized and highly permeable area due to the volcanic substrate. It does not interfere with any significant watercourses.

From a geological, geomorphological, and hydrogeological perspective, this southern section of the Etna slope represents the stratigraphic boundary between sedimentary and volcanic rocks (Branca et al., 2011). The railway line in this section is about 11.5 kilometres long and runs underground from the Misterbianco station to Piano Tavola in the Belpasso area. It then rises to the surface and continues along the current route, with a section being widened. The track mainly crosses lava flows, with a few short stretches of flat terrain containing recent sandy-gravelly alluvial deposits and alluvial deposits. The entire section runs along gently sloping or flat slopes that are stable. According to the *Piano per l'Assetto Idrogeologico* (PAI)[1], there are no areas at risk of flooding in the areas crossed by the railway line, although there is a geomorphological risk area in the municipality of Camporotondo Etneo (Regione, 2004).

The **Adrano-Randazzo** section of the railway track is located north of the SS 120 road and does not intersect with any other significant stream.

The presence of a volcanic substrate causes rainwater to quickly infiltrate, and even if it were to flow preferentially along natural or artificial drainage channels, the high permeability of the substrate would not result in the formation of a stable network. This area contributes to the replenishment of underground aquifers and to the flow of the Simeto River, which is further downstream. Between the towns of Maletto and Randazzo, the track passes above the Gurrida wetland, into which the Flascio River flows. The track does not interfere with the Gurrida's catchment area and cannot affect the quality of the water that reaches it, as the area between the wetland and the railway track is also characterized by highly permeable lava. In the western sector, volcanic rocks are widespread and outcropping between Adrano and the eastern outskirts of Bronte. The morphology of this stretch suggests the presence of a series of inactive ancient landslides.

[1] Regional Hydrogeological land use plan

In the **Randazzo-Riposto** section, lie the main interferences between the railway track and the local hydrographic network.
The territory is in the Alcantara basin and the minor basins between Alcantara and Simeto. The Alcantara river basin covers the provinces of Catania and Messina, flows into the Ionian Sea and it is bordered to the southwest and west by the Simeto basin and to the north by some small basins. The right side of the basin is mainly covered by highly permeable lava flows from Mount Etna, which have filled the pre-existing hydrographic network on a sedimentary substrate. Only on the stream side of the right hydrographic side are there modest incisions on sedimentary soils. The territory on the left hydrographic side is entirely composed of sedimentary soils. At the top of the hydrographic basin, the Gurrida lake has formed, created by a lava flow that blocked the channel of the Flascio river (a tributary of the Alcantara). In general, the territory has hilly and mountainous morphologies; the right side of the basin is bordered to the south by the central crater, to the west by the watershed with the Simeto river basin, to the north by the Nebrodi and Peloritani mountain ranges and to the east by the mouth of the Alcantara. The minor basins between Simeto and Alcantara have an area of 636 square kilometres and are located on the eastern side of Sicily in the provinces of Messina and Catania. One of the main bodies of water in the area is the Fiumefreddo river, which springs from the north-eastern slopes of Etna, where, due to the high permeability of the volcanic rocks, the water infiltrates the ground and then resurfaces on the plain, thanks to the presence of an impermeable clay substrate. The hydrographic network is simple, with main and secondary streams of a torrential character, characterized by flows mainly in the winter and sometimes only in the case of particularly intense rainfall events and for several consecutive days. Just outside the town of Randazzo, the railway runs parallel to the SS 120, crossing the districts of Arena, Pianodario, and Monte la Guardia, without intercepting any bodies of water. However, there are some ditches that have often been transformed into paved roads after the urbanization of the area and that can sometimes generate paths for the flow of rainwater (e.g., Fosso Arena). Near the town of Passopisciaro, the Circumetnea railway intercepts an impluvium that originally supplied rainwater from the Etna massif to the Alcantara river. This incision runs through very permeable outcrops that prevent significant runoffs, and the network has often been interrupted by subsequent lava flows. Before reaching the town of Linguaglossa, the railway intercepts the Vallone Palmellato, which in some stretches has been transformed into a road for access to properties. Immediately after the town, on the other hand, is the Vallone del Bue. In this case, the channel is often partially or completely occupied by cultivated areas that interrupt its hydraulic continuity, or even transformed into sometimes paved roads. In addition, at the highest elevations, the succession of lava flows has often resulted in the disappearance or abrupt deviation of stretches of impluvia that therefore appear disconnected from the hydrographic network in the basin. In the stretch between Piedimonte and Riposto, the railway track crosses alluvial lands with an abundant presence of clastic fraction of volcanic origin, and therefore intercepts several torrential streams that can discharge significant flows during its course. Downstream of the town of Piedimonte, at the border with the municipality of Mascali,

the Vallone Santa Venera is intercepted, which is generated near Monte Stornello, flows downstream of the towns of Vena and Presa and then flows into the *Torrente delle Forche* in the stretch between the Catania-Messina motorway and the SS 114. Proceeding south, the railway track intercepts the *Corvo stream* near the town of Nunziata di Mascali. This area was affected in 1928 by lava flows that modified its orography and consequently also the surface hydrology suffered interruptions, changes in course and collapses of stretches. Subsequently, human expansion further modified the course of these water courses, even if of a torrential nature. This phenomenon is evident within the inhabited centre of Nunziata and in the vicinity of the Circumetnea railway where the Corvo Stream is first collapsed and then transformed into a street, then returning to its open course only further downstream. Always heading south, the route encounters the Nespole Stream and the Cutula Stream, both tributaries of the Vallonazzo Stream, which has become a connecting road with the tourist marine area. The Nespole Stream has a rather large section even if completely reduced in capacity by infesting vegetation. Instead, the Cutula Stream has been completely transformed into a paved road. The Macchia Stream, crossed by the existing railway line shortly before the Giarre stop, has been affected in the past by catastrophic flood events[2].

In general, the hydraulic system of the territory is negatively influenced by the high density of the resident population, the high urbanization, often characterized by a high percentage of illegal construction, and by productive settlements (agricultural and industrial) resulting from planning that has considered their negative impact on the territory.

[2] In particular, in March 1995, a rain event of significant intensity (about 376 mm of rain fell in 12 hours) caused significant damage and the loss of 6 human lives in the Ionian area.

2.3 Circumetnea: the past, the present and the future

2.3.1 The history of Circumetnea

The construction of a rapid transport system was a priority of the post-Unification of Italy economic policy to modernize and unify the country. The new Italian government at the time faced many challenges in building the national railway system.

One of these difficulties was the particularly complex orography of much of the Italian territory, which made it difficult and expensive to build tracks, tunnels, and bridges. While technical challenges in the construction of the infrastructures could be addressed through the application of contemporary technological and knowledge-based solutions, economic constraints remained a significant obstacle. The construction of railways required significant investment: therefore, driven by financial difficulties determined by the historical moment, the Italian government increasingly resorted to the credit and capacity offered by concessionaire companies and private industry.

The situation in Sicily, like the whole of the south, was even more complex, due both to the morphology of the land and the backwardness of the existing connections.

It became clear that railway communication still did not have an efficient, organic arrangement: a 1875 inquiry into the social and economic conditions of Sicily revealed a series of problems related to railways construction (Canciullo, 1986, 2018), highlighting the need to increase road and railway work, describing the difficult road conditions within the island. During the winter, the lack of roads, bridges, and banks for rivers that flooded the countryside led to the interruption of communication between one village and another, promoting lawlessness and often making the administration and execution of law unfeasible. Another problem was certainly the slow progress and the prevalence of private interests: the few kilometres of railway built had faulty tracks as because they did not serve either the general interests of industry and trade or the needs of the populations. The realization of railways in Sicily began in the late 19th century. The railways during the first twenty years after Italian unification were designed mainly for the sulphur trade, significantly increased from the middle of 19th century (Giuffrida, 1967).

The need to reduce costs and make the transport faster was not the only factor that accelerated the construction of this first railway network. The need to improve connections between towns within Sicily and the need to make the supply of essential goods to the coastal cities faster became an immediate priority in the politics of the dominant elites of the time.

The most representative case is that of Robert Trewhella, an English entrepreneur who since the Seventies promoted the realization and put into operation several railway sections: as a representative of the English company, the Narrow Gadge Railways Company Sicily of London, builds the Palermo-Corleone line to ensure that Palermo had a prompt supply of wheat, grain, and hay; between Raddusa and Agira, he built the Raddusa-Sant'Agostino tramway, a small steam tramway for the transport of minerals and miners between the sulphur mines of Sant'Agostino and the Raddusa station; in Catania he founded the Sicilian Company for Public Works and built the Circumetnea, which would connect the city of Catania and the main centres around Mount Etna. Trewhella, who seems to have come to Sicily following the Garibaldian expedition, reaches here a solid economic position and a considerable social prestige, owning several sulphur mines and refineries in the province of Catania and Caltanissetta, many citrus grove properties in the territory of Catania and some hotels, including the Excelsior in Palermo. The construction of secondary railways such as the Circumetnea was encouraged above all by the need to ensure a rapid and efficient supply of necessities (Sergi, 1993). In particular, the first proposals for this line were formulated at the end of the seventies on the proposal of some provincial councillors of Catania, who had suggested to build a narrow-gauge line[3] to connect towns and villages at the foot of Etna.

The Circumetnea railway (Figure 4) was planned to start in Catania and travel inward, encircling Mount Etna before returning to the coast and heading towards Giarre and Riposto. The route was intended to pass through a highly developed agricultural region in eastern Sicily, specializing in cereals, legumes, almonds, hazelnuts, chestnuts, citrus fruits, straw, hay, cotton, white stone, and pumice stone. The section from Randazzo to Giarre was an intensively cultivated wine-producing area and a centre for the lumber trade (Sessa, 1994).

Figure 4 - Vintage image of the Circumetnea - Ref: Circumetnea archive

[3] Narrow-gauge refers to a railway track that has a gauge (the distance between the rails) that is narrower than the standard gauge. Standard gauge is typically 4 feet 8.5 inches (1,435 mm), but narrow-gauge can be any gauge less than that. Narrow-gauge railways are often built in locations where the cost of building a standard-gauge railway would be prohibitive, such as mountainous terrain or tight curves.

During the 1880s, all these products were transported to Messina along the internal road that started in Piedimonte. Only the trade from Adrano, which was known as Adernò at the time, was routed to Catania. It was clear that Catania wanted to pursue the project to channel the trade of the inland of Sicily through its port (https://www.circumetnea.it/la-storia/) .
On May 25, 1882, a consortium was formed between the province and the municipalities of Catania interested in the construction and operation of the railway. The first stretch was approved that year, but the completion of the last section was strongly opposed, due to fears that the line could cause a shift in trade towards the maritime port of Riposto, which was growing at that time. However, the bourgeoisie of the time supported the mercantile aspirations of Catania, advocating for the railway and determinedly pushing the project forward.
Representatives of the board of directors initiated negotiations with several companies for the award of the construction contract. Trewhella himself signed the compromise in September 1885, obligating him to build the railway for a total length of 120 km and to complete the final project at his own expense within six months.
The following year, Trewhella accepted the contract for the works on behalf of the Sicilian Public Works Company, which had been formed to take over the concession for the line. However, the company had extremely limited capital, which was insufficient to cover the construction of the line, which the company had committed to completing within three years.
The works began after securing the necessary funds for their realization. To this end, Trewhella entered contact with an anonymous company in Brussels[4]. Trewhella remained on the board of directors of the Società Siciliana until 1900, when he was replaced by Adriano Colocci, who became the technical director and CEO of the company. The damage caused by World War II to the infrastructure and rolling stock of the Circumetnea Railway led to a critical situation in the period immediately following the end of the conflict. The difficulties of post-war reconstruction had negative impacts on the company and its ability to adequately respond to the renewed and increased mobility needs of the Etna centres. These events led the state to declare the concession to the Società Siciliana dei Lavori Pubblici as defunct, and directly assumed the operation of the railway through a Governmental Commission Management, which ensured its activity until 2011, the year in which the figure of the Government Commissioner was abolished, and the management was placed under the direction of the General Manager of Local Public Transport of the Ministry of Infrastructure and Transport.
Although the route ran on a lava soil that did not involve any major technical difficulties, the construction of the foundation works proceeded slowly due to the limited capital available to the company. As a result, several changes were made to the originally planned route, contrary to the directives of the consortium. The line was gradually opened to traffic starting in 1895 and completed in July 1898. The railway used steam power for traction, and it offered services for both goods and passengers.

[4]La Caisse de subventions et annuites gouvernementales, provinciales et communales

At the time, there were approximately ten steam locomotives in operation, and the rolling stock included around 40 passenger carriages, 170 freight cars, and 10 service cars. During the early years of its operation, the railway faced many operational challenges and struggled to attract commercial traffic in the region. Due to the existing steep slopes, there were considerable difficulties for the transit of convoys. The train timetable, imposed by the Royal Inspectorate, obliged the Company to use a predetermined number of trains higher than that required by traffic, completely absent in some sections. The wine trade, due to the high tariffs and the slowness of the transit of rail trains, continued to favour road transport. From the opening until the end of the nineteenth century the line recorded very modest profits. The railway tracks used rails weighing 25 kg/m with wooden cross ties. The maximum speed was 27 km/h and the commercial speed reached, on the entire route, about 20 km/h.
About thirty years after its opening, a 10 km stretch was added to the original line, allowing a connection to Castiglione di Sicilia from Randazzo. This stretch, built between 1925 and 1926 and put into service in March 1927, was however decommissioned in the 1960s.
One of the most significant changes to the historical route of the Circumetnea Railway was the Paternò-Adrano section. The modernization works for this section, initiated in the 1980s, included some straightening of the route and partial undergrounding through the Adrano, Santa Maria di Licodia, and Biancavilla tunnels. The modernization was designed to allow for the future electrification of the current diesel-powered line and the transformation of the track gauge from narrow to standard.
Over time, the railway has undergone further minor route changes, some of which were due to interruptions caused by lava flows from Mount Etna: in 1911 (Linguaglossa-Randazzo eruption), 1923 (Linguaglossa eruption), 1928 (Mascali eruption), and 1981 (Randazzo eruption).
Since the 1980s, the Circumetnea Railway has launched a program to improve and modernize its railway infrastructure and create a modern alternative transportation system to the car, focusing on the narrow gauge and diesel-powered line. As part of this program, a first section from Borgo station to the port of Catania was completed and opened for service in 1999. To expand this section, work has already begun on the urban sections of Catania Borgo-Nesima, Giovanni XXIII-Stesicoro, and Galatea-Giovanni XXIII, and work will soon commence on the Stesicoro-Airport and Nesima-Misterbianco sections.

2.3.2 The Circumetnea today and in the future

Figure 5 - The Circumetnea train along the lava flows near Bronte - Ref: Circumetnea archive.

Today, the Circumetnea plays an active role in local transportation and tourism. The line is mainly used by commuters and the transport service offered is targeted towards connecting the main settlements on the slopes of Mount Etna to the city of Catania. The service is provided through a 110 km narrow gauge diesel-powered railway, a series of buses that complement and supplement the railway service within urban centres, and a metropolitan line, which is electrified and standard gauge, within the urban area of Catania and is currently being expanded and integrated with the suburban railway line. Circumetnea helps to reduce traffic congestion and air pollution in the Etnean area and constitutes an important model for "green" travel as a low-emission and low-impact form of transportation.

Its value as a heritage is beginning to be appreciated and exploited as a form of slow mobility and sustainable tourism (Cannizzaro & Corinto, n.d.; Petino et al., 2018) (Figure 5). While it is not primarily a tourist train, there are occasionally organized tourist rides with vintage railcars. In recognition of the value of its landscape, FCE (Ferrovia Circumetnea), the company responsible for the management of the railway, offers four themed itineraries based on wine touring, cycling, a cultural itinerary, and an opportunity to explore the region on a historic train that travels along the slopes of Mount Etna, passing through small towns and truly evocative lava landscapes. The entire journey takes more than 3 hours and allows for stops to visit various villages.

2.3.3 *Future perspectives*

There are many objectives of the major Ferrovia Circumetnea project in Catania: from reducing road congestion, CO2 emissions, noise pollution and road accidents to promoting intermodal transport and improving the railway network.
The Ferrovia Circumetnea in Catania is the only major project in Italy in the first-round of 2019 decisions by the European Commission on interventions over EUR 75 million. A total package of 25 major projects to support health, energy, environment, research, and transport. The financing approved by Brussels (Decision CE 1705/2019) for the project to extend the metropolitan section of the Circumetnea. The last 6.8 kilometres stretch (from Stesicoro to Fontanarossa Airport) will be built entirely underground. Work began in 2017: currently five meters are being excavated per day with the mechanical mole TBM, nicknamed "Agata" in honor of the city's patron saint. In the light of the above, there is a significant potential for the Circumetnea to be a tourist attraction and a valuable asset for both local community and tourists.

2.4 The works of the Circumetnea

The proper functioning of the railway infrastructure requires not only the railway tracks and trains, but also the consideration of other elements such as works of art and stations, including all the buildings. Along the line, there are six tunnels (excluding the one under the urban area of Catania), 11 arched viaducts, 11 metal beam bridges, many bridges over canals, underpasses, aqueducts, and overpasses. On the Castiglione variant, there were 8 tunnels and 14 bridges and viaducts (Figure 6).

2.4.1 *Circumetnea bridges*

The bridges on the railway line were constructed using techniques from the 19th century manual for building railway bridges, but the use of local materials such as volcanic stone makes them stand out as unique in the regional landscape.
The existing bridges on the railway line are of various architectural and structural types, including arched bridges in masonry, metal beam bridges, and pre-stressed reinforced concrete bridges. The use of local materials, such as volcanic stone, not only gives these bridges a unique and distinctive character, but also emphasizes the importance of sustainable construction practices that incorporate local resources. The bridges on this line also demonstrate the evolution of railway bridge construction techniques over time, reflecting the historical period in which they were built. The bridges of this railway line are not only iconic landmarks but also an important representation of the region's history and culture.

Figure 6 – Top: Identification of bridges along the Riposto-Castiglione section; bottom: some of the masonry bridge along the Circumetnea rail line

The bridges on the railway line have the following architectural/structural types:

Masonry arched bridges: This type of bridge, widely used with moderate spans (less than 12 meters) for both single and multiple span bridges, blends well with the environment due to the use of local volcanic stone.

Metal beam bridges: Metal structures, peculiar to the historical period in which the railway was built, are widely used both in small bridges to cross local roads (L= 6÷8 meters) and in some larger bridges where a metal beam lattice type with an upper deck is used.

Pre-stressed reinforced concrete bridges: The type of pre-stressed reinforced concrete bridges with double T-beam and cast-in-place slab is applied to cross some local roads, sometimes derived from human transformation of streambeds.

As previously illustrated, the research conducted focuses on the **arched masonry bridges** along the line. These bridges are characterized by heterogeneous typologies, in terms of number of arches, materials, and geometry. From the material and construction perspective, these structures have the same characteristics, weighted according to size. The vaults, made of volcanic stone or brick masonry, have full round, or variously lowered round arches. There are two diagonal bridges, both with vaults in brick masonry; this is because the construction of diagonal bridges in volcanic stone masonry would have certainly required a stereotomic study and application incompatible with the financial resources and estimated construction times for the railway line. The springings of the arches are made of ordinary-grained cut stone.

The spandrel walls are made of ordinary rubble masonry with regular or mosaic facing and with cut stone cantonals worked with ordinary grain; in the piers, the facing is made of rubble masonry worked in horizontal rows. The pediments, the walkway walls and the return walls are in masonry with both mosaic and regular facing.

For the purposes of the research, a classification of the masonry bridges under study has been carried out. A first distinction has been made from the material perspective: bridges with arches in brick masonry (**Type 1**) and bridges with arches in volcanic stone masonry (**Type 2**).

A second level of classification was made on the type of arches, which, in the case of the bridges along the Circumetnea, can be full-height (**A1**) or lowered (**A2**). A third level of classification was made on the bridge type: small bridge (**P1**) with a span ≤ 3 meters, bridge (**P2**) with a span > 3 meters, viaduct (**P3**) with multiple spans. It was decided to include in the classification whether the bridge was straight (**C0**) or curved (**C1**). Finally, it was deemed necessary, given the presence of two diagonal bridges, to make an additional specification on this feature, assigning the letter **D0** to non-diagonal bridges and **D1** to diagonal ones (Figure 7).

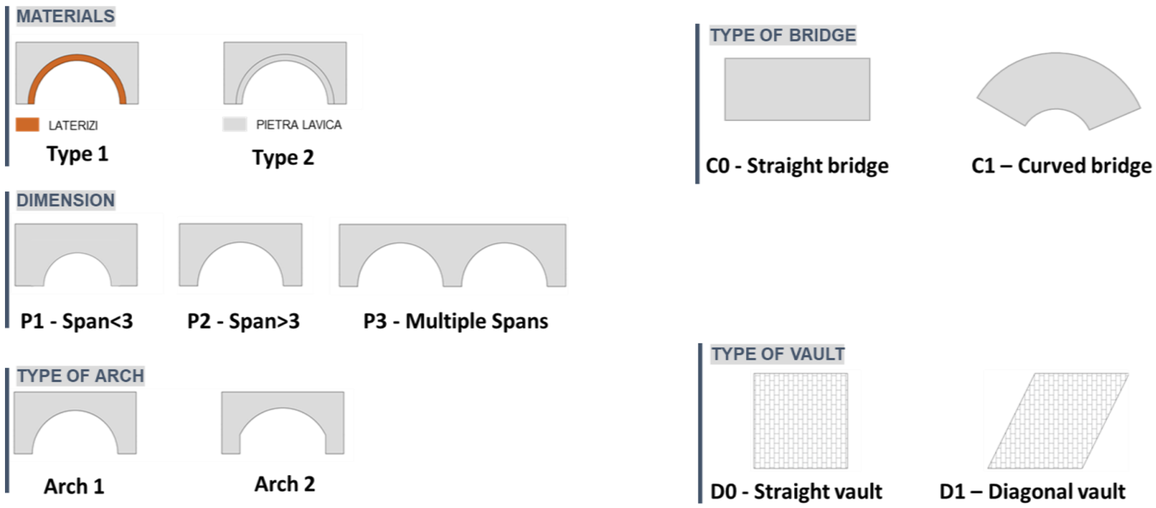


Figure 7 – Classification of the bridges along Circumetnea

Next, a detailed list of the bridges found along the analysed railway section:

Type 1 (T1) Bridges with brick arches

T1. A1 Bridges with full-height arches

T1. A1. P2 Bridges

- A bridge (span 6 m) near Giarre;
- A bridge with a span of 5 meters not far from Piedimonte Etneo;

T1. A1. P3 Viaducts

- A curved viaduct with four spans, two of 6 meters, one of 10 and one of 5 m near Giarre;
- A viaduct with three spans of 6 meters crossing the Cutula stream;
- A viaduct with 4 spans of 12 meters each over the Santa Venera stream;
- A viaduct with three spans crossing the current Via Noci, once the Carmine stream, now protected;
- The bridge with three spans, one of 10 meters and the other two of 6 meters, crossing the Chiuse del Signore stream;

T1. A2 Bridges with lowered arches

T1. A2. P1. D Small bridges

- a small underpass with three meters of span located near Mascali;

T1. A2. P2. D Bridges

- An oblique span 4,28 and straight span 4, is located in the town of Linguaglossa. The peculiarity of these structures is the treatment of the diagonal vault element.

T1. A2. P3 Viaducts

- A bridge with two spans of 8 meters each over the Birbo stream, now tombed;
- A bridge with two spans of 8 meters each over the Chiuse del Signore stream;

Type 2 (T2) Bridges with stone arch

T2. A1 Bridges with full-height arches

T2. A1. P1. Small bridges

- A small bridge 3 meters at the entrance of Linguaglossa;
- A small bridge 3 meters in Solicchiata;
- A small bridge 3 meters in Bronte;
- A small bridge 3 meters in Bronte;

T2. A1. P2. Bridges

- A bridge with a span of 10 meters near the municipality of Giarre;
- A bridge with a span of 4 meters over the Costa Stream;

T2. A1. P3 Viaducts

- A 10-meter, three-span viaduct near the municipality of Mascali that crosses the present-day Viale Kennedy, once called Vallone Croce, now "tombed";
- A curved viaduct with four arches of 8 meters each in Maletto;
- A curved viaduct with four arches of 8 meters each in Maletto;

The proposed subdivision is maintained throughout the entire manuscript. In the following chapters (Chapter 3 and Chapter 4), the characteristics of the bridges under investigation will be further discussed, both with a focus on the bibliographical-historical research and the outcome of the digital survey.

Chap. 3 Knowledge: archival research and cataloguing

As per the Italian guidelines for monitoring and management of existing bridges (MIT, 2020), knowledge plays a crucial role in comprehensively understanding the behaviour of structures. This principle also applies to the historical aspect of bridges, encompassing any historical documents that recount events related to their construction. Analysing the original project is of crucial importance as it aids in grasping the design concept and provides essential insights into potential design errors, gaps, and the reliability of simplified calculations used at that time for structural modeling and verification.

In this chapter, we present the findings of our archival research conducted at the State Archive of Catania and the Archive of the Circumetnea. The consulted documentation mainly comprised project drawings and related documents, which enabled us to delve into the motivations behind the projects and any subsequent modifications. Through an examination of the metric calculations accompanying the project drawings, it was possible to glean additional information regarding the materials and construction techniques employed.

3.1 Archival research

The research and acquisition of the documentary material regarding Circumetnea and its bridges took place in two different phases, interspersed by the period of closure during the COVID-19 pandemic. The research process began by consulting the documentation preserved at the State Archives of Catania. Subsequently, access was granted to the additional materials stored at the archive of the Circumetnea management. This examination of the historical archival materials provided invaluable insights into the rich past of Circumetnea, shedding light on its artifacts and historical significance. The reports accompanying some of the design papers made it possible to investigate unprecedented construction and technological aspects of the works supporting the railway line.

Through cross-referencing the information gathered from archives research, historical cartography, and web maps, the historical documentation was matched to the artefacts under examination. In particular, the overlapping with the Istituto Geografico Militare (IGM) 25,000 and the cartography of the catchment areas proved to be essential since some artefacts, in the historical documentation, are identified exclusively by their watercourse, district, or kilometric progression (no longer consistent due to the numerous variants made to the line). The collected information was subsequently employed to develop a cataloguing template, which was employed to categorize the gathered documentation and the identified bridges of interest within the territorial area.

3.1.1 State Archive research

Figure 8 - One of the documents found in the State Archive

The documentary research at the State Archive in Catania was carried out towards the end of 2019. The State Archive serves as a repository for significant historical documents and materials pertaining to the region of Sicily, including the archives of the "Consorzio della Ferrovia Circumetnea." These documents (Figure) were transferred to the State Archive in 1984 under the authorization of the Archival Superintendence. They are stored in room no. 24, shelf no. 3, boxes no. 13 to no. 24.

The archival material is organized into seven series, comprising a total of 192 folders:

1. Documents concerning the establishment and general matters of the Consorzio;
2. Projects and related documents for the three railway sections;
3. Accounting records;
4. Disputes;
5. Personnel documents;
6. Miscellaneous documents;
7. Protocols.

During the research, the focus was primarily on the second series, and the selection of envelopes to be examined was based on the information provided in the inventory. From the consulted material, digital copies of plans, longitudinal and transverse profiles of the entire railway line, as well as designs for bridges, tunnels, tollbooths, depots, and stations along with their respective cost estimates were obtained.

While the research encompassed various aspects of the railway line and involved acquiring a substantial amount of documentation on the structures associated with the railway, the specific focus was on masonry bridges. The bridge projects along the Circumetnea are divided into three sections: the first section from Riposto to Randazzo, the second section from Randazzo to Adrano, and the third section from Adrano to Catania. The bridge projects are represented in their definitive form, considering the three levels of design - preliminary, definitive, and executive.

3.1.2 Circumetnea Archive research

The research conducted at the Circumetnea Archive took place in 2021. The archive mainly preserves documents related to the management of the railway line from a financial point of view. Nevertheless, it was possible to find the projects of some bridges (Figure 9) as well as a large amount of material regarding the buildings serving the railway line.

Figure 9 - Some rolled documents found in the Circumetnea Archive

3.1.3 Results

This paragraph describes the results of the historical and archival research conducted during the cognitive phase of the case study under investigation.

The acquisition work of the documentation is preparatory for the future digitization project that the FCE intends to undertake in collaboration with the University of Catania. To facilitate easy access to the retrieved documentary material from the two archives, cataloguing sheets have been specifically created. These sheets are a combination of the catalogue proposed by the Central Institute for Cataloging and Documentation ICCD (http://www.iccd.beniculturali.it/) and the inventory sheets for existing bridges proposed by MIT.

The cataloguing sheets have been prepared in Italian as they are intended for use by the institution managing the Circumetnea. In the case of materials from the State Archive, it was possible to capture images of the documents, as scanning them required authorizations that were not available. The captured images were rectified to remove camera distortions and merged to create high-quality copies for reading and consultation.

The structure of the sheets is as follows: the first part includes the name of the compiler, the date, and a unique code for identification. This is followed by the document's location (city, country), specifying whether it was obtained from the State Archive or the Circumetnea Archive, along with the name of the fonds or document collection. The "Subject" section provides the original title of the document, the project's scale (preliminary, definitive, or executive), detailed content with relative scale of representation (if provided), the document's author (if stated), and any signatures and stamps present. The "Object" section refers to the bridge that is certainly or presumably represented in the document. Finally, the technical data section includes information on the medium used (type of paper, type of pen etc.).

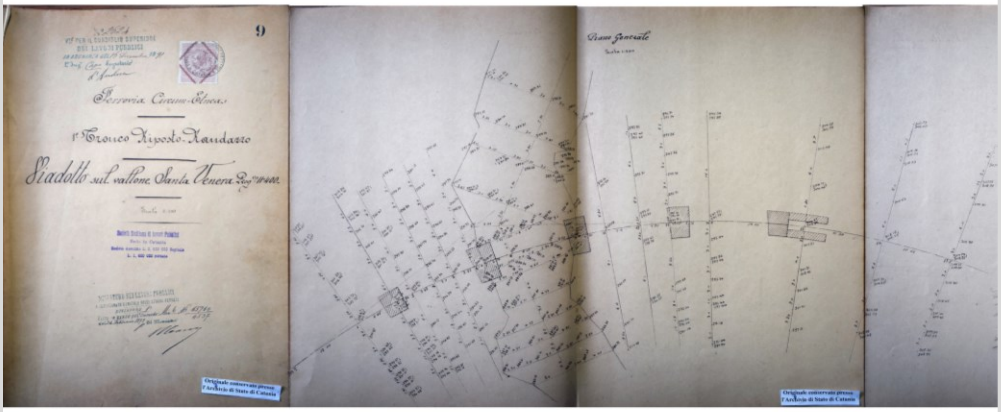
Additionally, the paragraph includes photographic reproductions of the documents, displayed in A4 groups to ensure legibility, and provide a clear representation of the content. At the end of this paragraph, you will find sample sheets, along with a preliminary report containing considerations derived from the comparative analysis of the files, documentation, and case studies under examination.

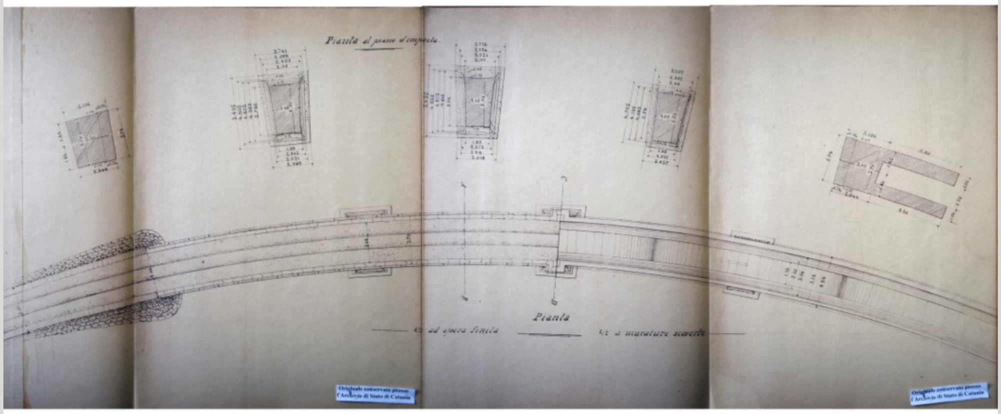
COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH01**
DATA	31/12/2022	

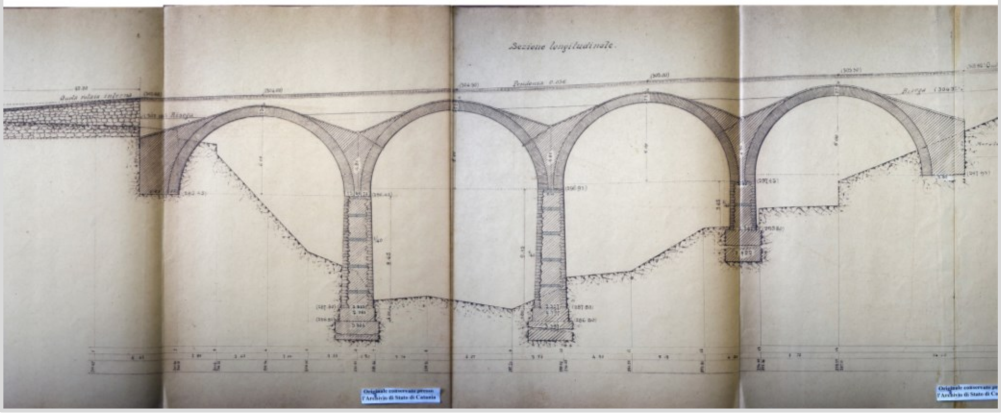
LOCALIZZAZIONE DOCUMENTO	
COMUNE	Catania
PROVINCIA	Catania
STATO	Italia
COLLOCAZIONE SPECIFICA	
LOCALIZZAZIONE	Archivio di Stato di Catania
INDIRIZZO	Via Vittorio Emanuele II, 156, 95131 Catania CT
DENOMINAZIONE RACCOLTA	Fondo Circumetnea
OGGETTO	
TITOLO DOCUMENTO	1° tronco Riposto-Randazzo Viadotto sul Vallone Santa Venera Prog.va 11.400 Scala 1:100
TIPOLOGIA	Esecutivo
CONTENUTO DEL DOCUMENTO	Piano Generale (1:200); Pianta al piano di imposta (1:100 ndr); Pianta 1/2 ad opera finita e 1/2 a murature scoperte (1:100 ndr); Sezione longitudinale (1:100 ndr); Sezione CD (1:100 ndr); Sezione AB (1:100 ndr); Prospetto a valle (1:100 ndr); Dettali della nicchia, del parapetto, del coronamento e dello smusso dei muri di testa (nd)
AUTORE ELABORATO	-
FIRME E TIMBRI PRESENTI	Pouillaude - Ingegnere Direttore tecnico R. Trewhella - Direttore della Società Siciliana dei Lavori Pubblici Timbro del Ministero dei Lavori Pubblici
SOGGETO	
DENOMINAZIONE	Viadotto Santa Venera
ID_SCHEDA	RIL10
DATI TECNICI	
MATERIA E TECNICA	China nera su lucido
TIPO DI FOGLIO	Plico ripiegato in A4
DIMENSIONI	27,9 cm x 441 cm
NOTE	Visto in senso del Decreto Ministeriale No 635760/4537 del 24 Febbraio 1892

COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH01**
DATA	31/12/2022	

DOCUMENTO

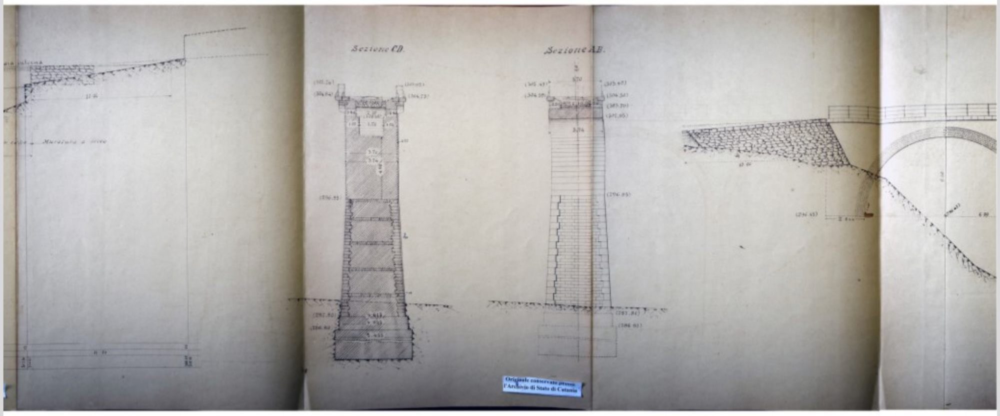


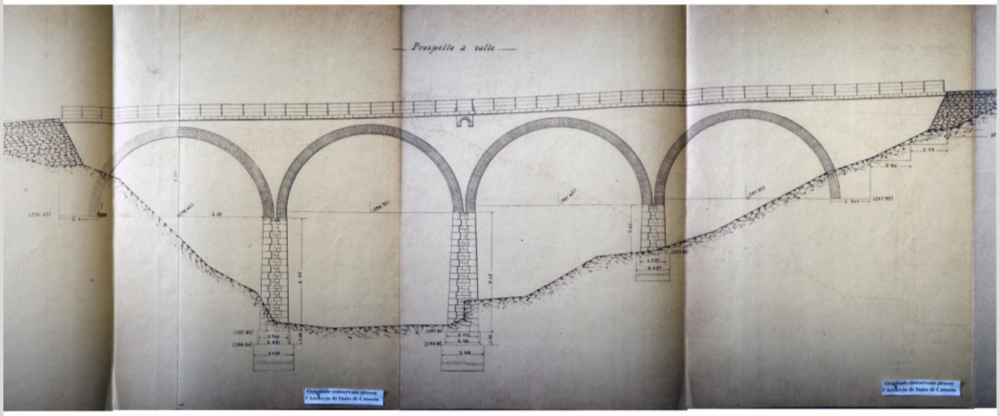


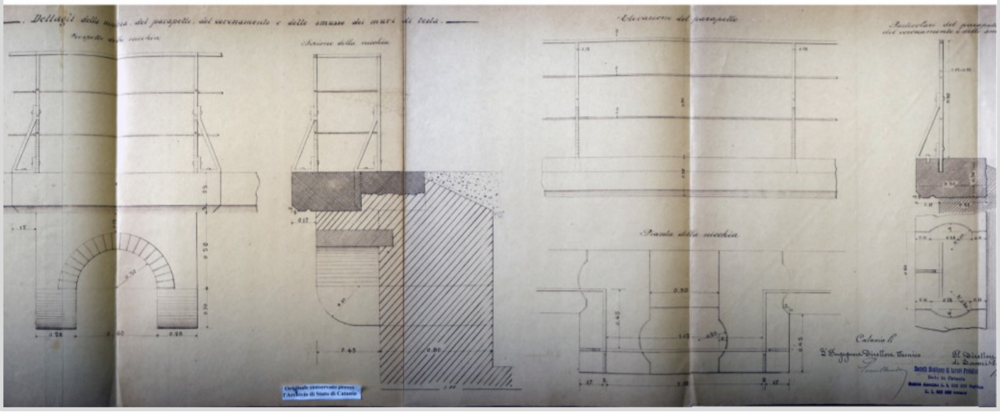


COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH01**
DATA	31/12/2022	

DOCUMENTO





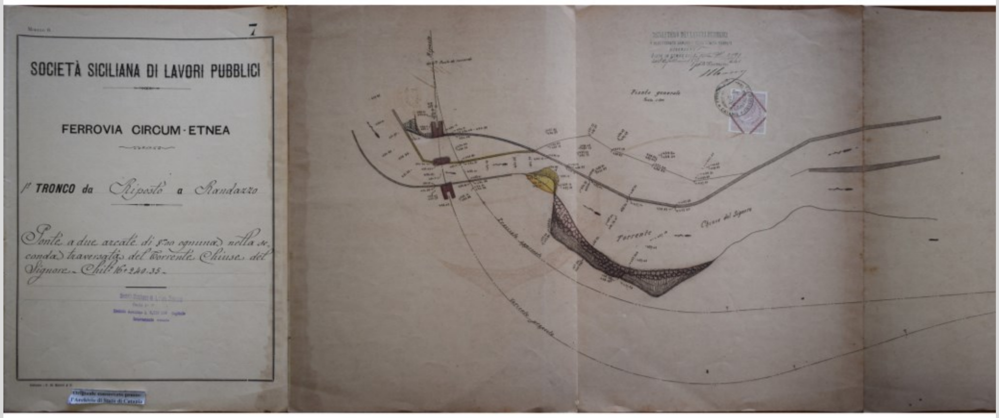


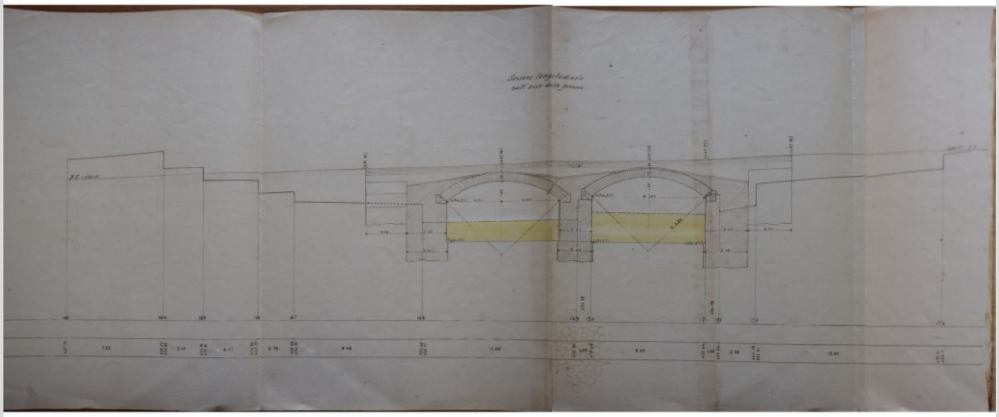
COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH02**
DATA	31/12/2022	

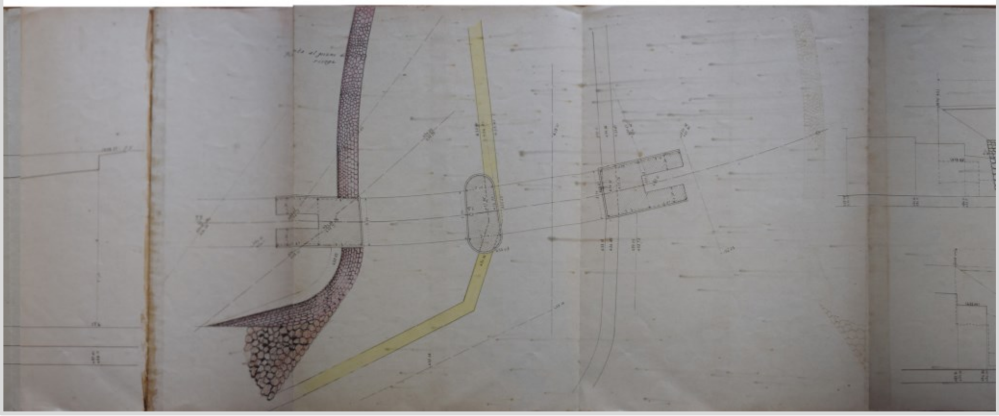
LOCALIZZAZIONE DOCUMENTO	
COMUNE	Catania
PROVINCIA	Catania
STATO	Italia
COLLOCAZIONE SPECIFICA	
LOCALIZZAZIONE	Archivio di Stato di Catania
INDIRIZZO	Via Vittorio Emanuele II, 156, 95131 Catania CT
DENOMINAZIONE RACCOLTA	Fondo Circumetnea
OGGETTO	
TITOLO DOCUMENTO	1° tronco Riposto-Randazzo Ponte a due arcate di 8 metri ognuna nella seconda traversata del Torrente Chiuse del Signore. Chil-o 16+240,35
TIPOLOGIA	Esecutivo
CONTENUTO DEL DOCUMENTO	Piano Generale (1:500); Sezione longitudinale sull'asse della ferrovia; Pianta al piano di risega; Prospetto a valle; Prospetto a monte; Sezione trasversale (1:100); Sezione dei muri d'accompagnamento (1:50); Profilo della deviazione (1:200)
AUTORE ELABORATO	-
FIRME E TIMBRI PRESENTI	R. Trewhella - Direttore della Società Siciliana dei Lavori Pubblici
SOGGETO	
DENOMINAZIONE	Viadotto in muratura sul torrente Chiuse del Signore
ID_SCHEDA	RIL15
DATI TECNICI	
MATERIA E TECNICA	China, matita e matite colorate su carta
TIPO DI FOGLIO	Plico ripiegato in A4
DIMENSIONI	27,9 cm x 336 cm
NOTE	

COMPILATORE	Raissa Garozzo	ID SCHEDA __ARCH02
DATA	31/12/2022	

DOCUMENTO

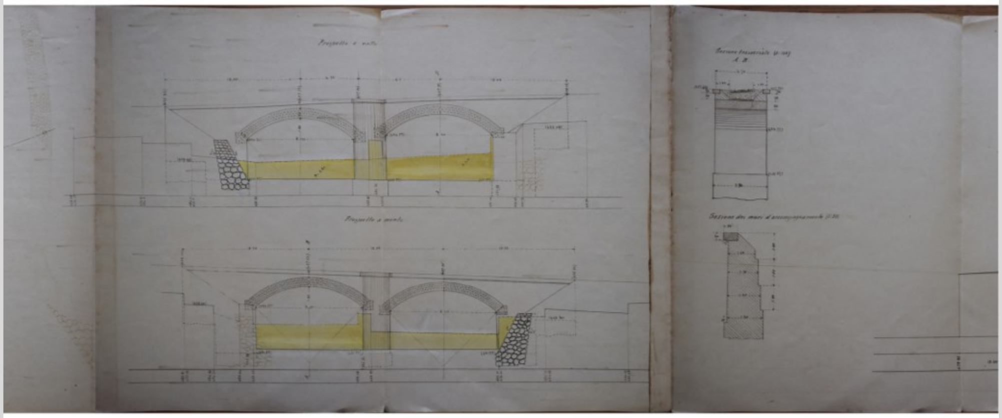


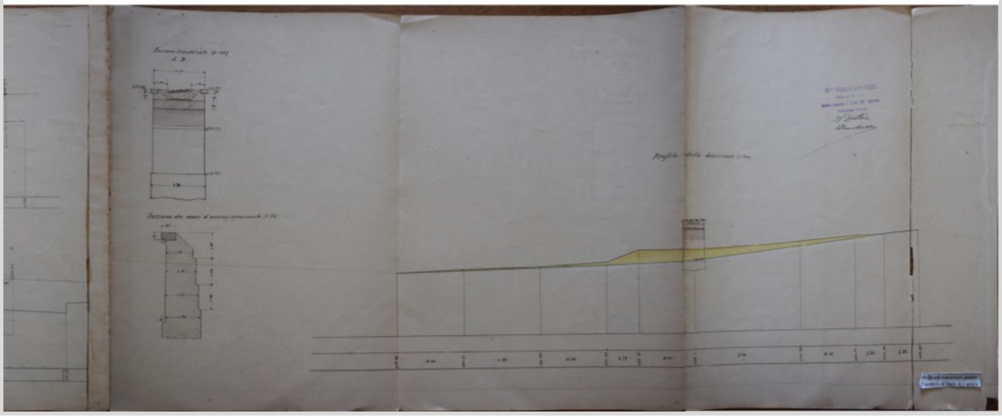




COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH02**
DATA	31/12/2022	

DOCUMENTO



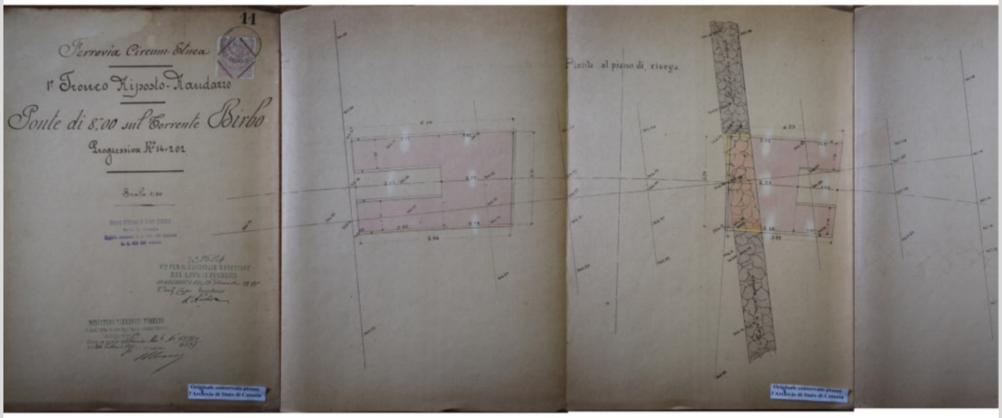


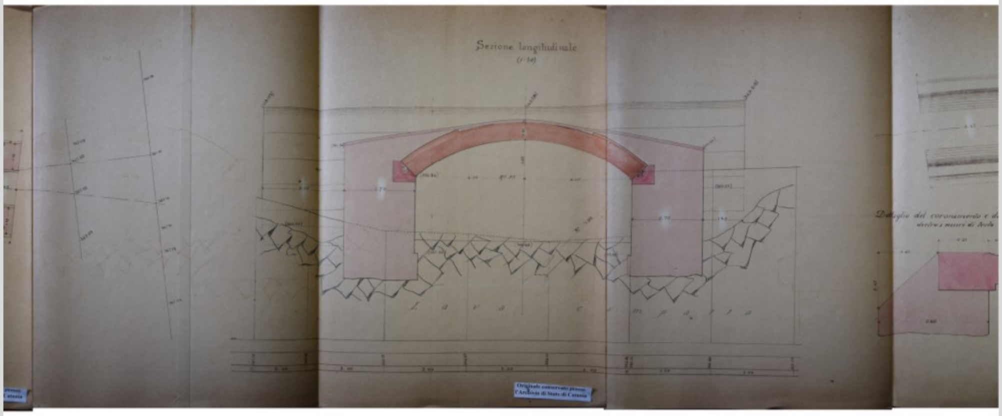
COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH03**
DATA	31/12/2022	

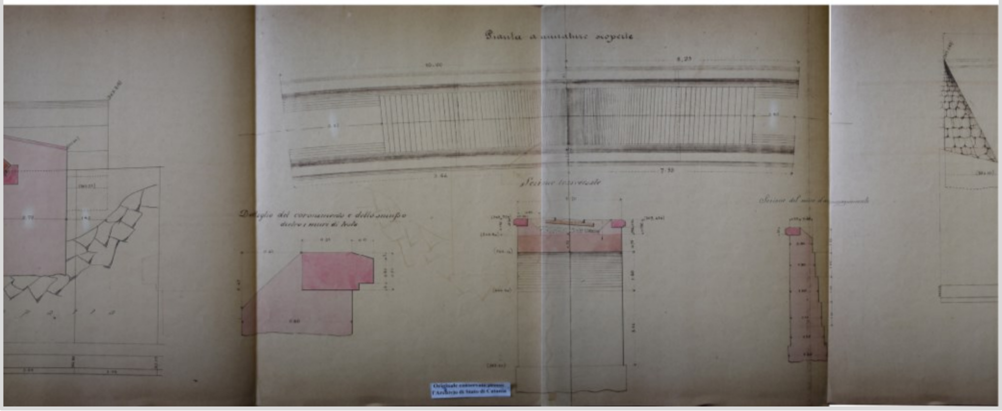
LOCALIZZAZIONE DOCUMENTO	
COMUNE	Catania
PROVINCIA	Catania
STATO	Italia
COLLOCAZIONE SPECIFICA	
LOCALIZZAZIONE	Archivio di Stato di Catania
INDIRIZZO	Via Vittorio Emanuele II, 156, 95131 Catania CT
DENOMINAZIONE RACCOLTA	Fondo Circumetnea
OGGETTO	
TITOLO DOCUMENTO	1° tronco Riposto-Randazzo Ponte di 8,00 m sul Torrente Birbo Progressiva K 14+202 Scala 1:50
TIPOLOGIA	Esecutivo
CONTENUTO DEL DOCUMENTO	Pianta al piano di risega; Sezione longitudinale (1:50); Pianta a murature scoperte; Dettaglio del coronamento e dello smusso dietro i muri di testa; Sezione trasversale; Sezione del muro di accompagnamento; Prospetto a valle; Progetto a monte
AUTORE ELABORATO	-
FIRME E TIMBRI PRESENTI	Pouillaude - Ingegnere Direttore tecnico R. Trewhella - Direttore della Società Siciliana dei Lavori Pubblici Timbro del Ministero dei Lavori Pubblici Visto per il consiglio superiore dei Lavori Pubblici
SOGGETO	
DENOMINAZIONE	Viadotto in muratura sul Torrente Birbo
ID_SCHEDA	RIL13
DATI TECNICI	
MATERIA E TECNICA	China, matita e acquarelli su carta
TIPO DI FOGLIO	Plico ripiegato in A4
DIMENSIONI	27,9 cm x 273 cm

COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH03**
DATA	31/12/2022	

DOCUMENTO

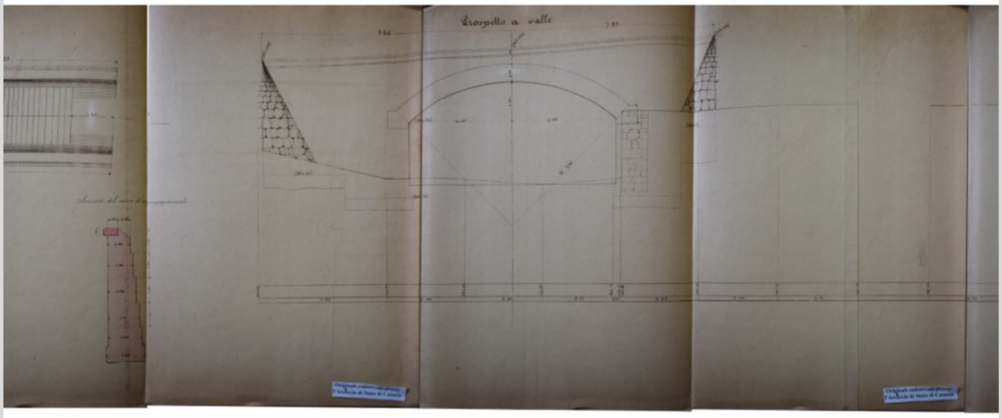


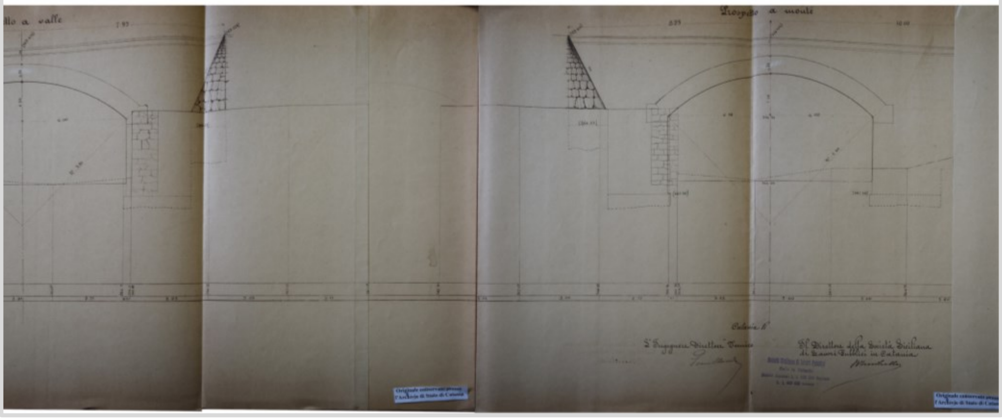




COMPILATORE	Raissa Garozzo	ID SCHEDA __ARCH03
DATA	31/12/2022	

DOCUMENTO



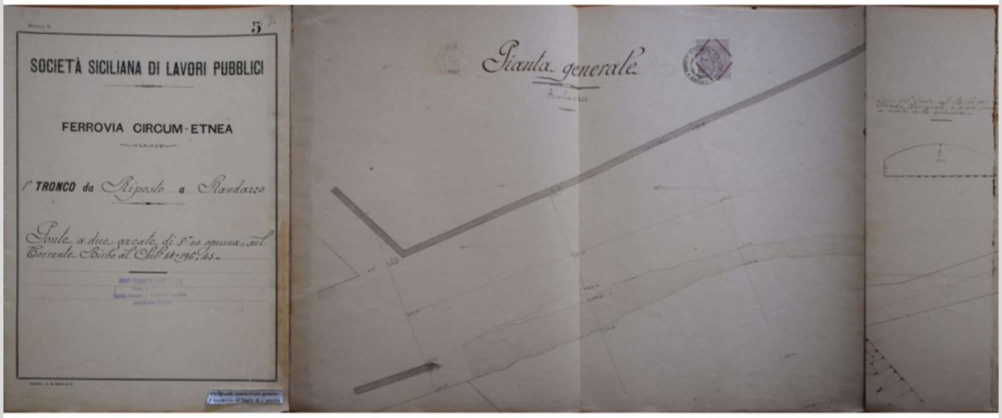


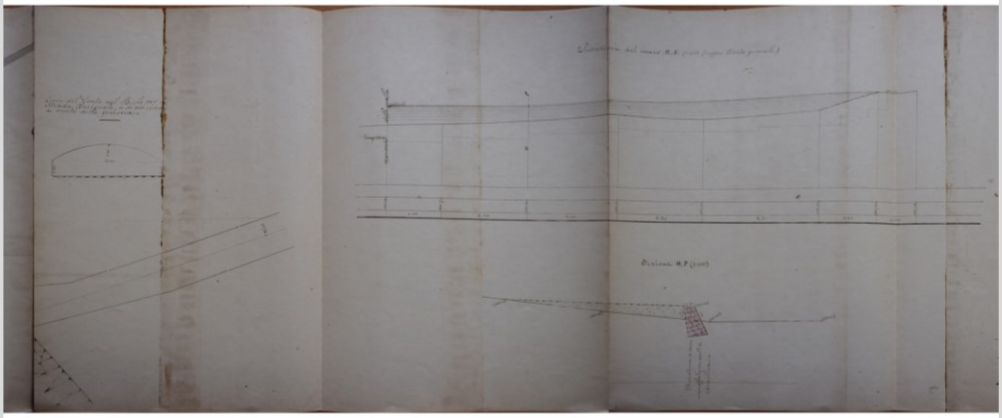
COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH04**
DATA	31/12/2022	

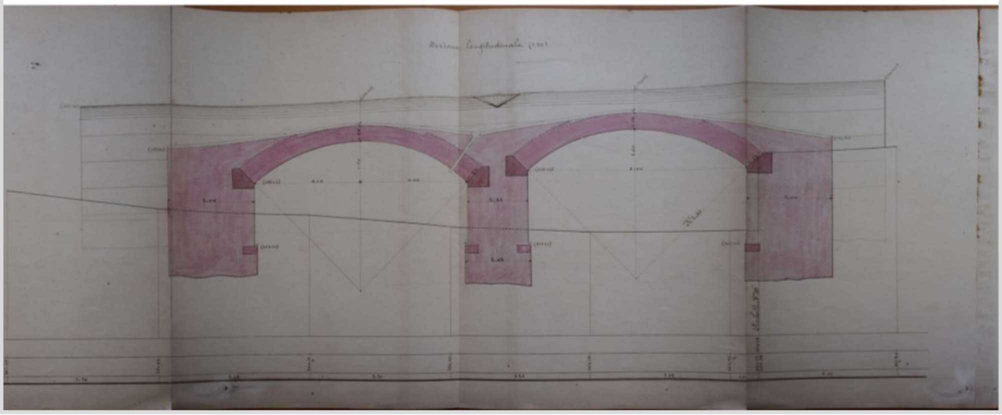
LOCALIZZAZIONE DOCUMENTO	
COMUNE	Catania
PROVINCIA	Catania
STATO	Italia
COLLOCAZIONE SPECIFICA	
LOCALIZZAZIONE	Archivio di Stato di Catania
INDIRIZZO	Via Vittorio Emanuele II, 156, 95131 Catania CT
DENOMINAZIONE RACCOLTA	Fondo Circumetnea
OGGETTO	
TITOLO DOCUMENTO	1° tronco Riposto-Randazzo Ponte a due arcate di 8,00 m ognuna sul Torrente Birbo al Chil.o 14+196,45
TIPOLOGIA	Esecutivo
CONTENUTO DEL DOCUMENTO	Pianta generale (1:100); Luce del Ponte sul Birbo per la Strada Nazionale, a m. 200 circa a monte della ferrovia; Elevazione del muro MN (1:100); Sezione OP (1:100); Sezione longitudinale (1:50); Pianta della risega (1:50); Prospetto a monte (1:100); Prospetto a valle (1:100); Pianta a murature scoperte (1:100); Sezione AB (1:50); Sezione CD (1:50); Sezione EF (1:50)
AUTORE ELABORATO	-
FIRME E TIMBRI PRESENTI	R. Trewhella - Direttore della Società Siciliana dei Lavori Pubblici
SOGGETO	
DENOMINAZIONE	Viadotto in muratura sul Torrente Birbo
ID_SCHEDA	RIL13
DATI TECNICI	
MATERIA E TECNICA	China, matita e acquarelli su carta
TIPO DI FOGLIO	Plico ripiegato in A4
DIMENSIONI	27,9 cm x 278 cm

COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH04**
DATA	31/12/2022	

DOCUMENTO

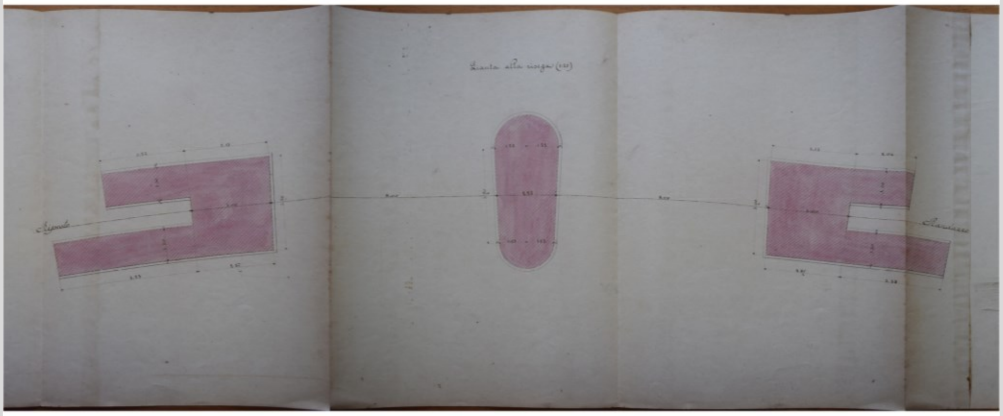


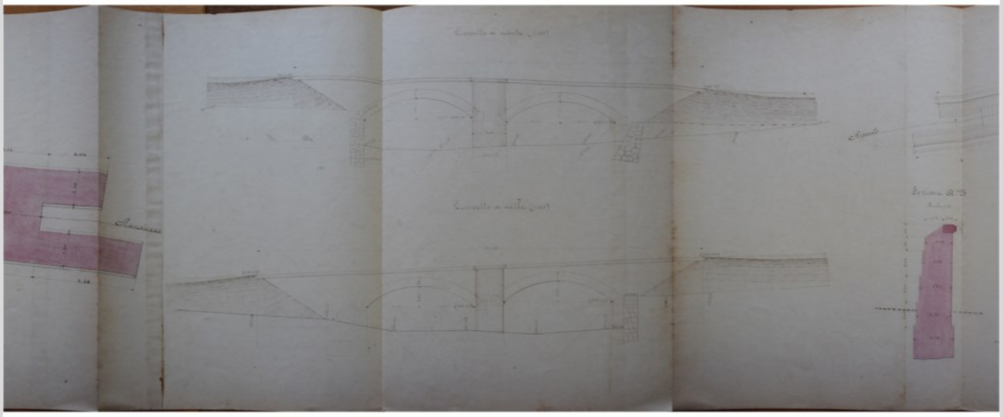


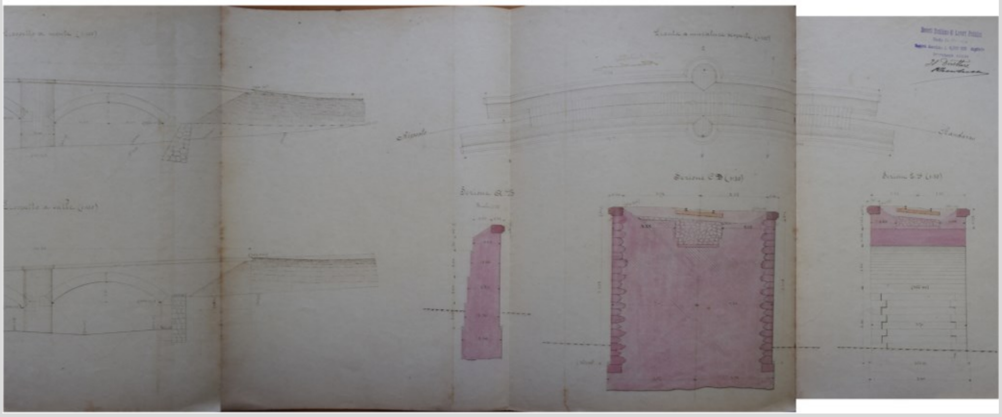


COMPILATORE	Raissa Garozzo	ID SCHEDA __ARCH04
DATA	31/12/2022	

DOCUMENTO



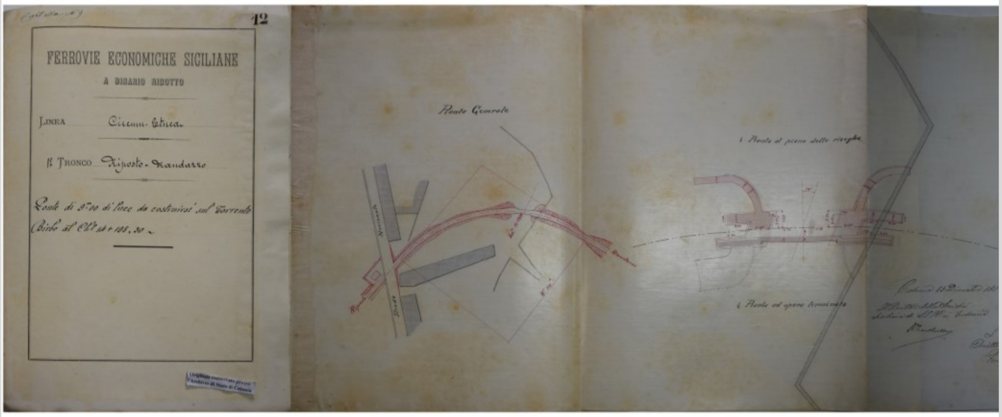


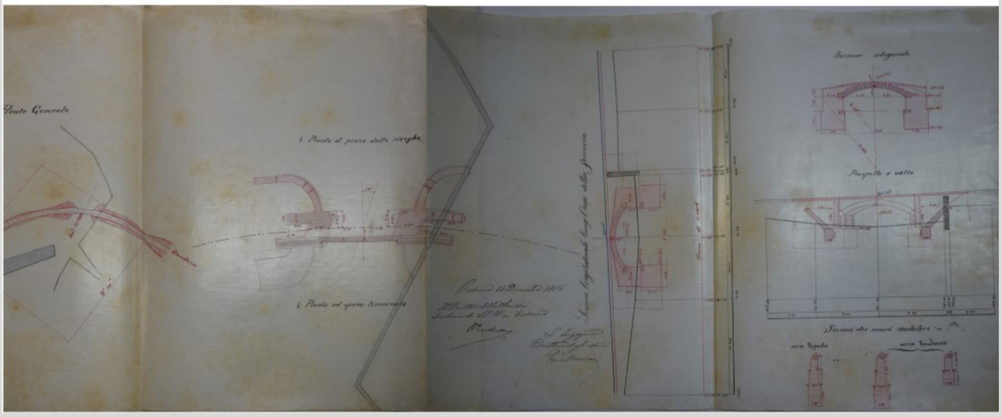


COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH05**
DATA	31/12/2022	
LOCALIZZAZIONE DOCUMENTO		
COMUNE	Catania	
PROVINCIA	Catania	
STATO	Italia	
COLLOCAZIONE SPECIFICA		
LOCALIZZAZIONE	Archivio di Stato di Catania	
INDIRIZZO	Via Vittorio Emanuele II, 156, 95131 Catania CT	
DENOMINAZIONE RACCOLTA	Fondo Circumetnea	
OGGETTO		
TITOLO DOCUMENTO	1° tronco Riposto-Randazzo Ponte di 9,00 m di luce da costruirsi sul Torrente Birbo al Ch.o 14+195,30	
TIPOLOGIA	Esecutivo	
CONTENUTO DEL DOCUMENTO	Pianta generale; 1/2 pianta al piano delle riseghe; 1/2 Pianta ad opera terminata; Sezione longitudinale lungo l'asse della ferrovia; Sezione ortogonale; Prospetto a valle; Sezioni dei muri andatori - verso RIposto e verso Randazzo	
AUTORE ELABORATO	-	
FIRME E TIMBRI PRESENTI	Pouillaude - Ingegnere Direttore tecnico R. Trewhella - Direttore della Società Siciliana dei Lavori Pubblici	
SOGGETO		
DENOMINAZIONE	Viadotto in muratura sul Torrente Birbo	
ID_SCHEDA	RIL13	
DATI TECNICI		
MATERIA E TECNICA	China, matita e acquarelli su carta	
TIPO DI FOGLIO	Plico ripiegato in A4	
DIMENSIONI	27,9 cm x 105 cm	
NOTE	Presente la data del 15 Dicembre 1886	

COMPILATORE	Raissa Garozzo	ID SCHEDA __ARCH05
DATA	31/12/2022	

DOCUMENTO



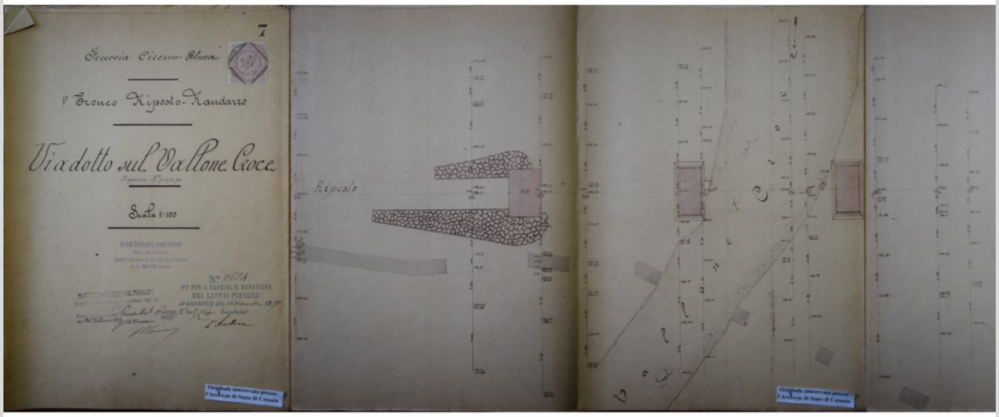


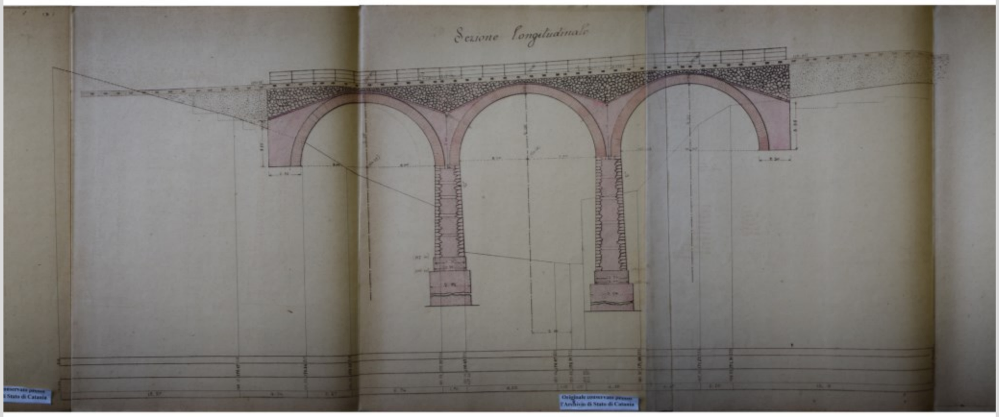
COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH06**
DATA	31/12/2022	

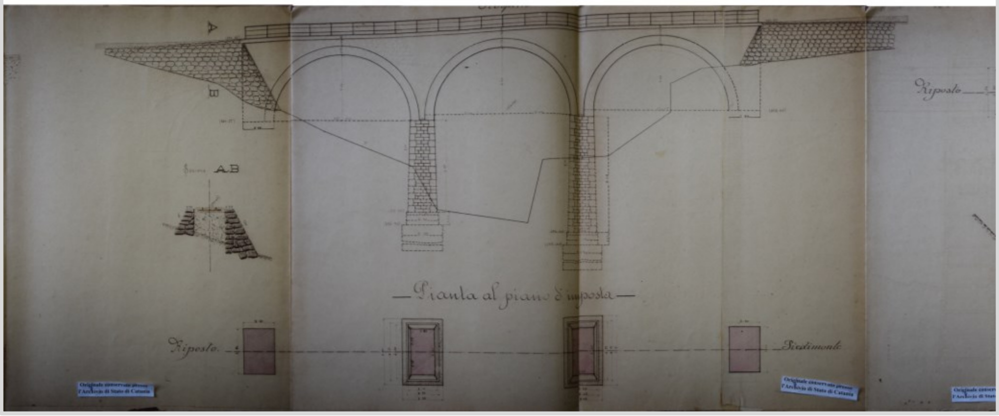
LOCALIZZAZIONE DOCUMENTO	
COMUNE	Catania
PROVINCIA	Catania
STATO	Italia
COLLOCAZIONE SPECIFICA	
LOCALIZZAZIONE	Archivio di Stato di Catania
INDIRIZZO	Via Vittorio Emanuele II, 156, 95131 Catania CT
DENOMINAZIONE RACCOLTA	Fondo Circumetnea
OGGETTO	
TITOLO DOCUMENTO	1° tronco Riposto-Randazzo Viadotto sul Vallone Croce Scala 1:100
TIPOLOGIA	Esecutivo
CONTENUTO DEL DOCUMENTO	Pianta generale (ndr); Sezione longitudinale; Prospetto; Pianta al piano di imposta; Pianta superiore a murature scoperte; Sezione AB; Sezione CD; Dettaglio del parapetto a coronamento e dello smusso dei muri di testa;
AUTORE ELABORATO	-
FIRME E TIMBRI PRESENTI	Pouillaude - Ingegnere Direttore tecnico R. Trewhella - Direttore della Società Siciliana dei Lavori Pubblici Timbro del Ministero dei Lavori Pubblici Visto per il consiglio superiore dei Lavori Pubblici
SOGGETO	
DENOMINAZIONE	Viadotto in muratura presso Mascali
ID_SCHEDA	RIL08
DATI TECNICI	
MATERIA E TECNICA	China, matita e acquarelli su carta
TIPO DI FOGLIO	Plico ripiegato in A4
DIMENSIONI	27,9 cm x 278 cm
NOTE	

COMPILATORE	Raissa Garozzo	ID SCHEDA __ARCH06
DATA	31/12/2022	

DOCUMENTO

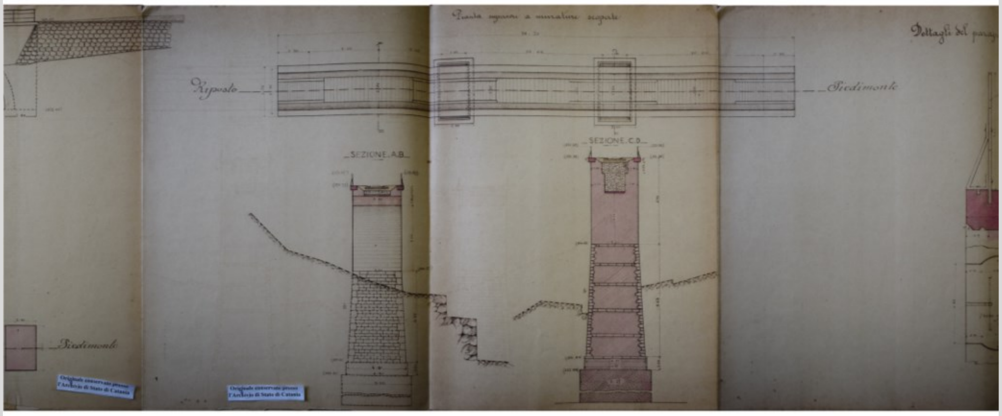


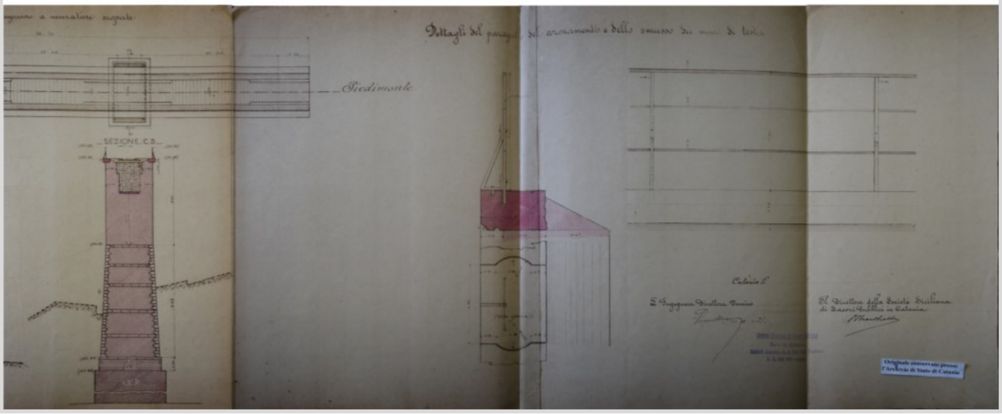




COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH06**
DATA	31/12/2022	

DOCUMENTO



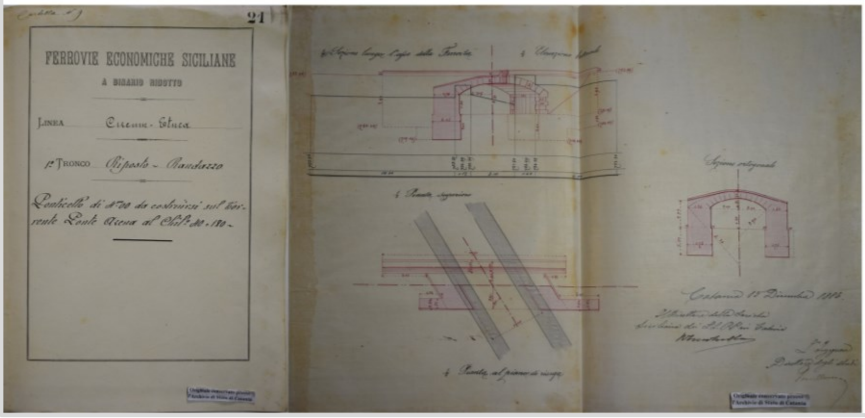


COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH07**
DATA	31/12/2022	

LOCALIZZAZIONE DOCUMENTO	
COMUNE	Catania
PROVINCIA	Catania
STATO	Italia
COLLOCAZIONE SPECIFICA	
LOCALIZZAZIONE	Archivio di Stato di Catania
INDIRIZZO	Via Vittorio Emanuele II, 156, 95131 Catania CT
DENOMINAZIONE RACCOLTA	Fondo Circumetnea
OGGETTO	
TITOLO DOCUMENTO	1° tronco Riposto-Randazzo Ponticello di 4.00 m da costruirsi sul Torrente Ponte Arena al Chl.o 40+180
TIPOLOGIA	Esecutivo
CONTENUTO DEL DOCUMENTO	1/2 Sezione lungo l'asse della Ferrovia; 1/2 Elevazione laterale; 1/2 Pianta superiore; 1/2 Pianta al piano di risega
AUTORE ELABORATO	-
FIRME E TIMBRI PRESENTI	Pouillaude - Ingegnere Direttore tecnico R. Trewhella - Direttore della Società Siciliana dei Lavori Pubblici
SOGGETO	
DENOMINAZIONE	(Incerta) Ponte diagonale Linguaglossa
ID_SCHEDA	(Incerta) RIL17
DATI TECNICI	
MATERIA E TECNICA	China, matita e acquarelli su carta
TIPO DI FOGLIO	Plico ripiegato in A4
DIMENSIONI	27,9 cm x 63 cm
NOTE	Presente la data 15 Dicembre 1886

COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH07**
DATA	31/12/2022	

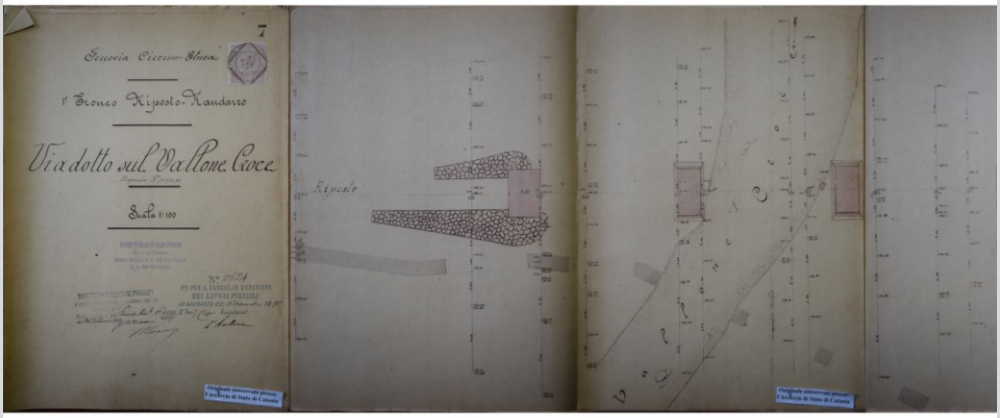
DOCUMENTO

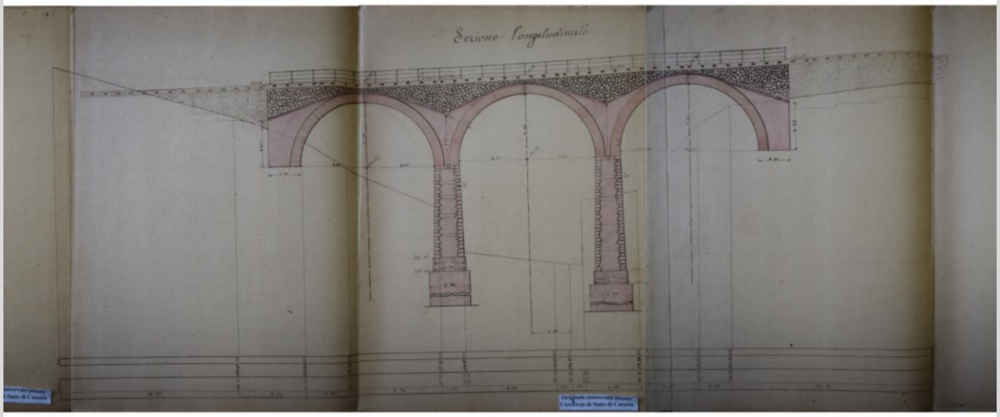


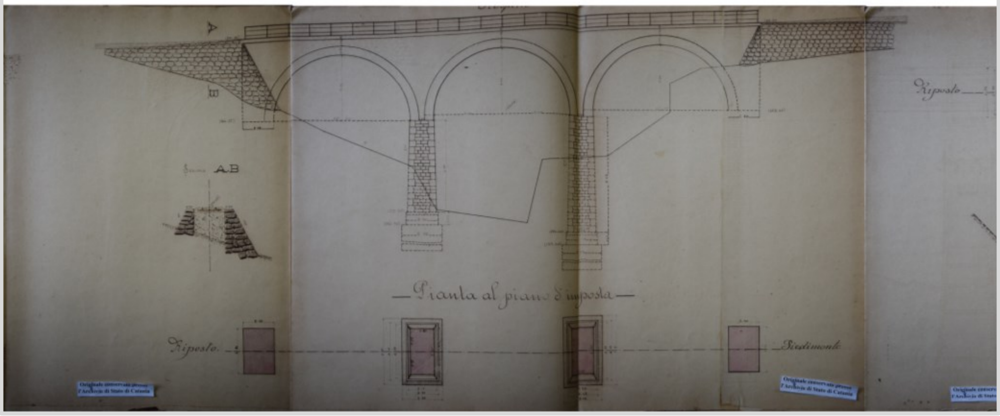
COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH08**
DATA	31/12/2022	
LOCALIZZAZIONE DOCUMENTO		
COMUNE	Catania	
PROVINCIA	Catania	
STATO	Italia	
COLLOCAZIONE SPECIFICA		
LOCALIZZAZIONE	Archivio di Stato di Catania	
INDIRIZZO	Via Vittorio Emanuele II, 156, 95131 Catania CT	
DENOMINAZIONE RACCOLTA	Fondo Circumetnea	
OGGETTO		
TITOLO DOCUMENTO	1° tronco Riposto-Randazzo Viadotto sul Vallone Croce Scala 1:100	
TIPOLOGIA	Esecutivo	
CONTENUTO DEL DOCUMENTO	Pianta generale (ndr); Sezione longitudinale; Prospetto; Pianta al piano di imposta; Pianta superiore a murature scoperte; Sezione AB; Sezione CD; Dettaglio del parapetto a coronamento e dello smusso dei muri di testa;	
AUTORE ELABORATO	-	
FIRME E TIMBRI PRESENTI	Pouillaude - Ingegnere Direttore tecnico R. Trewhella - Direttore della Società Siciliana dei Lavori Pubblici Timbro del Ministero dei Lavori Pubblici Visto per il consiglio superiore dei Lavori Pubblici	
SOGGETO		
DENOMINAZIONE	Viadotto in muratura presso Mascali	
ID_SCHEDA	RILXX	
DATI TECNICI		
MATERIA E TECNICA	China, matita e acquarelli su carta	
TIPO DI FOGLIO	Plico ripiegato in A4	
DIMENSIONI	27,9 cm x 278 cm	
NOTE		

COMPILATORE	Raissa Garozzo	**ID SCHEDA __ARCH08**
DATA	31/12/2022	

DOCUMENTO

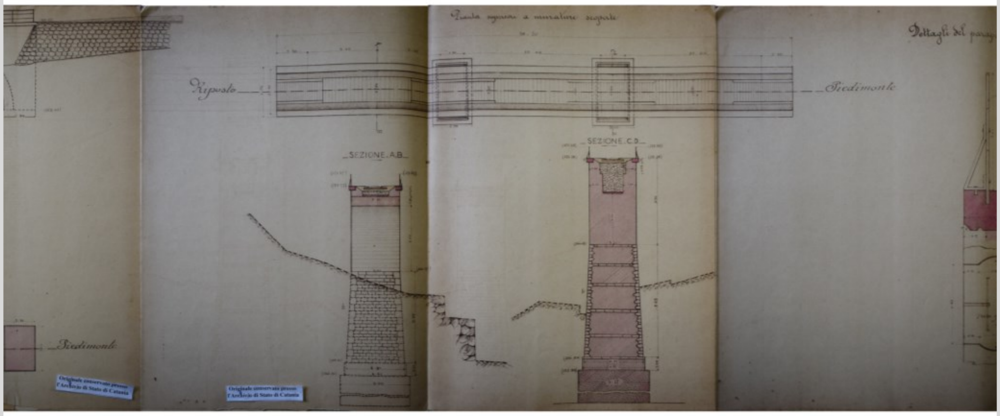


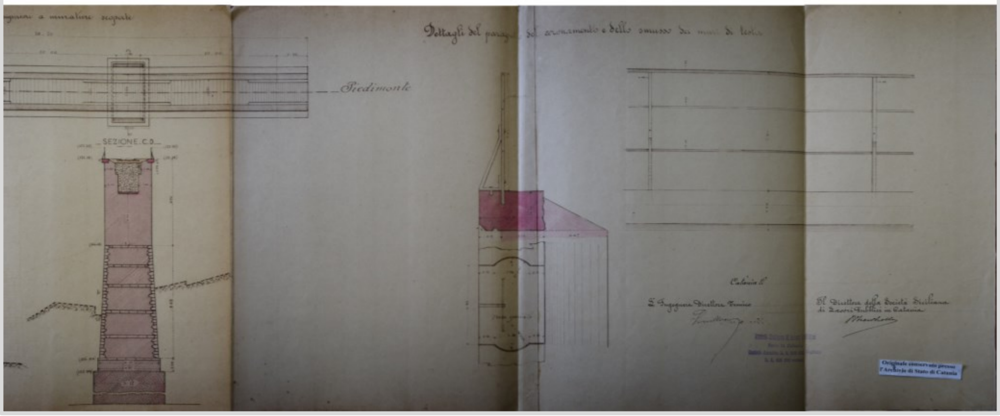




COMPILATORE	Raissa Garozzo	ID SCHEDA __ARCH08
DATA	31/12/2022	

DOCUMENTO





3.1.4 Preliminary analysis of the archival documentation

This paragraph presents several evaluations regarding the retrieved historical archival documentation.

- A bridge (span 6 m) near Giarre;

Original name: *Sottopassaggio speciale di metri 6,00 da costruirsi per la Strada Provinciale Mascali-Annunziata al Chilometro 6+809,12*

Compared to the bridge built, the curvature of the railway line is reversed. This is certainly due to a change in the route, from Riposto to Piedimonte, made later, which is evidenced through a document in (Figure 10) that, unfortunately, does not indicate a date. Compared to the project, the wing walls are no longer present.

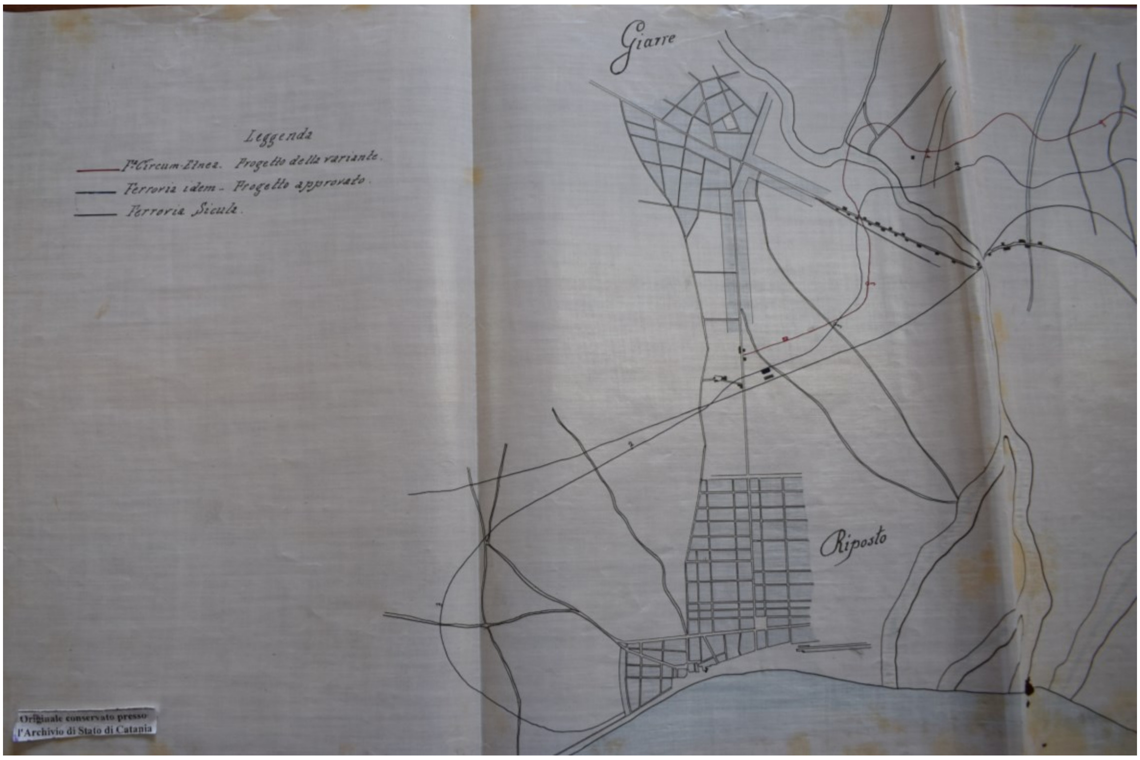


Figure 10 - A change in the route, from Riposto to Piedimonte, that affects the construction of some bridges.

- Viaduct with 4 spans of 12 meters each over the Santa Venera stream;

This project was found at the State Archive with the name *Viadotto sul Vallone Santa Venera Progressiva 11+400* and in the Circumetnea Archive as *Viadotto Santa Venera a 4 luci di 12 metri ciascuna*

It was not possible to carry out any survey of the viaduct in question. At present, for the purposes of this research, the information regarding this bridge can be traced back solely to the archive documentation found.

The project preserved at the State Archive (Figure 11a) consists of a general plan in scale 1:200, floor plan, half floor plan of finished work and half with exposed walls, longitudinal section, sections, valley prospect, details of the parapet niche, coping, and sloping of end walls, elevation of the parapet, and niche plan. This project is one of the most detailed found, as it includes some details at a higher level of detail. The project bears the stamp of the General Inspectorate of Railways on February 24, 1892. It also bears the signature of the Technical Director Engineer: Pouillaude; Director of the Sicilian Public Works Company in Catania: Robert Trewhella.

The Project preserved at the Circumetnea Archive (Figure 11b) consists of a plan of the walls, longitudinal profile, section of the central pier and the pier called "Randazzo" (likely indicating direction), valley prospect, plan of exposed walls with details for the cut stone, section of the coping and end of the wall at the valley shoulder.

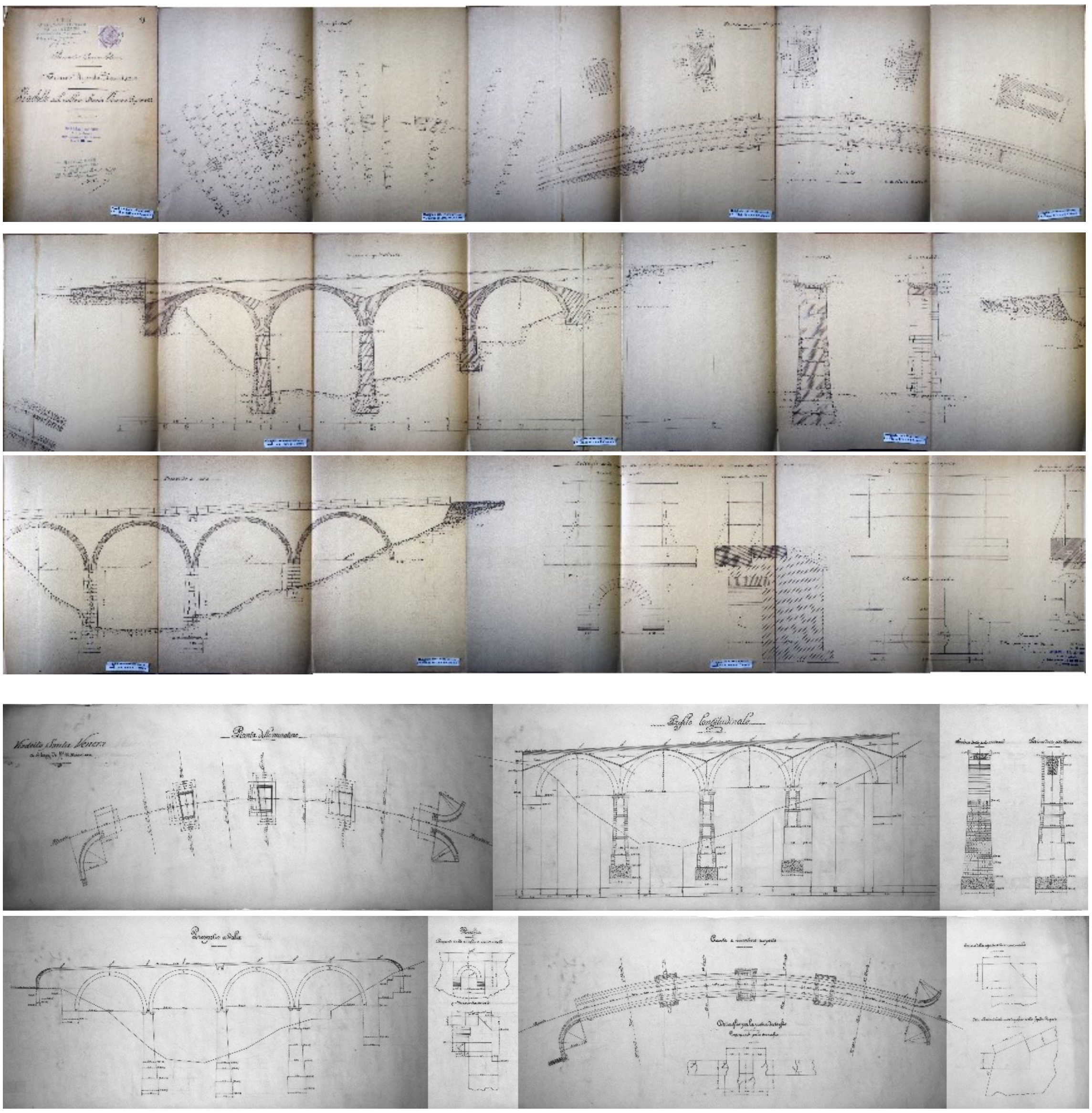


Figure 11 – Top: The project of Santa Venera bridge found at the State Archive; bottom: the same project found at the archive of Circumetnea

- Viaducts with lowered brick arches
- A bridge with two spans of 8 meters each over the Birbo stream;
- A a bridge with two spans of 8 meters each over the Chiuse del Signore stream;

The design variations on the section under consideration are clear from the archive documentation, from a comparison of the longitudinal profiles from 1886, 1891 and 1892 (Figure 12)

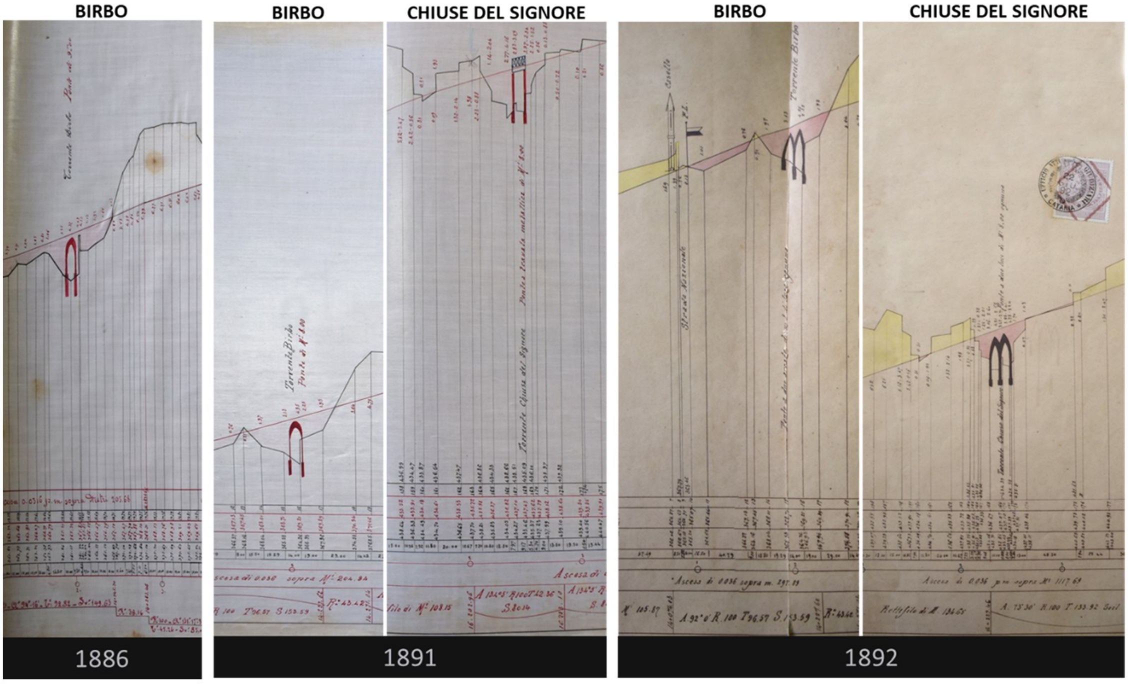


Figure 12 - Longitudinal profiles of the line in correspondence with the bridges over the Birbo and Chiuse del Signore rivers

In the first project of 1886, the Birbo consisted of a single arch bridge with a span of 9 m and a lowered span of 1.50 m. The abutments, both 3.5 m wide, were made of steel. The abutments, both 3.154 m wide, were characterised by curved wing walls to ensure a smooth flow of water. The 1891 project, needed due to alterations in height, provided for a single lowered arch bridge with a span of 8 m and an arrow of 1.60 m (Figure 13a). As reported in a note accompanying the project, the span of the bridge was determined by taking as a reference another bridge previously built which crossed the same stream about one hundred metres upstream. This bridge, identified through the interpretation of documents and careful observation of the IGM 25,000 cartography and the hydrographic basins, is currently walled up (Figure 13b). The current two-arch configuration dates to 1892 (Figure 13c).

Similarly, the bridge crossing the Chiuse del Signore stream, which was first designed in 1891, was initially conceived as a metal truss with a 6 m long masonry arch. The final drawing, in line with the current state of the artefact, also dates to 1892.

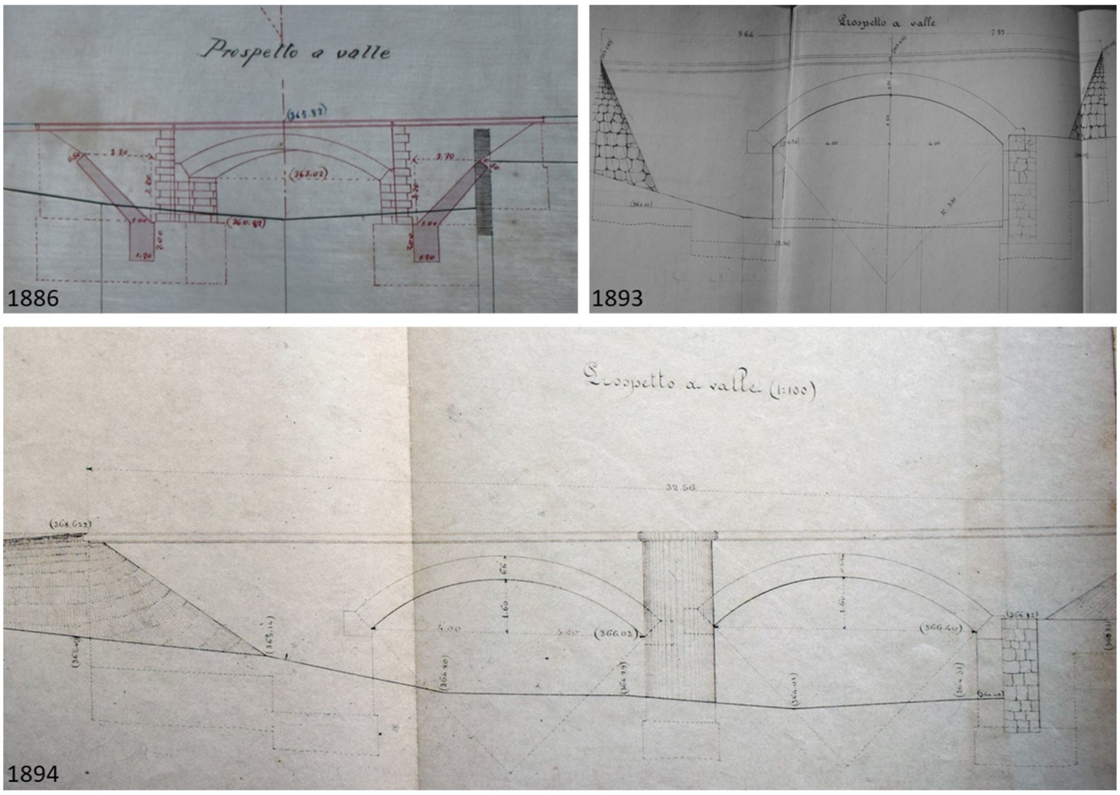


Figure 13 - The downstream elevations of: a) the 1886 project; b) the 1893 project; c) the 1894 project.

- Viaducts with full-height masonry arches
  - A 10-meter, three-span viaduct near the municipality of Mascali that crosses the present-day Viale Kennedy, once called Vallone Croce, now "tombed"
  - Curved viaduct with four arches of 8 meters each in Maletto
  - Curved viaduct with four arches of 8 meters each in Maletto

A plan of the bridge over the Vallone Croce has been recovered at the state archives. It is interesting to read the profile of the riverbed as well as the depth and section of the foundations. Documentation on the Maletto bridge (55+881.01) was instead found at the Circumetnea Archives.

- Small bridges with stone full-height arches
  - Small bridge 3 meters at the entrance of Linguaglossa
  - Small bridge 3 meters in Bronte

A generic documentation was found of this type, applicable to the three trunks, called Minor Works of Art: Bridge Type of 3 metres.

3.2 Cataloguing

3.2.1 Materials and methods

Creating a comprehensive database for the preservation of heritage masonry arch bridges is a crucial aspect of ensuring the long-term sustainability of these structures. The database should be designed to include a wide range of information related to the bridge's design and construction, including the material properties of the bridge's components, its loading capacity, and structural integrity. This information is critical for understanding the bridge's current condition and identifying potential vulnerabilities that may need to be addressed in order to ensure its long-term structural stability.

Additionally, data on the bridge's condition, including any past repairs or maintenance that have been performed, should also be included in the database. This information can help professionals in charge of the maintenance to understand the history of the bridge and the impact that previous repairs may have had on its condition. This information can be used to inform future preservation strategies and can help to identify potential issues that may need to be addressed to ensure the bridge's long-term sustainability.

Furthermore, the database should include geographical information such as the location of the bridge, maps and photographs of the bridge, and other relevant data such as historical context, social, economic, and environmental impacts. This information can be used to understand the bridge's place within the broader context of its community and region and can aid in the identification of potential hazards and impact of the bridge's failure.

Additionally, the use of GIS technology within the database allows for the integration of various data sources and provides the ability to analyse and visualize the data in various formats, such as maps, 3D models and simulations. This can aid in identifying potential vulnerabilities, assessing the impact of various hazards, and informing maintenance and preservation strategies. GIS can also aid in the design of emergency plans and risk management strategies (Quinci et al., 2022).

The centralization of this information in a database allows for easy access to it and can help to ensure that important data is not lost or overlooked. This is especially beneficial for researchers, engineers, and preservationists who are working to understand the history and condition of these structures and for the design of preservation and maintenance plans (Agapiou et al., 2015). Additionally, it can aid in the identification of the most significant bridges that require preservation and track the progress of preservation efforts over time. In this way, heritage masonry arch bridges can continue to serve as functional infrastructures while preserving their cultural and historical significance. Another interesting and particularly challenging approach is the combination of the BIM approach with the GIS system. This is even more true when dealing with cultural assets that are distributed across the territory. It therefore becomes very useful for railway bridges (Ramírez Eudave & Ferreira, 2021)

3.2.2 Identification in the territory and census

This phase of the research focused on identifying the bridges and buildings serving the railway line and cataloguing them with reference to architectural and geometric characteristics (Figure 2). The first step was to localize the artifacts in question using Google Earth, in order to quickly identify, when possible, the characteristics of the structures identified through Google Street Maps, operating a preliminary armchair mapping (Inglese & Paris, 2020).

This information was subsequently integrated through on-site inspections. Visual inspections, followed by surveying procedures, added some key information about the case studies that could not be found without visiting the sites.

The data was then imported into the QGIS (Quantum Geographic Information System) platform. The traced path and pins inserted previously in Google Earth retained the vectorization (becoming lines and points respectively). It was chosen to overlay these elements on different web maps (Google Maps and Google Street Maps). Basic cartography (IGM 25,000) and that of the main and secondary hydrographic basins were also used. In the case of bridges, from the cartographic base, we moved to the enrichment of information, with the aim of producing a grid of attributes organized according to categories related to position (latitude and longitude), number of arches, materials, archive documentation found, and type of survey carried out, as shown in Table 1.

								SURVEY						ARCHIVE		
ID	LAT	LONG	ARCH	N ARC	LUCE [m]	M ARCH	M BRIDGE	ACCESS	FOTO	SFM	TLS	DRONE	VIDEOG	PROGET	COMP	DESCR
Ponte Riposto	37°43'40.63"N	15°12'10.47"E	Tutto sesto	1	9	Pietra lavica	Pietra lavica	•	•	•	•					
Viadotto 4 arcate	37°44'32.46"N	15°10'34.46"E	Tutto sesto	4	6-6-10-6	Mattoni	Pietra lavica		•					•		
Ponticello	37°44'53.22"N	15°10'33.62"E	Tutto sesto	1	3	Mattoni	Pietra lavica	•	•		•			•	•	
Ponte Mascali	37°44'56.26"N	15°10'33.44"E	Tutto sesto	3	3	Mattoni	Pietra lavica		•							
Ponticello	37°45'22.95"N	15°10'32.00"E	Ribassato	1	3	Mattoni	Pietra lavica	•	•	•						
Viadotto Vallone Croce	37°45'25.60"N	15°10'26.12"E	Tutto sesto	3	10	Pietra lavica	Pietra lavica	•	•	•	•	•		•	•	•
Ponte Torrente Vallonazzo	37°45'33.70"N	15°10'18.93"E	Ribassato	1	4	Pietra lavica	Pietra lavica		•							
Viadotto Santa Venera	37°47'32.09"N	15°10'14.28"E	Tutto sesto	3	12									•	•	•
Ponte Piedimonte Etneo	37°47'57.83"N	15°10'16.01"E	Tutto sesto	1		Mattoni	Pietra lavica		•							
Viadotto Vallone Carmine	37°48'4.56"N	15°10'26.37"E	Tutto sesto	3	12	Mattoni	Pietra lavica	•	•					•		
Ponte sul Torrente Birbo	37°48'43.25"N	15°10'26.49"E	Ribassato	2	8	Mattoni	Pietra lavica	•	•	•	•			•	•	•
Viadotto sul torrente Chiuse del Signore	37°48'49.78"N	15° 9'47.27"E	Ribassato	2	8	Mattoni	Pietra lavica							•	•	•
Ponticello Linguaglossa	37°49'49.88"N	15° 8'30.02"E	Tutto sesto	1	3	Pietra lavica	Pietra lavica	•	•	•	•					
Ponticello Linguaglossa	37°50'15.21"N	15° 8'21.89"E	Ribassato	1	4	Mattoni	Pietra lavica	•	•	•	•					
Ponte Castiglione	37°51'15.19"N	15° 6'39.31"E	Tutto sesto	1	4	Cls	Pietra lavica	•	•							
Ponticello Solicchiata	37°52'35.52"N	15° 3'16.19"E	Ribassato	1	3	Pietra lavica	Pietra lavica	•	•	•	•		•	•		
Ponte/Galleria Randazzo	37°52'30.90"N	14°57'17.16"E	Ribassato	1	4	Mattoni	Pietra lavica	•	•	•	•					
Ponte	37°49'35.97"N	14°51'46.56"E	Tutto sesto	4		Pietra lavica	Pietra lavica		•							
Ponticello Bronte	37°47'22.66"N	14°50'21.02"E	Tutto sesto	1	2	Pietra lavica	Pietra lavica	•	•	•	•		•	•		
Ponticello Bronte	37°46'59.79"N	14°50'17.45"E	Tutto sesto	1	2	Pietra lavica	Pietra lavica	•	•		•		•	•		

In this case too, to connect the information and make it easier to get to know the masonry bridges of the Circumetnea, special sheets have been created. These sheets are the result of the union of two classification standards, respectively used for the classification of cultural assets and for the classification of bridges (masonry and non-masonry). The classification sheets for bridges, attached to the Italian guidelines for monitoring and managing existing bridges with some inspection sheets, previously produced for the Circumetnea under an agreement with the Department of Civil Engineering and Architecture of the University of Catania, were therefore merged with the archival material arrangement introduced by the ICCD (Figure 14).

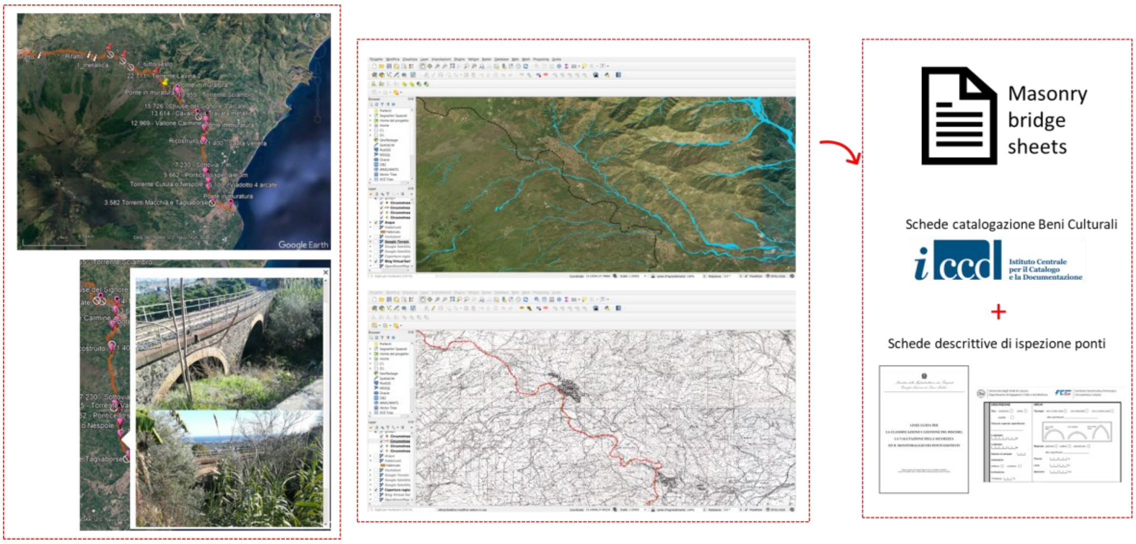


Figure 14 - The procedure that led to the creation of cataloguing sheets for the bridges of Circumetnea.

The sheets are structured as follows: a first part indicates the compiler, the date, and a unique code to identify the sheet. We then move on to the general data concerning the bridge: its name, and various identification codes. A first code is the internal code of the Circumetnea, provided by the authority itself. Slots have been prepared for the National Information Archive of Public Works (AINOP) and for the Public Works Identifier (IOP), which allows a specific work to be uniquely identified. The location (municipality and province), kilometre progression and geographical coordinates allow an indication of the position of the bridge in the territory and with respect to the line. The type of bridge is then indicated, the type of code as indicated in the previous paragraph, the type of connection, the period of construction and the cultural instance that characterises the bridge and makes it to all intents and purposes a cultural heritage. We then move on to information regarding the relationship with the context and the geometric-dimensional characteristics, with particular attention to the vaulted element. Finally, the provenance of the data and the possible presence of related archival documents are specified (the inclusion of the link to the archival material's cataloguing card is allowed). Finally, the sheet presents an excerpt of the Regional Technical Map (CTR) and an orthophoto with a scale bar and some sample images of the bridge under examination.
Some sample sheets are given at the end of this paragraph.

COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL29
DATA	31/12/2022	

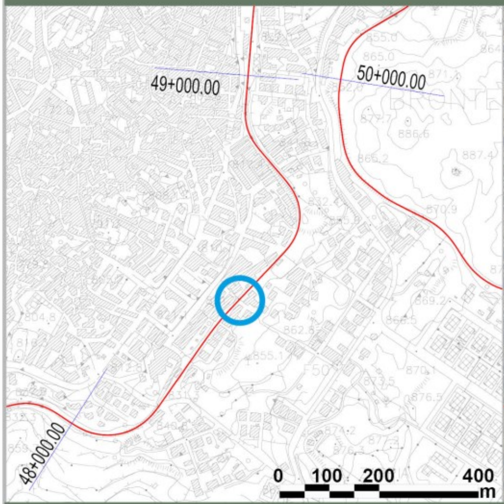
DATI GENERALI PONTE	
DENOMINAZIONE	Sottopasso in muratura presso Bronte
IDENTIFICATIVO	
ID interno FCE	ID034
IOP	-
AINOP	-
LOCALIZZAZIONE	
Comune	Bronte
Provincia	Catania
Stato	Italia
PROGRESSIVA	
Progressiva iniziale	km 48+468.33
Progressiva finale	km 48+474.95
COORDINATE GEOGRAFICHE	
Latitudine	37°46'59.79"N
Longitudine	14°50'17.45"E
TIPOLOGIA PONTE	Sottopasso in muratura
CODICE TIPOLOGIA	T2.A1.P1.C0.D0
TIPO DI COLLEGAMENTO	Ponte su zona urbanizzata
EPOCA/ANNO EDIFICAZIONE	Fine Ottocento
ISTANZA CULTURALE	Valore storico, tipologico e paesaggistico

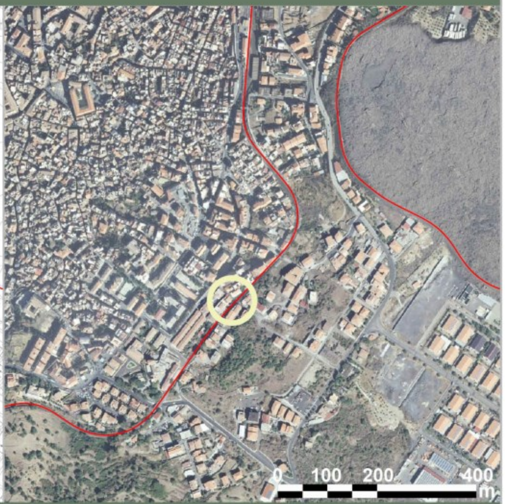
COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL29**
DATA	31/12/2022	

RELAZIONE CON IL CONTESTO	
MORFOLOGIA DEL SITO	Pendio dolce
CONTESTO AMBIENTALE	Contesto cittadino
OPERE IN PROSSIMITÀ	Nessuna
ACCESSIBILITÀ	Raggiungibile attraverso passaggio carrabile
CARATTERISTICHE GEOMETRICO-DIMENSIONALI	
LUCE COMPLESSIVA (retta)	2,50 metri
LARGHEZZA TOTALE IMPALCATO	6,50 metri
NUMERO CAMPATE	Una
LUCE CAMPATE	2,50 metri
PROFILO ARCO	Semi-circolare
VOLTA	Retta
TRACCIATO	Retto
CARATTERISTICHE MATERICHE	
VOLTA	Volta in conci di pietra lavica
PILA	-
SPALLA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
TIMPANO	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
MURO D'ALA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
FONDAZIONE	-
NOTE	
PROVENIENZA DEI DATI	Ispezione visiva, rilievo digitale
DOCUMENTI REPERITI	-
COMMENTI	

COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL29
DATA	31/12/2022	

STRALCIO CTR	STRALCIO VISTA AEREA





RILIEVO FOTOGRAFICO

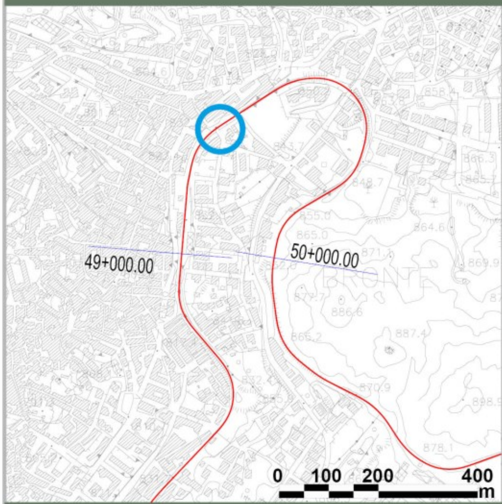
COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL28
DATA	31/12/2022	
DATI GENERALI PONTE		
DENOMINAZIONE	Sottopasso in muratura presso Bronte	
IDENTIFICATIVO		
ID interno FCE	ID036	
IOP	-	
AINOP	-	
LOCALIZZAZIONE		
Comune	Bronte	
Provincia	Catania	
Stato	Italia	
PROGRESSIVA		
Progressiva iniziale	Km 49+270.89	
Progressiva finale	Km 49+275.35	
COORDINATE GEOGRAFICHE		
Latitudine	37°47'22.60"N	
Longitudine	14°50'21.04"E	
TIPOLOGIA PONTE	Sottopasso in muratura	
CODICE TIPOLOGIA	T2.A1.P1.C0.D0	
TIPO DI COLLEGAMENTO	Ponte su zona urbanizzata	
EPOCA/ANNO EDIFICAZIONE	Fine Ottocento	
ISTANZA CULTURALE	Valore storico, tipologico e paesaggistico	

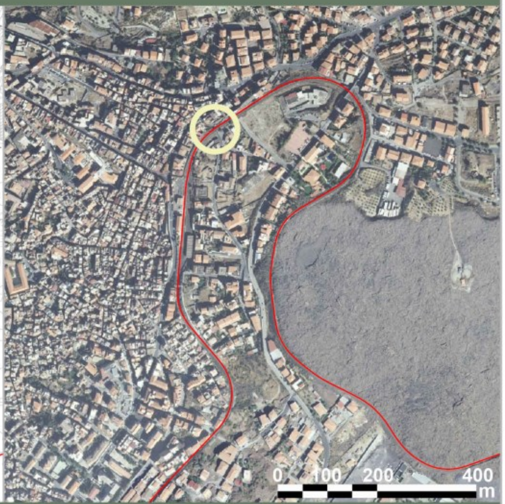
COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL28
DATA	31/12/2022	

RELAZIONE CON IL CONTESTO	
MORFOLOGIA DEL SITO	Pendio ripido
CONTESTO AMBIENTALE	Contesto cittadino
OPERE IN PROSSIMITÀ	Nessuna
ACCESSIBILITÀ	Raggiungibile attraverso passaggio carrabile
CARATTERISTICHE GEOMETRICO-DIMENSIONALI	
LUCE COMPLESSIVA (retta)	2,50 metri
LARGHEZZA TOTALE IMPALCATO	3,70 metri
NUMERO CAMPATE	Una
LUCE CAMPATE	2,50 metri
PROFILO ARCO	Semi-circolare
VOLTA	Retta
TRACCIATO	Retto
CARATTERISTICHE MATERICHE	
VOLTA	Volta in conci di pietra lavica
PILA	-
SPALLA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
TIMPANO	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
MURO D'ALA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
FONDAZIONE	-
NOTE	
PROVENIENZA DEI DATI	Ispezione visiva, rilievo digitale
DOCUMENTI REPERITI	-
COMMENTI	

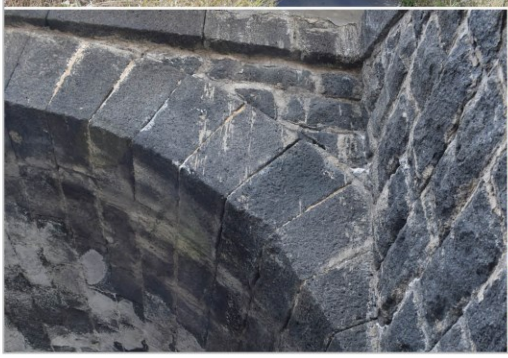
COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL28**
DATA	31/12/2022	

STRALCIO CTR	STRALCIO VISTA AEREA





RILIEVO FOTOGRAFICO



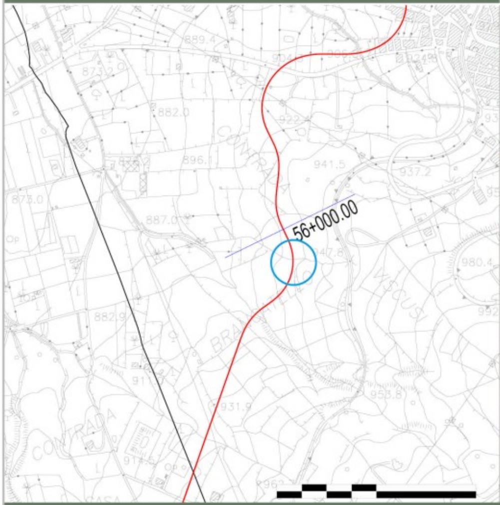
COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL27**
DATA	31/12/2022	

DATI GENERALI PONTE	
DENOMINAZIONE	Viadotto curvo Maletto
IDENTIFICATIVO	
ID interno FCE	ID039
IOP	-
AINOP	-
LOCALIZZAZIONE	
Comune	Maletto
Provincia	Catania
Stato	Italia
PROGRESSIVA	
Progressiva iniziale	km 55+861.77
Progressiva finale	km 55+900.25
COORDINATE GEOGRAFICHE	
Latitudine	37°49'17.69"N
Longitudine	14°51'36.80"E
TIPOLOGIA PONTE	Viadotto curvo a quattro arcate
CODICE TIPOLOGIA	T2.A1.P3.C1.D0
TIPO DI COLLEGAMENTO	Ponte su discontinuità orografica (piccolo canale)
EPOCA/ANNO EDIFICAZIONE	Fine Ottocento
ISTANZA CULTURALE	Valore storico, tipologico e paesaggistico

COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL27
DATA	31/12/2022	
RELAZIONE CON IL CONTESTO		
MORFOLOGIA DEL SITO	Pendio moderato	
CONTESTO AMBIENTALE	Contesto agricolo	
OPERE IN PROSSIMITÀ	Nessuna	
ACCESSIBILITÀ	Raggiungibile attraverso terreni privati o mediante binari	
CARATTERISTICHE GEOMETRICO-DIMENSIONALI		
LUCE COMPLESSIVA (retta)	32,00 metri	
LARGHEZZA TOTALE IMPALCATO	4,20 metri	
NUMERO CAMPATE	Quattro	
LUCE CAMPATE	8 metri	
PROFILO ARCO	Semi-circolare	
VOLTA	Retta	
TRACCIATO	Curvo	
CARATTERISTICHE MATERICHE		
VOLTA	Volta in conci di pietra lavica	
PILA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
SPALLA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
TIMPANO	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
MURO D'ALA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
FONDAZIONE	-	
NOTE		
PROVENIENZA DEI DATI	Ispezione visiva, rilievo digitale, documentazione di archivio	
DOCUMENTI RINVENUTI	ARCH08	
COMMENTI		

COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL27**
DATA	31/12/2022	

STRALCIO CTR	**STRALCIO VISTA AEREA**



RILIEVO FOTOGRAFICO

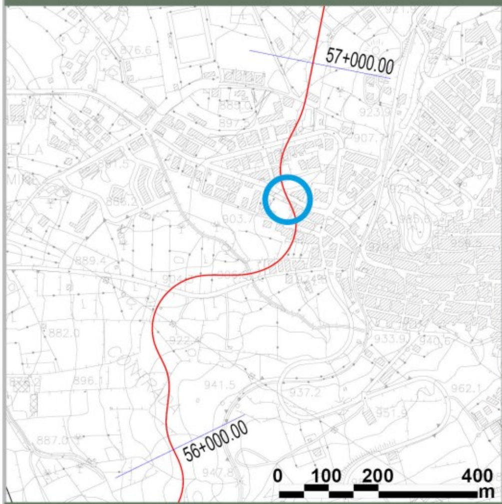
COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL26**
DATA	31/12/2022	

DATI GENERALI PONTE	
DENOMINAZIONE	Sottopasso in muratura presso Bronte
IDENTIFICATIVO	
ID interno FCE	ID041
IOP	-
AINOP	-
LOCALIZZAZIONE	
Comune	Maletto
Provincia	Catania
Stato	Italia
PROGRESSIVA	
Progressiva iniziale	Km 56+628.43
Progressiva finale	Km 56+669.70
COORDINATE GEOGRAFICHE	
Latitudine	37°49’35.97”N
Longitudine	14°51’46.56”E
TIPOLOGIA PONTE	Viadotto in muratura
CODICE TIPOLOGIA	T2.A1.P3.C1.D0
TIPO DI COLLEGAMENTO	Viadotto su zona urbanizzata
EPOCA/ANNO EDIFICAZIONE	Fine Ottocento
ISTANZA CULTURALE	Valore storico, tipologico e paesaggistico

COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL26
DATA	31/12/2022	
RELAZIONE CON IL CONTESTO		
MORFOLOGIA DEL SITO	Pendio dolce	
CONTESTO AMBIENTALE	Contesto cittadino	
OPERE IN PROSSIMITÀ	Nessuna	
ACCESSIBILITÀ	Raggiungibile attraverso terreno privato	
CARATTERISTICHE GEOMETRICO-DIMENSIONALI		
LUCE COMPLESSIVA (retta)	32,00 metri	
LARGHEZZA TOTALE IMPALCATO	4,20 metri	
NUMERO CAMPATE	Quattro	
LUCE CAMPATE	8,00 metri	
PROFILO ARCO	Semi-circolare	
VOLTA	Retta	
TRACCIATO	Curvo	
CARATTERISTICHE MATERICHE		
VOLTA	Volta in conci di pietra lavica	
PILA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
SPALLA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
TIMPANO	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
MURO D'ALA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
FONDAZIONE	-	
NOTE		
PROVENIENZA DEI DATI	Ispezione visiva, materiale FCE	
DOCUMENTI REPERITI	-	
COMMENTI	Presenza di tiranti metallici	

COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL26**
DATA	31/12/2022	

STRALCIO CTR	STRALCIO VISTA AEREA



RILIEVO FOTOGRAFICO

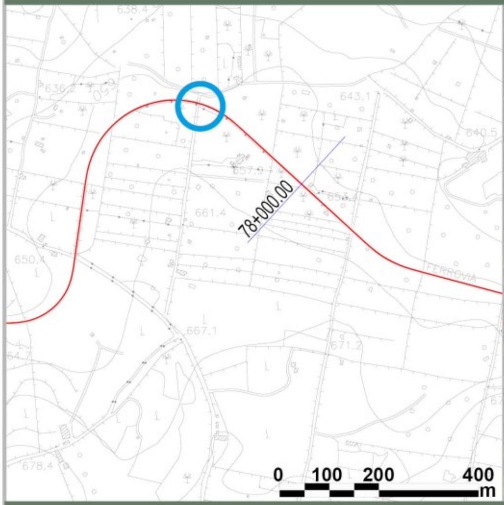
COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL22
DATA	31/12/2022	

DATI GENERALI PONTE	
DENOMINAZIONE	Sottopasso presso Solicchiata
IDENTIFICATIVO	
ID interno FCE	ID063
IOP	-
AINOP	-
LOCALIZZAZIONE	
Comune	Castiglione di Sicilia
Provincia	Catania
Stato	Italia
PROGRESSIVA	
Progressiva iniziale	Km 77+729.37
Progressiva finale	Km 77+732.91
COORDINATE GEOGRAFICHE	
Latitudine	37°52'35.52"N
Longitudine	15° 3'16.19"E
TIPOLOGIA PONTE	Sottopasso in muratura
CODICE TIPOLOGIA	T2. A1. P1. C0.D0
TIPO DI COLLEGAMENTO	Viadotto su area rurale
EPOCA/ANNO EDIFICAZIONE	Fine Ottocento
ISTANZA CULTURALE	Valore storico, tipologico e paesaggistico

COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL22
DATA	31/12/2022	
RELAZIONE CON IL CONTESTO		
MORFOLOGIA DEL SITO	Pianura	
CONTESTO AMBIENTALE	Contesto rurale	
OPERE IN PROSSIMITÀ	Nessuna	
ACCESSIBILITÀ	Raggiungibile attraverso passaggio carrabile	
CARATTERISTICHE GEOMETRICO-DIMENSIONALI		
LUCE COMPLESSIVA (retta)	-	
LARGHEZZA TOTALE IMPALCATO	4 metri	
NUMERO CAMPATE	Una	
LUCE CAMPATE	2,5 metri	
PROFILO ARCO	Semi-circolare	
VOLTA	Retta	
TRACCIATO	Retto	
CARATTERISTICHE MATERICHE		
VOLTA	Volta in conci di pietra lavica	
PILA	-	
SPALLA	Muratura ordinaria di pietrame lavico con paramento a vista a blocchi lavici rozzamenti squadrati	
TIMPANO	Muratura ordinaria di pietrame lavico con paramento a vista a blocchi lavici rozzamenti squadrati	
MURO D'ALA	Muratura ordinaria di pietrame lavico con paramento a vista a blocchi lavici rozzamenti squadrati	
FONDAZIONE	-	
NOTE		
PROVENIENZA DEI DATI	Ispezione visiva, rilievo digitale	
DOCUMENTI REPERITI	-	
COMMENTI		

COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL22**
DATA	31/12/2022	

STRALCIO CTR	**STRALCIO VISTA AEREA**



RILIEVO FOTOGRAFICO

COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL17
DATA	31/12/2022	

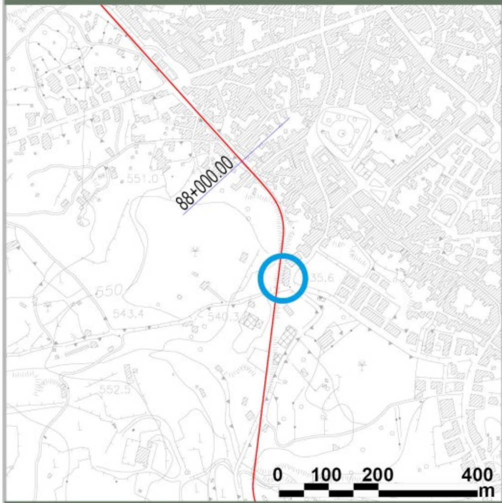
DATI GENERALI PONTE	
DENOMINAZIONE	Ponte diagonale Linguaglossa
IDENTIFICATIVO	
ID interno FCE	ID078
IOP	-
AINOP	-
LOCALIZZAZIONE	
Comune	Linguaglossa
Provincia	Catania
Stato	Italia
PROGRESSIVA	
Progressiva iniziale	Km 88+282.80
Progressiva finale	Km 88+288.36
COORDINATE GEOGRAFICHE	
Latitudine	37°50’15.21”N
Longitudine	15° 8’21.89”E
TIPOLOGIA PONTE	Sottopasso in muratura
CODICE TIPOLOGIA	T1. A1. P2. C1.D1
TIPO DI COLLEGAMENTO	Viadotto su area rurale
EPOCA/ANNO EDIFICAZIONE	Fine Ottocento
ISTANZA CULTURALE	Valore storico, tipologico e paesaggistico

COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL17
DATA	31/12/2022	

RELAZIONE CON IL CONTESTO	
MORFOLOGIA DEL SITO	Pendio moderato
CONTESTO AMBIENTALE	Contesto urbanizzato
OPERE IN PROSSIMITÀ	Nessuna
ACCESSIBILITÀ	Raggiungibile attraverso passaggio carrabile
CARATTERISTICHE GEOMETRICO-DIMENSIONALI	
LUCE COMPLESSIVA (retta)	-
LARGHEZZA TOTALE IMPALCATO	4 metri
NUMERO CAMPATE	Una
LUCE CAMPATE	2,5 metri
PROFILO ARCO	Ribassato
VOLTA	Retta
TRACCIATO	Retto
CARATTERISTICHE MATERICHE	
VOLTA	Volta in conci di laterizi
PILA	-
SPALLA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
TIMPANO	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
MURO D'ALA	Muratura ordinaria di pietrame lavico con paramento a vista a blocchi lavici rozzamenti squadrati
FONDAZIONE	-
NOTE	
PROVENIENZA DEI DATI	Ispezione visiva, rilievo digitale
DOCUMENTI REPERITI	(Incerta) ARCH07
COMMENTI	

COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL17**
DATA	31/12/2022	

STRALCIO CTR	**STRALCIO VISTA AEREA**



RILIEVO FOTOGRAFICO

COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL15
DATA	31/12/2022	

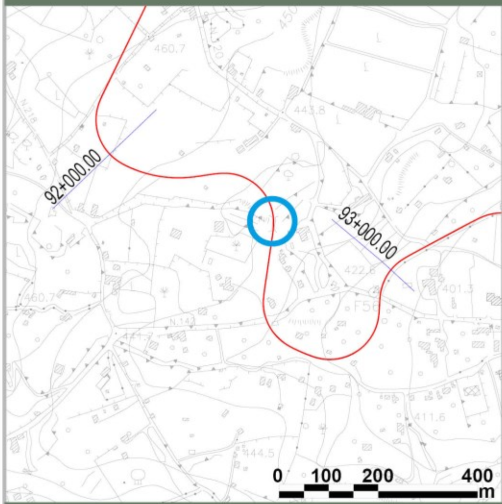
DATI GENERALI PONTE	
DENOMINAZIONE	Viadotto in muratura sul torrente Chiuse del Signore
IDENTIFICATIVO	
ID interno FCE	ID083
IOP	-
AINOP	-
LOCALIZZAZIONE	
Comune	Piedimonte Etneo
Provincia	Catania
Stato	Italia
PROGRESSIVA	
Progressiva iniziale	Km 92+388.77
Progressiva finale	Km 92+417.50
COORDINATE GEOGRAFICHE	
Latitudine	37°48’55.15”N
Longitudine	15° 9’38.59”E
TIPOLOGIA PONTE	Viadotto in muratura
CODICE TIPOLOGIA	T1.A2.P3.C1.D0
TIPO DI COLLEGAMENTO	Viadotto su area rurale
EPOCA/ANNO EDIFICAZIONE	Fine Ottocento
ISTANZA CULTURALE	Valore storico, tipologico e paesaggistico

COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL15**
DATA	31/12/2022	

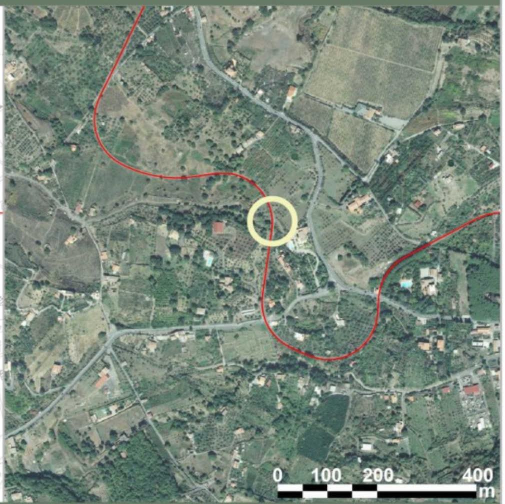
RELAZIONE CON IL CONTESTO	
MORFOLOGIA DEL SITO	Pianura
CONTESTO AMBIENTALE	Contesto rurale
OPERE IN PROSSIMITÀ	Nessuna
ACCESSIBILITÀ	Raggiungibile attraverso terreno privato
CARATTERISTICHE GEOMETRICO-DIMENSIONALI	
LUCE COMPLESSIVA (retta)	-
LARGHEZZA TOTALE IMPALCATO	-
NUMERO CAMPATE	Due
LUCE CAMPATE	8,00 metri
PROFILO ARCO	Ribassato
VOLTA	Retta
TRACCIATO	Curvo
CARATTERISTICHE MATERICHE	
VOLTA	Volta in conci di laterizio
PILA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari. Presenza di rostro
SPALLA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
TIMPANO	Muratura ordinaria di pietrame lavico con paramento a vista a mosaico
MURO D'ALA	-
FONDAZIONE	-
NOTE	
PROVENIENZA DEI DATI	Materiale storico-archivistico, immagini fornite dai proprietari e dalla FCE
DOCUMENTI REPERITI	ARCH02
COMMENTI	

COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL15**
DATA	31/12/2022	

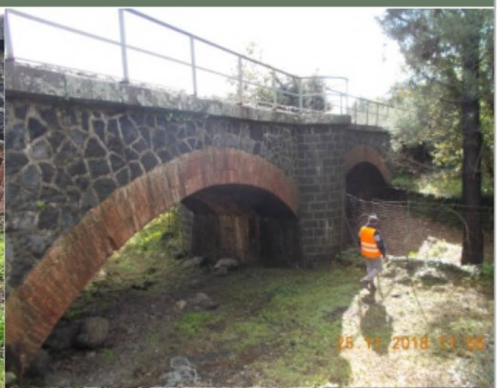
STRALCIO CTR



STRALCIO VISTA AEREA



RILIEVO FOTOGRAFICO



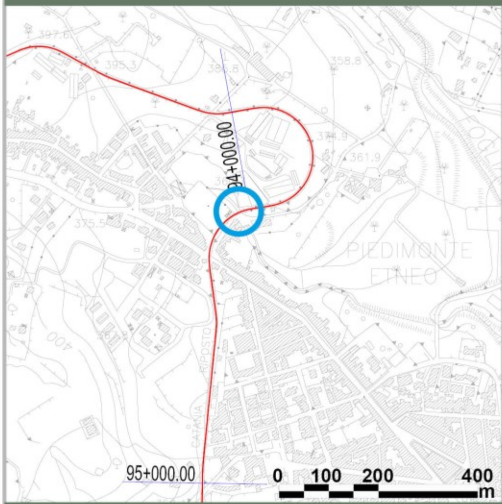
COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL13
DATA	31/12/2022	
DATI GENERALI PONTE		
DENOMINAZIONE	Viadotto in muratura sul Torrente Birbo	
IDENTIFICATIVO		
ID interno FCE	ID085	
IOP	-	
AINOP	-	
LOCALIZZAZIONE		
Comune	Piedimonte Etneo	
Provincia	Catania	
Stato	Italia	
PROGRESSIVA		
Progressiva iniziale	Km 94+421.11	
Progressiva finale	Km 94+432.03	
COORDINATE GEOGRAFICHE		
Latitudine	37°48'43.25"N	
Longitudine	15°10'26.49"E	
TIPOLOGIA PONTE	Viadotto in muratura	
CODICE TIPOLOGIA	T1.A2.P3.C1.D0	
TIPO DI COLLEGAMENTO	Viadotto su zona urbanizzata	
EPOCA/ANNO EDIFICAZIONE	Fine Ottocento	
ISTANZA CULTURALE	Valore storico, tipologico e paesaggistico	

COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL13**
DATA	31/12/2022	

RELAZIONE CON IL CONTESTO	
MORFOLOGIA DEL SITO	Pianura
CONTESTO AMBIENTALE	Contesto cittadino
OPERE IN PROSSIMITÀ	Nessuna
ACCESSIBILITÀ	Raggiungibile attraverso passaggio carrabile
CARATTERISTICHE GEOMETRICO-DIMENSIONALI	
LUCE COMPLESSIVA (retta)	30,5 metri
LARGHEZZA TOTALE IMPALCATO	3,70 metri
NUMERO CAMPATE	Due
LUCE CAMPATE	8,00 metri
PROFILO ARCO	Ribassato
VOLTA	Retta
TRACCIATO	Curvo
CARATTERISTICHE MATERICHE	
VOLTA	Volta in conci di laterizio
PILA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari. Presenza di rostro
SPALLA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
TIMPANO	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
MURO D'ALA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari
FONDAZIONE	-
NOTE	
PROVENIENZA DEI DATI	Rilievo digitale, documentazione d'archivio
DOCUMENTI REPERITI	ARCH03, ARCH04, ARCH05
COMMENTI	

COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL13
DATA	31/12/2022	

STRALCIO CTR	STRALCIO VISTA AEREA



RILIEVO FOTOGRAFICO

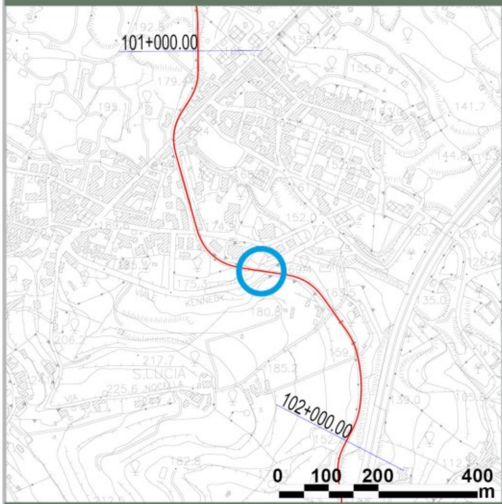
COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL08
DATA	31/12/2022	

DATI GENERALI PONTE	
DENOMINAZIONE	Viadotto in muratura presso Mascali
IDENTIFICATIVO	
ID interno FCE	ID108
IOP	-
AINOP	-
LOCALIZZAZIONE	
Comune	Mascali
Provincia	Catania
Stato	Italia
PROGRESSIVA	
Progressiva iniziale	Km 101+536.54
Progressiva finale	Km 101+556.97
COORDINATE GEOGRAFICHE	
Latitudine	37°45'25.60"N
Longitudine	15°10'26.12"E
TIPOLOGIA PONTE	Viadotto in muratura
CODICE TIPOLOGIA	T2.A1.P3.C0.D0
TIPO DI COLLEGAMENTO	Viadotto su zona urbanizzata
EPOCA/ANNO EDIFICAZIONE	Fine Ottocento
ISTANZA CULTURALE	Valore storico, tipologico e paesaggistico

COMPILATORE	Raissa Garozzo	ID SCHEDA __RIL08
DATA	31/12/2022	
RELAZIONE CON IL CONTESTO		
MORFOLOGIA DEL SITO	Pendio dolce	
CONTESTO AMBIENTALE	Contesto cittadino	
OPERE IN PROSSIMITÀ	Nessuna	
ACCESSIBILITÀ	Raggiungibile attraverso passaggio carrabile	
CARATTERISTICHE GEOMETRICO-DIMENSIONALI		
LUCE COMPLESSIVA (retta)	38,2 metri	
LARGHEZZA TOTALE IMPALCATO	3,84 metri	
NUMERO CAMPATE	Tre	
LUCE CAMPATE	10,00 metri	
PROFILO ARCO	Semi-circolare	
VOLTA	Retta	
TRACCIATO	Retto	
CARATTERISTICHE MATERICHE		
VOLTA	Volta in conci di pietra lavica	
PILA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
SPALLA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
TIMPANO	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
MURO D'ALA	Muratura ordinaria di pietrame lavico con paramento a vista a corsi regolari	
FONDAZIONE	-	
NOTE		
PROVENIENZA DEI DATI	Rilievo digitale, documentazione d'archivio	
DOCUMENTI REPERITI	ARCH06	
COMMENTI	Presenza di tiranti metallici	

COMPILATORE	Raissa Garozzo	**ID SCHEDA __RIL08**
DATA	31/12/2022	

STRALCIO CTR	**STRALCIO VISTA AEREA**



RILIEVO FOTOGRAFICO

Chap. 4 Digital Survey – Research item 1

4.1 The role of digital surveying in the protection and preservation of masonry bridges

Conservation and design interventions require a multidisciplinary approach, therefore a process of knowledge by progressive levels of investigation is crucial. The architecture of masonry bridges is significant in the interpretation and representation of the territory (Bonanno, 1999; Fabbrocino et al., 2022; Inglese & Paris, 2020). Although life drawing is a privileged tool in this sense (Manganaro, 2011), in the analysis of the bridge-territory system and in the digital reproduction of the artefact, the point cloud has a vast potential and is suitable for multiple fields of application (Barrile et al., 2019; Frias & Sánchez-Rodríguez, 2021; Riveiro et al., 2016b; Tang & Akinci, 2012; Valença et al., 2017).

In (Damiata, 2014) the cloud from photogrammetry is used for the stereotomic analysis of a diagonal bridge. In (León-Robles et al., 2019) historical-archival research and digital survey are used as database for the creation of Historical Bridge Information Models (HBrIM). (Sánchez-Rodríguez et al., 2018) introduces, instead, a new methodology for the automated processing of large point clouds for the diagnosis of structural flaws in masonry bridges. In (Savini et al., 2021) the importance of an integrated approach for the knowledge of the technological and structural characteristics of masonry bridges is pointed out by applying the archaeological stratigraphic method and a 3D data management starting from the digital survey.

It is evident how the historical-critical analysis of the original project, together with the geometric-structural survey of the railway works of art are essential for the protection and transmission of the historical identity that masonry bridges testify to (Altuntas et al., 2017; Trizio et al., 2021). Moreover, the safety and efficiency of masonry bridges need to be guaranteed because of the crucial role these infrastructures play in the transportation system(Frangopol & Bocchini, 2012; Orbán, 2007; Pellegrino et al., 2011).

Masonry bridges are characterized by high fragility and require special attention(Sarhosis et al., 2016). Any preventive action, as maintenance is, needs to be achieved as expeditiously, safely, and affordably as possible. Proactive conservation plans answer to the increased need of safeguarding the historical heritage, to mitigate the effects of endogenous and external hazards. Aiming at the digital acquisition of these structures and the creation of digital twins (Pepe et al., 2019), several NDT (Non-Destructive Testing) technologies can be used, such as terrestrial laser scanning, infrared thermography, 360-degree imaging, and unmanned aerial vehicles (Conde et al., 2017; Mugnai et al., 2023; Orbán & Gutermann, 2009; Solla et al., 2013; Talebi et al., 2022).

The 3D survey of masonry bridges is somewhat complex and may require the integration of terrestrial and aerial surveys (Alani et al., 2020). Aerial photogrammetry is a fast and relatively low-cost way to obtain 3D information to monitor cultural heritage assets, especially for difficult-to-proper-reach assets (Micelli & Cascardi, 2020; Mongelli et al., 2017). However, it allows the acquisition of all the details of the upper part of the bridge; Instead, the lower parts, such as vaults, are more easily surveyed through traditional terrestrial surveys, as LIDAR (LIght Detection And Ranging) (Armesto et al., 2010; Yuan et al., 2022).

An essential factor in using these technologies is ensuring the safe inspection and damage assessment of bridges (Mandirola et al., 2022). Such an approach is suitable in the aftermath of a disaster (e.g., after a seismic event) and to support disaster risk reduction strategies, to achieve resilient bridge infrastructures. In (Biscarini et al., 2020), UAV photogrammetric survey is used for visual inspection and 3D model reconstruction, while infrared thermography identifies ongoing material flaws. The result of data integration obtained from the interdisciplinary investigations and the metric information derived from integrated instrumental surveys allow for the creation of HBrIM models with a high level of geometric detail (Marra et al., 2023).

Making the obtained output accessible to professionals and stakeholders involved in the maintenance and conservation planning is crucial. In (Fabbrocino et al., 2022), a virtual system with integrated digital tools and online repositories was set up to operate visual inspections for the assessment of the artifacts state. In addition to that, computer vision-based techniques have been developed to automate visual inspections integrated with (semi)autonomous drones to collect images to achieve complete automation of simultaneous inspection and crack detection in railway bridges (Marin et al., 2021).

4.2 Survey techniques and instrument

Digital surveying has become nowadays an essential tool for the documentation, analysis, and conservation of historic masonry arch bridges. These structures are valuable cultural heritage assets that require careful preservation. Digital surveying techniques offer several advantages over traditional surveying methods, including higher accuracy, greater efficiency, and the ability to capture detailed information about the structure's condition and behaviour. This information can be used to assess the structure's safety, identify areas of deterioration or damage, and develop effective maintenance and repair strategies. Digital surveying also allows for the creation of detailed 3D models of the bridge, which can be used for a variety of purposes, including visualization, analysis, and documentation. Another advantage of digital surveying is its efficiency. Digital surveying techniques can be used to capture large amounts of data quickly and accurately, reducing the time and cost associated with traditional surveying methods. This is particularly important for historic bridges, which often require frequent monitoring and assessment to ensure their ongoing preservation.

Finally, digital surveying can be used to capture data in challenging or hazardous environments. For example, LIDAR can be used to capture data in areas with limited access or high levels of traffic, while aerial photogrammetry can be used to capture data from above the bridge, reducing the need for scaffolding or other access equipment.

A general overview of these surveying techniques and instruments follows.

LIDAR is a remote sensing technology that uses laser light to measure distances and create precise 3D models of objects and environments. It works by emitting a laser beam and measuring the time it takes for the light to bounce back from a surface. By repeating this process many times per second, LIDAR can generate high-resolution point cloud data that represents the shape and geometry of the surrounding area. This data can be used for a variety of applications, such as mapping, surveying, and autonomous driving.

Terrestrial photogrammetry is a technique used to measure the size, shape, and position of objects on the ground using photographs. It involves taking multiple overlapping images of an object or area from different angles and using specialized software to extract 3D information from the images. Terrestrial photogrammetry is often used in surveying, archaeology, architecture, and engineering.

Aerial photogrammetry is a similar technique to terrestrial photogrammetry, but it involves taking photographs from a bird's-eye view using drones, airplanes, or satellites. Aerial photogrammetry can be used to create high-resolution maps, orthophotos, and 3D models of large areas, such as cities, forests, and agricultural fields. It is commonly used in urban planning, environmental monitoring, and precision agriculture.

SLAM (Simultaneous Localization and Mapping) is a technique used in robotics and computer vision to create maps of unknown environments while simultaneously navigating through them. SLAM systems use a combination of sensors, such as LIDAR, cameras, and inertial measurement units (IMUs), to estimate the robot's position and orientation relative to the environment, and to build a map of the surroundings. SLAM is essential for autonomous systems that need to navigate in complex and dynamic environments, such as robots, drones, and self-driving cars.

Videogrammetry is a technique used to extract 3D information from videos. It works by tracking the movement of specific points in a video and using this information to reconstruct the shape and motion of the objects in the scene. Videogrammetry can be used in a variety of applications, such as motion capture, sports analysis, and virtual reality. It is also used in filmmaking and visual effects to create realistic 3D animations from live-action footage.

4.3 Survey campaigns

The documentary research presented in the chapter 3 was coupled with the **digital survey** campaign. The integration of several surveying methodologies, such as laser scanning, photogrammetry (ground and drone-assisted), videogrammetry and SLAM techniques was required due to the peculiarities of the bridges investigation. Different survey techniques were integrated according to the environmental conditions and the type of artefact to be surveyed. A total of 37 bridges were identified along the Circumetnea route, but only 13 of these were accessible. 18 of them were photographed and only 11 were surveyed, using the abovementioned techniques.

In the following subsections examples are reported some of the case studies.

In this study, a selection of bridges has been chosen for detailed analysis due to their perceived significance with regards to both their environmental and landscape context, as well as their belonging to different typologies which have consequently necessitated varied approaches. The cultural dimension and historical importance of certain bridges have rendered the use of different combinations of digital surveying tools indispensable to accurately capture their complex features.

Two-arched bridge in Piedimonte Etneo (see sheet RIL13): This bridge has two spans of 8 meters each and once crossed a watercourse, the Birbo stream, today tombed. The bridge fits the type defined by code T1. A2. P3. C1.D0 and its context is of recent urbanisation. The salient features of this bridge, apart from the interesting design history discussed in Chapter 2, are its moderate height, the easy accessibility of the part housing the railway tracks, its morphological characteristics, and above all the presence of a water-cutter and a low vault that can be easily inspected.

Skew masonry arched bridge in Linguaglossa (see sheet RIL17): This bridge is an oblique one, located in the town of Linguaglossa. The peculiarity of these structure is the treatment of the diagonal vault element. So, in this specific case, the focus was on the survey of the vaulted element and the geometric analysis of the construction technique.

Four arched viaduct in Maletto (see sheet RIL26): This bridge is the curved four-arch bridge in Maletto, T2. A1. P3. C1. D0., the twin of an immediately following bridge with the same characteristics (RIL26). This bridge it had to be analysed with a particular focus on its context, due to landslide affecting the slope on which it is located. In this case, therefore, an integrated survey was performed that was also useful for understanding the relationship between the bridge and its context.

4.3.1 Bridge with two spans of 8 meters each over the Birbo stream;

Figure 15 The Maletto bridge and the FCE train

The double-span bridge (Figure 15), designed in 1892, is located on the edge of the historical city centre of Piedimonte Etneo, at kilometre 106 001,37 along the current route. Curving with a radius of almost 88 m, the bridge crossed the Birbo torrent[5], now buried.
It consists of two barrel-vaults with a lowered arch and a span of 1.60 m; both spans have a net span of 8 m and are 3.70 m deep.
As evidence of the previous flow of the Birbo, there are semi-circular rostrums, which end with a pedestrian refuge. The piers, abutments, return walls and gables are made of ordinary lava stone masonry with a regular course face and cornerstones of ordinary-grained cut lava stone. The vault is made of bricks.
Currently only one bridge of similar configuration has been identified along the line: it is located at km 103,964.22, on private land and crossed the Chiuse del Signore stream (see RIL15). The two bridges have the same dimensions but are different for the convexity of the curvature and for the masonry typology, in this case with a stone face arranged in mosaic.
To capture the morphology of the Piedimonte Etneo bridge in its entirety, both BLK and BLK2Go, a LIDAR SLAM, was used to verify the efficiency of this system for bridges of this size.

Laser scanning

The Leica Geosystem BLK 360 laser scanner was used, with a maximum range of 60 m and a scanning speed of 360,000 points/sec. To compensate for any shady areas and to obtain a complete numerical model, 14 station points were set up, including 4 under the vaults (one pair per arch), 6 on the front and 4 on the back. The result of these surveying operations is a high-resolution numerical model (570,193,486 points) (Figure 16).

[5] Birbo river has as ramifications the streams "Chiuse del Signore", "Chiovazzi" and "Girasa"

Figure 16 - On top, laser scanning survey project, right and bottom, perspective views of the point cloud

Photogrammetry

It was considered necessary to integrate this survey with photogrammetry, to better assess the conservation status of the two vaults, effectively capturing a snapshot of the artifact at the time of acquisition. For this purpose, a dataset of 463 high-resolution images (4496x3000 pixels) was collected with a Nikon D5300, focal length 18 mm. These images were processed using the Agisoft Metashape digital photogrammetry software. The point cloud obtained consists of 99,606,216 points. Orthophotos (Figure 17) were extracted from the mesh obtained processing the original point cloud, for two-dimensional metric drawings and subsequent analysis. This method enabled a more accurate documentation of the vaults' conservation state, aiding in their preservation and facilitating future restoration efforts.

Figure 17 – Orthophoto obtained through terrestrial photogrammetry

SLAM

The digital survey was carried out through two scans: the first scan (3.31 minutes) to capture the scope walls and bridge arches, and the second scan (4.44 minutes) to capture the upper part of the bridge, specifically the rail section, moving from Via Sante Puglisi towards Casello 93, digitally acquired for a parallel project conducted on Circumentea buildings (Raissa Garozzo & Cettina Santagati, 2021). During the acquisition process, two operators were present: one operator supported the instrument, paying attention to changes in direction and walking speed, adjusting as necessary, while the other operator, positioned nearby, monitored the real-time acquisition through a dedicated portable device (Figure 18).

Figure 18 The bridge survey using the BGLK2GO

Following the acquisition phase, a processing stage was conducted using register360. The two scans were then aligned using visual alignment techniques. The result is a point cloud comprising 10,078,039 points. In Figure 19, the distinct coloration (blue for the first scan, green for the second) highlights the two different setups.

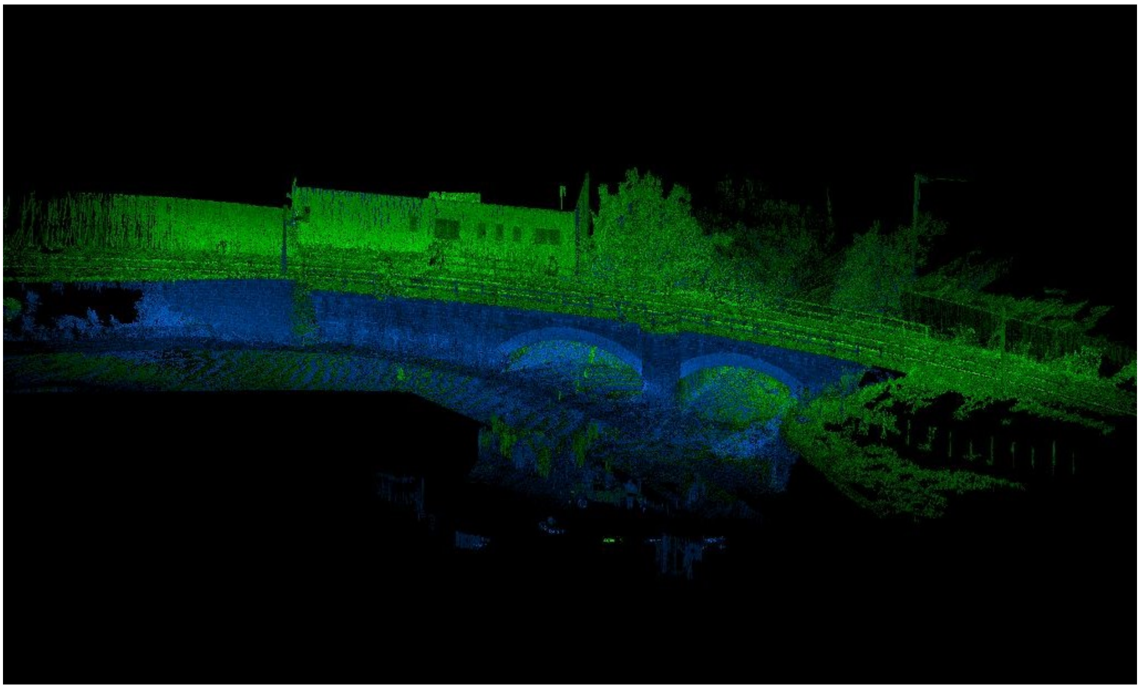


Figure 19 - The union of the BLK2Go and the BLK point clouds

4.3.2 *Skew masonry arched bridges in Linguaglossa:*

With this case study, it was possible to analyse the importance of using digital surveying to understand the underlying geometry in the design and execution of architectural elements.

Figure 20 - The skew masonry arch bridge in Linguaglossa and a detail of its vault

Skew masonry arched bridges represent a very common solution in the rail infrastructure since they allow to cross a watercourse, a valley or a road along a route that is not orthogonal to the train tracks. From both a technological and a constructive point of view, this kind of bridges testify the ability of the workers in the stereometric cut of stones and the installation of ashlars. The geometrical study of a skewed-arched masonry bridge by means of digital representation and surveying enables a critical view on the effectiveness of digital tools to reconnect and better understand the present and the past. Considering the goals of this research, the methodology developed is aimed at the rigorous verification of the geometry of the bridge using the investigation tools of the disciplines of surveying and representation as a system of interpretation and knowledge, from the real object to the designed shape (Cipriani et al, 2017; Vitali, 2017; Spallone et al, 2019).

In this specific case, the study of the geometry and equipment of the vaults of oblique masonry bridges is a question linked to stereotomic tracing rules, solving a problem that in the past was treated bidimensionally by means of 3D modelling. Digital technologies facilitate the description of lines, surfaces, and volumes directly in space, continuously, and with high levels of precision (Salvatore, 2009; Fallavolita, Salvatore, 2012).

Hence, a first phase of study of stereotomic and skew bridges construction treatises has been carried out to focus the research outlines and the main features of skew vaults, particularly the English or helicoidal methods. Subsequently, it has been carried out an integrated digital survey of the identified case study by using low-cost photogrammetric techniques.

The proposed case study is a skew masonry bridge located in Linguaglossa (Figure 20), about 40 kilometres far from Catania.

The brickwork of the bridge was set out using the helicoidal method. Therefore, it is possible to assume an English style influence in the design of the bridge, because this is a very unusual type of brickwork configuration in the Sicilian case.
The bridge analysed consists of a depressed-arched barrel vault lowered with an arrow equal to 0,97 m. The oblique span is 4,28 meters, the straight span is 4 meters. The width of the barrel, measured parallel to abutments, is about 3,7 m. The thickness of the brick vault is about 0,67 m, with a Flemish bonds bricklaying. The spandrel walls are in lava stone masonry as well as the abutments. The state of preservation is rather good.
Some traces of efflorescence have been found along the arch and the abutments. The low elevation of the bridge led, in time, the damaging of the intrados due to trucks that often undercross the bridge.
The numerical model obtained forms the basis for the subsequent study which involved the following steps: the unroll of the surface; the test of the net to verify the geometric rules behind the tracing of helicoidal equipment; construction of the ideal mathematical model starting from the geometric characteristics extracted from the surveyed surface; development of the subsequent mathematical surface; the comparison between the two models (Figure 21).
Considering the moderate height of the bridge and the easy-to-reach and reduced-traffic street where it is located, the multi-image photogrammetry data acquisition has been chosen to carry out the digital survey.
This method was also chosen for its well-known expeditious and low-cost characteristics. The shooting was conducted using a Nikon D5300, focal length of 18 mm, with a resolution of 24 MP, for a total of 296 images, taken from the ground. The GDS (Ground Sampling Distance) is 2.9 mm/pix.

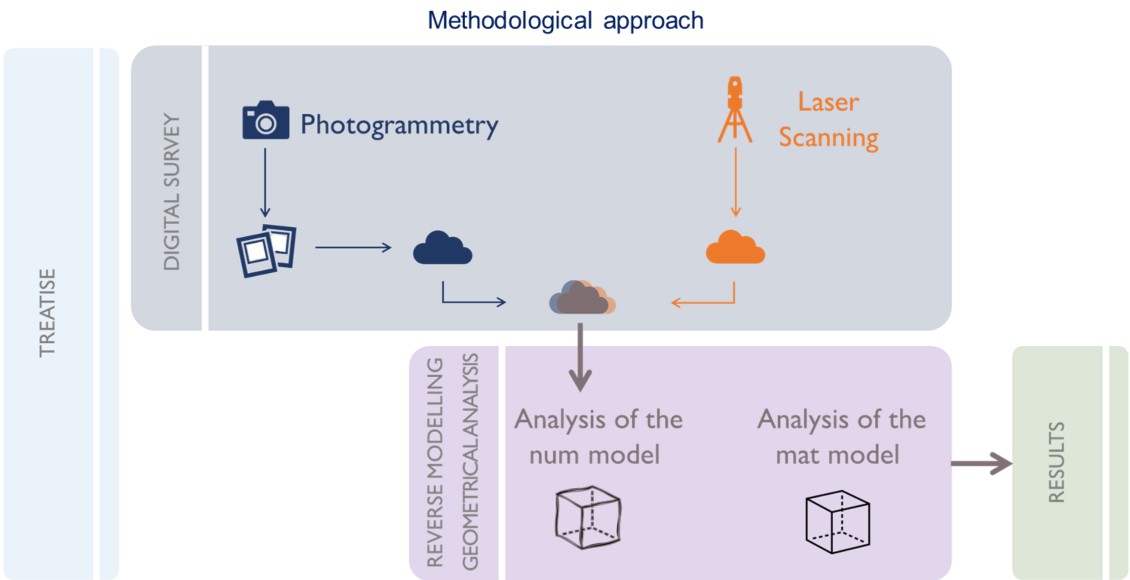


Figure 21 - The methodological approach proposed

The photographic dataset was automatically processed with Agisoft Metashape. A first stage of cameras alignment was followed by a sparse and then a dense point cloud reconstruction (40.177.863 points) (Figure 22).

Figure 22 The dense point cloud reconstruction of the bridge

The 3D acquisition and processing phase were followed by a graphical analysis, aiming at finding the geometrical rules underlying the design of the identified helical apparatus, to understand if it was realized according "rule of the art".

The point cloud has been manually segmented to extrapolate the vault. Therefore, the cloud portion was imported in CloudCompare for developing the surface. First, the RANSAC (RANdom SAmple Consensus) Shape Detection plugin was used to estimate the best-fit cylinder. Thanks to this, it was possible to align the cloud according to the y axis and get the required information for the cylindrical unrolling (x and z coordinates), using the Unroll command.

The results are the net surface of the intrados and the relating deviation map with the histogram showing the deviation distribution (Figure 23), based on which it was possible to choose the best result after several attempts.

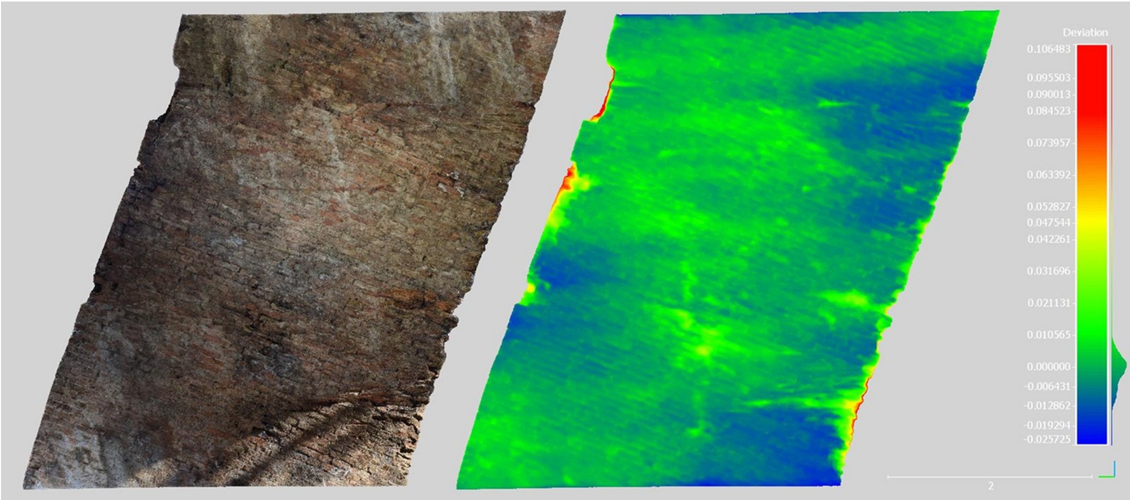


Figure 23 - The net surface of the intrados and the relating deviation map

Then the unrolled point cloud, converted in a .rcp format, was imported in AutoCAD together with the other converted one to carry out the geometrical analysis aimed at the verification of the consistency "rule of art" in the helicoidal method.
First, the generatrixes of the cylinder were drawn on the top and front orthographic projections and on the net surface of the intrados. Then, the longitudinal helices have been traced, based on the obtained point clouds.
The theoretical model has been modelled in Rhinoceros using measurements deduced from the point cloud. The constructed cylinder was sectioned by two planes inclined with a degree equal to 22. Once the surface was obtained, it was unrolled using the Unroll Surface command. Then, the result was imported in AutoCAD for the graphical analysis.
Firstly, considering the number of voussoirs on the crown, 69 generatrixes have been drawn on the intrados net and then projected both on the top and on the front. The longitudinal helices, whose direction was established by tracing a perpendicular line from the point A to the point B as a guide, according to the Curioni's method (Curioni, 1875), were drawn and projected in the other orthographic view (Figure 24).
The comparison between the ideal and the real models was made through overlapping. From the aforementioned, no substantial differences arise. Considering the deformations due to time and the already quantified error of the point cloud, the bridge seems to be built according to the "rule of art. Particularly it seems that the reference for the design of the bridge could be the Curioni Manual that is, as previously said, a collection of studies with updates, theoretical and experimental insights always careful to "art progress".
The research carried out on one of the oblique bridges of the Circumetnea railroad route showed that the construction of the vault was carried out in a workmanlike manner.

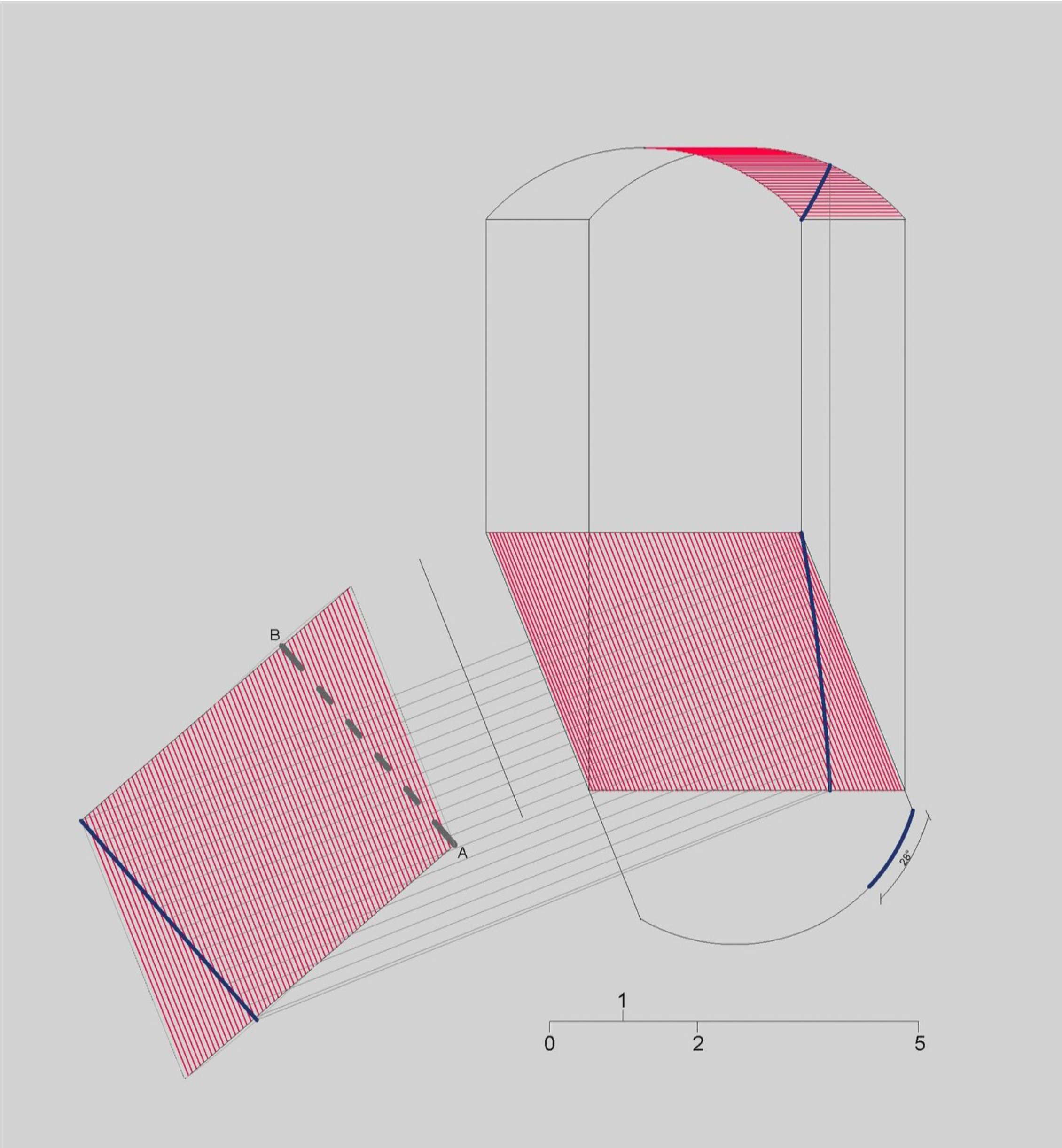


Figure 24 - The longitudinal helices construction

Through the tools of surveying and digital representation, it was possible to investigate in depth the geometrical rules underlying the design and construction of the helical apparatus identified. Another relevant result is related to the verification of the development procedure of the numerical model, directly carried out on the point cloud starting from the geometric information measured (radius of the arc, arrow, angle of obliquity), through the evaluation of the deviation from an automatic algorithm of best fitting of the cylindrical surface.
Given that the helicoidal equipment is closely related to the statics of the bridge, the subsequent stages of research will be directed to the assessment of the vulnerability of the arch to understand how much this equipment, no longer in use in construction practice, is still a technological solution of highest quality, whose knowledge can become of fundamental importance when it is necessary to undertake responsible and sustainable interventions of consolidation and conservation.

Finally, another interesting research perspective can be found in the deepening of the figure of the engineer Trewhella, to understand his active contribution in the construction of this type of bridge in relation to his British cultural background.

4.3.3 Maletto bridge

This particularly large bridge required the integration of laser scanning and drone photogrammetry. In the specific case study, the bridge had to be analysed with a particular focus on its context, due to a landslide.

Figure 25 - The Maletto bridge during the 2022 survey campaign

The analyzed bridge (Figure 25) consists of four depressed-arched barrel vaults. The span of all the vaults is equal to 8 meters, accordingly to the archival documentation found in the Circumetnea archives. The width of the barrel, measured parallel to the abutments, is about 4,2 m. The thick-ness of the brick vault is 60 cm, to which a 20 cm concrete layer is applied to support the place-ment of protective corrugated metal sheets. The spandrel walls are made using lava stone as well as the abutments. This bridge follows the same design solution as two other ones on the Circumetnea route (located in Maletto and in Mascali municipality). The TLS survey activity for the 3D acquisition of the Maletto bridge was conducted in two different phases. The first experience took place in 2021 using the Leica BLK360 Imaging Laser Scanner (scan rate: 360.000 pts/sec, accuracy: 6mm at 10m / 8mm at 20m, ranges: up to 60 m, size: H 165mm, D 100mm, weight: 1 kg).

Ten station points were set up to obtain a numerical model as complete as possible. Due to the presence of the landslide, it was possible just to partially survey the bridge. Indeed, just two of the four spans were clear out. The upper part of the bridge was not surveyed. The obtained numerical model is about 66,5 million points. The alignment error is equal to 0.007 m and the average overlapping is 44%.
The second survey campaign was conducted in 2022, after Circumetnea carried out an excavation to clean the site from the previous landslide. Despite the new arrangement, it was impossible to perform a much larger number of scans, due to the presence of a water stream and clay soil. Again, ten scans were performed. The obtained numerical model is almost 250 million points (Figure 26).

Figure 26 - Point cloud obtained through TLS survey

The acquisition of photogrammetric data was carried out using a dji quadricopter equipped with a 20-megapixel optical sensor. Three different flight plans, manually controlled, were programmed to geometrically reconstruct the bridge structure in a detailed 3D numerical model. The acquisition positions were chosen according to an angle of view ranging from 0 to 45° plus a nadiral flight to acquire images of the upper part of the bridge. To have an accurate GSD, the offset distances were lower than 20m. Moreover, oblique photographs were also taken with the camera tilted at -30° to capture hidden structural elements such as the arch bridge intrados, thus allowing achieving further details and characterizing the blind spots of the bridge.
A further nadiral flight was carried out to reconstruct a geo-morphological model of the area affected by the landslide movement, which included the involved portion of the bridge. In the post-processing phase, the acquired images were combined to create two different dense point clouds using the structure from motion technique as proposed by (Westoby et al., 2012) who used two-dimensional images acquired from multiple viewpoints, with at least 70% overlap between two adjacent frames, to de-fine a three-dimensional model of the framed subject.
The adopted SfM procedure produced two dense point clouds with different characteristics in terms of quality and quantity. The cloud (Figure 27) representing the single model of the bridge has a ground resolution of 4.28mm/pix and a total density of 63 million points.

The second cloud allowed reconstructing the geometry of the landslide body; it has a ground resolution of 4.13 cm/pix and a density of 13 million points. From this cloud, a digital elevation model (DEM) with a resolution of 8 cm/pix and a high resolution orthomosaic were derived (Figure 28).

Figure 27 - Point cloud obtained through UAV survey

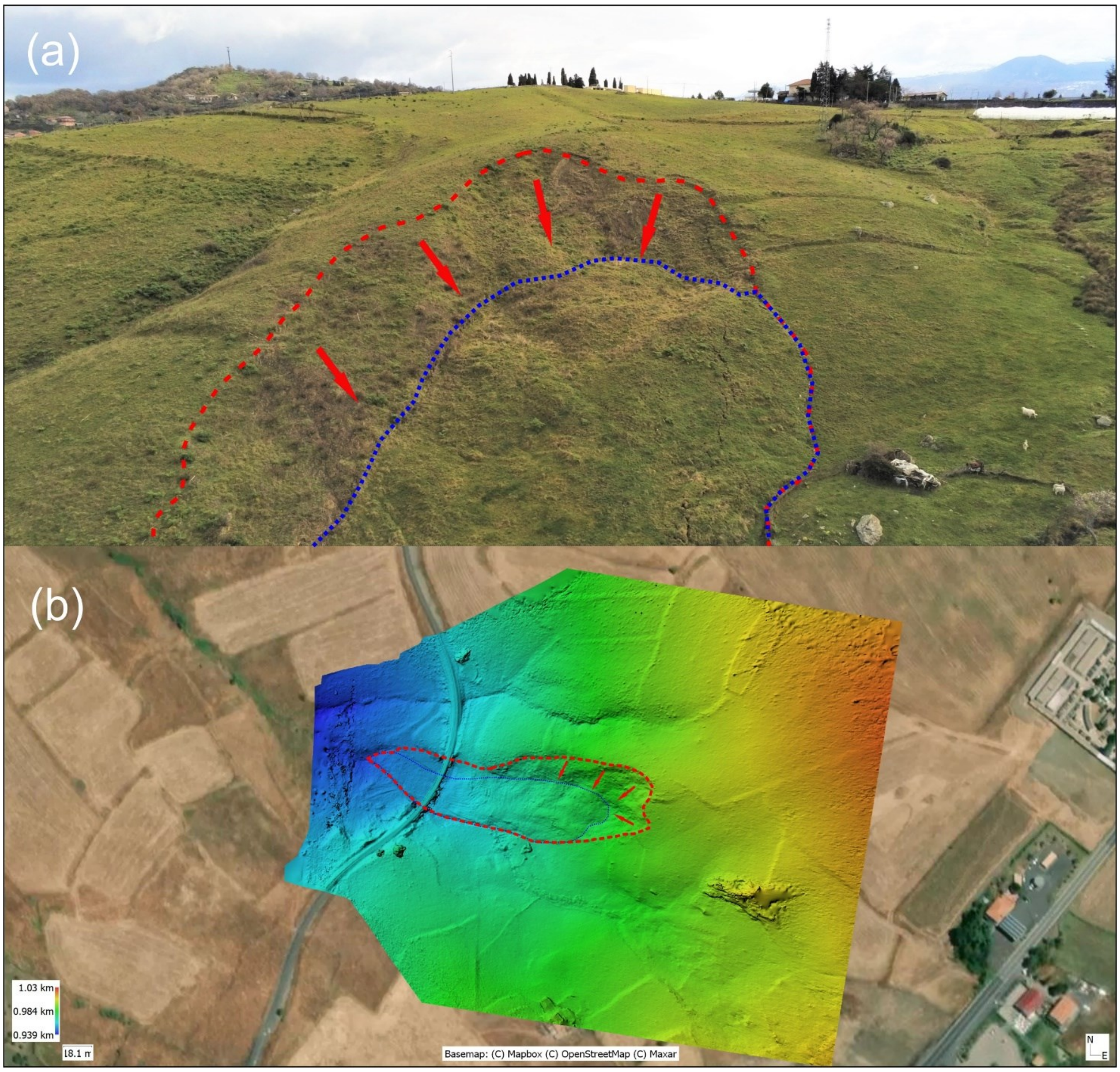


Figure 28 - Aerial photo taken by drone of the partial detachment niche and respective landslide body (a), DEM digital elevation model of the study area, with geometric reconstruction of the entire landslide (b)

Three different point clouds were obtained from this research work: the first BLK point cloud with the landslide, the second BLK360 point cloud, after the earthworks, and the point cloud obtained through UAV survey. Excluding the first TLS campaign, which will be the subject of a future comparative analysis inherent in aspects more related to the landslide, some metric and visual analyses are proposed for comparative purposes, to evaluate the accuracy and the reliability of the TLS and UAV models.
The comparison was performed with the open-source software CloudCompare, using the Cloud-to-Cloud algorithm (C2C), which allows measurement of the metric deviation between two clouds. The BLK360 point cloud was chosen as the reference cloud because it is characterized by higher accuracy. The comparison was performed by analyzing the global accuracy of the entire point cloud. The global comparison shows that most deviations range from 0 mm to 1,25 cm (blue and green points). Larger deviations (red points) occur where the drone point cloud is missing, especially at bridge spans. Figure 29 provides a blue/red color scale for the C2C analyses between the BLK360 and UAV point clouds.

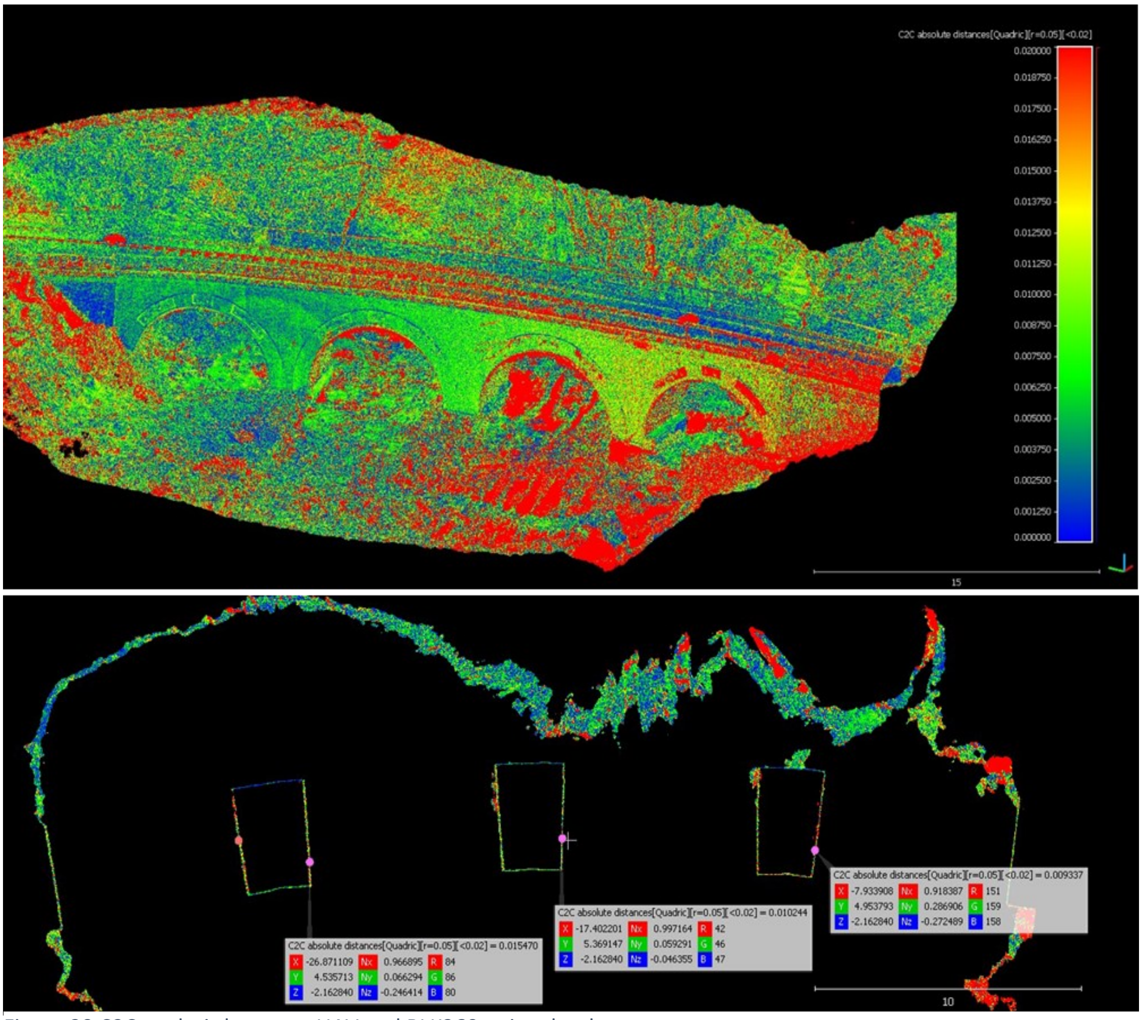


Figure 29 C2C analysis between UAV and BLK360 point clouds

The survey of masonry bridges is particularly challenging, precisely because of the morphological characteristics of these structures. The integrated survey is often the best strategy for a restitution as accurate as possible. In the case of the bridge of Maletto, a hybrid strategy has been adopted.

In the case of the bridge under investigation, it was not possible to achieve enough overlap between the clouds in both survey LIDAR campaigns to eventually make automatic alignments feasible. The use of the point cloud from drone, therefore, in addition to allowing the survey of parts that would otherwise be difficult to reach safely (such as the railroad), was used as a reference to perform the alignments between scans taken from camera points that were too far from each other.

4.4 Proposal of survey protocols

Based on the information obtained through the surveys and research conducted within the scope of this study, specific protocols have been developed for surveying masonry bridges. These protocols aim to establish a practical framework that guides operators in conducting surveys of bridges with different dimensions and diverse characteristics. The table presented below illustrates the suggested techniques categorized as "ideal," "suitable," and "not recommended" for surveying masonry bridges, depending on the typology of bridge (low and high single-span bridge, low and high multiple-span bridge). The symbol “+” indicates a combined technique, whereas the geometric-dimensional survey and the detailed survey are denoted by the colour black and grey respectively.

The aforementioned proposed protocols are shown in Table 2. Some of these protocols are herein commented. For instance, the use of drone surveying is discouraged for low bridges, including both single-span and multiple-span structures, due to the limited maneuverability associated with these types of bridges. In such cases, simultaneous localization and mapping (SLAM) technique is well-suited. This technique, involving a single surveying session, is suitable in the case in which the underlying ground level and the upper portions of the bridge can be reached within the same surveying session. Aerial photogrammetry is generally suggested for multiple-span high bridge, as the limits of the drone can be bypassed and the laser scanner allows an easy survey of vaulted elements.

The establishment of these protocols provides a standardized approach to bridge surveys, ensuring consistency and accuracy in data collection. By employing the suggested techniques, operators can effectively capture the necessary information while considering the specific requirements and characteristics of masonry bridges.


Ideal
Suitable
Not recommended
Low single-span bridge
High single-span bridge
Low multiple-span bridge
High multiple-span bridge
Laser scanner
SLAM
Aerial photogrammetry
Terrestrial photogrammetry
Videogrammetry
Geometric-dimensional survey
Detailed survey

Table 2

Chap. 5 Semantics – Research item 2

5.1 Introduction

5.1.1 Digital survey, AI, and semantics: an ever-changing scenario

In recent years, digital surveys have moved from being pioneering applications to become routine procedures. Numerical models, known as point clouds, describe geometric and non-geometric information, essential in several fields of applications, including architecture and infrastructures (Bisheng et al., 2017; Bosche et al., 2015; Fröhlich et al., 2004; Maietti et al., 2020; Yang et al., 2022). Moreover, recurrent acquisitions of point clouds over time allow multitemporal monitoring, through the comparison of the data acquired during different times. On the other hand, data obtained provides numerous qualitative and quantitative information on the artefact, but ontologically indistinct (Colucci et al., 2021; Hmida et al., 2012). Hence, data interpretation is moved to a later moment and requires the involvement of a trained operator (Migliari, 2001). The interpretation of semantic data is strongly debated by the scientific community. Artificial Intelligence with Deep Learning (DL) techniques can provide valuable support in this direction, speeding up long and repetitive procedures prone to human error. The learning process of neural networks can be guided by ontologies that, as conceptualisations of a domain of interest, are able to feed these systems with the needed information. Hence, ontologies are widely used in semantic web development and have a pivotal role in DL applications (McGuinness et al., 2002; Sure et al., 2002). Besides that, ontologies are nowadays introduced in BIM workflows to semantically structure data and help in the management of repositories and web libraries. The semantic-related aspects of information modelling, especially in terms of level of granularity, and the opportunities given by a well-structured database related to BIM models, are some of the liveliest research topics in information modelling, in both heritage and infrastructure fields.

5.2 Research gap and research proposal

Masonry arch bridges, especially railway ones, are civil engineering artworks characterized by specific features. Although they are parts of in-use infrastructures, they should not be considered as infrastructure assets in the narrower sense, since their construction straddles the line between the 19th and the 20th century, and they are no longer being built nowadays. Therefore, rather than considering the design approach, it is necessary to deal with the management as well as the preservation and valorisation of this heritage, since it is prone to natural and anthropic hazards likely to any other cultural asset.

Handling with masonry arch bridges means finding a meeting point between the best practices for infrastructure management and those for the study and enhancement of cultural heritage.

This aspect makes this area of study not yet strongly explored. Moreover, ontologies in the engineering field have been extended adopting several standards and developing ontology building tools. This led to a broader comprehension of the importance of standardised vocabularies and formalised semantics. There is a need for workflows and procedures that allows a reliable data exchange with the appropriate level of granularity indeed. Although buildingSMART International project IFC-Bridge (Borrmann et al., 2019) proposed a bridge oriented extension of IFC (Industry Foundation Classes), it particularly focuses on the design of reinforced concrete bridges and lacks a structured solution for managing the complex analysis of bridges state of health.

On the other hand, considering masonry bridges from a Cultural Heritage point of view, neither the standard specifically designed for cultural heritage, the CIDOC Conceptual Reference Model (CRM) (ICOM/CIDOC CRM Special Interest Group, 2011), nor its extension contains a specific focus on masonry arch bridges.

Given the above-mentioned scenario, two key research questions arise:

Which ontology structure is best suited to describe the different aspects necessary to investigate to get a more complete understanding of masonry arch bridges?

How this knowledge domain could be exploited for a BIM semi-aided modeling with a focus on vulnerability assessment?

The development of new ontologies or the extension of one of the aforementioned standards for a holistic analysis of masonry bridges are surely an interesting step in the evaluation of the state of health of these assets, which requires a deep analysis of available standards and ontologies. Creating a new data schema or an extension could also serve to add semantic layers to H-BIM models or to help neural networks in semi-automatic point cloud segmentation, helping operators to simplify time-consuming and repetitive procedures.

The presented research aims at showing the result of an in-depth analysis conducted on masonry arched bridges computational ontologies; following this, the authors propose a semantic conceptualization in masonry arch bridge domain, structured with three group of key concepts needed in the process of knowledge: bridge elements, materials, and defects.

This conceptualization represents the very first step in the creation of an ontology that will be used as a knowledgebase for deep neural network training, toward bridge parts and defects semantic recognition, with the dual goal of aiding the automatic segmentation of masonry bridge point clouds and supporting the semi-automatic creation of informative models, structuring part of the metadata. From this point of view, choosing the best-suited-to-these-tasks formal structure is crucial.

5.3 Materials and methods

In this framework the research is focused on the semantic aspects, where the design of a masonry arched bridge computational ontology will constitute the basis for the automatization of the segmentation process being - the knowledgebase for deep neural network training - and the connection with the new concepts in the H-BIM workflow.

The under-development ontology needs to meet both the cultural and the structural aspects of masonry bridges. In addition, to smoother the creation of the ontology, a mixed approach exploiting top-down, and bottom-up potential has been considered. Indeed, the first one was functional to identify the classes and concepts to be described. The other one helped to characterize the materials and construction techniques that are specific for each geographic area. In this case, the masonry arch bridges of Circumetnea have been selected as a case study to support materials and construction techniques identification and test the ontology applicability to the purposes of the research.

To accomplish the first approach, historical treatises and manuals need to be consulted to extrapolate the terminology, the identification of parts and their relationships. As for the constructive techniques and materials, they vary according to the area and the construction period. All these aspects concur to define the different typologies. In addition, also the structural aspects and state of conservation issues need to be considered. Once all these aspects are explored and identified, the conceptualisation step of the ontology can be run up to define a scheme.

The data scheme needs to be verified against other existing schemas (i.e., IFC-bridge, CIDOC) to understand if it is better to develop an extension of those existing ontologies or develop a brand-new one. Furthermore, the comparison allows us to understand which concepts are considered and which ones must be added. In any case, the data schema needs to be implemented in terms of materials, building techniques and state of preservation according to a selected case study.

In summary, the methodology is structured as follows:

- Conceptualisation: it provides an in-depth survey of existing vocabularies and taxonomies. Then, the identification of the relationships and hierarchies between parts to choose the proper classes, subclasses, and properties of the developing ontology is required. It is crucial to conduct in-depth research by consulting technical manuals and treatises and analysing several case studies and their typologies.
- Comparison of existing ontologies: it is helpful to understand whether it is better to use an existing ontology or create a new one.
- Ontology development: a particular attention is given to the level of granularity. Some levels of information to be added, for instance, are related to the semantic structure, construction techniques, and typical defects.

The research work here presented focuses more on the first two aspects of the pipeline herein described.

5.3.1 Definition of requirements

Creating an ontology is a very complex process from a technical point of view (i.e., use of ontology editors and frameworks, knowledge of programming languages) and requires a deep understanding of the instance to be classified. Given the above-mentioned considerations, working on masonry bridges requires information about three essential aspects: i) the construction techniques and materials, ii) the elements concerning the geometry and, finally, iii) the aspects regarding the masonry bridges state of health, which can be defined through an analysis of defects. The ontology field in the AEC (Architecture Engineering Construction) industry has been strengthened by the adoption of several standards and by a higher recognition of the importance of standardized vocabularies. Among masonry bridges, especially if carriageable or pedestrian, it is possible to find ancient specimens. Due to their configuration, these assets are characterised by a stratigraphy that need to be analysed through an interdisciplinary and archaeological-oriented approach (Savini et al., 2021). In this direction, the reference to CIDOC and its extension fits perfectly. Nevertheless, masonry railroad bridges make such a classification difficult to apply and require, at the very least, the revision or the creation of an ad hoc CIDOC extension.

In terms of geometric aspects, part of the requirements is satisfied by the IFC standard, as the most common vendor-independent format to exchange BIM models. At the moment, IFC does not fully support infrastructure constructions like roads, bridges and tunnels, despite the recent developments of IFC4, which include the under-development IFC-Bridge extension.

The extension presents, indeed, a first rough subdivision in substructure superstructure and deck, that goes to a more accurate subdivision into abutment, deck, deck_segment, foundation, pier, pier_segment, pylon, substructure, superstructure, surfacestructure. This level of granularity is suitable for structural analysis or other kinds of applications, as it is evident from the framework of Discrete Macro-Element Method (DMEM) software, e.g. HiSTrA Bridges (Caddemi et al., 2019).

The element vault is not classifiable now according to the IFC-bridge format but as a user-defined element; indeed, despite allowing the attribution of an arch structure, IFC-bridge does not lets to fully define its configuration. In the study and analysis of masonry arch bridges, both from a structural and a conservation point of view, aspects related to the vault are essential, especially dealing with geometrical information (i.e., type of arch that generates the vault - round a., lowered a., pointed a.; type of vault - straight v., oblique v.).

For an accurate knowledge of the artifact, also aiming at the integration of information on the health status, it is necessary to go into a higher level of detail. This becomes crucial, for instance, in the analysis of geometric aspects as in the study of skew vaults or when, for reasons related to the analysis of decay, it becomes critical to analyse the single ashlar that is part of the vault. In this direction, the aspect linked to the documentary information heritage regarding the bridge object is certainly important. Therefore, linking all the information to the corresponding parts is a key point in the creation of a fine-grained BIM model, able to become an information hub

capable of describing the architectural object in its entirety, in order to investigate the semantics of bridge components and the construction phases of these assets.
Deepening the aspects related to the masonry bridge's state of health, the classification and analysis of defects is a very specific one, characterized by a considerable complexity. This is due to the close relation of defects with both materials and geometric apparatus of bridges. It therefore requires further investigations and the creation of a purpose-built classification that needs to be developed subsequently and according to the semantisations.
A further point, related to the training of neural networks, sees the importance of using semantics to guide the training of neural networks, both in the field of image recognition and in the generation of synthetic datasets. In this case, a core point is related to the use of an ontology that contains information on the position in space of elements composing masonry bridges.
Aiming at this, advances the hypothesis of the creation of an ad hoc ontology, consistent with the IFC-bridge standard, that is believed to be, with its interoperable address, the most suitable tool to pursue the purposes of this research.

5.3.2 Conceptualisation

The conceptualization process started organizing concepts based on a semantic triple model, a set of three entities that codifies a statement about semantic data in the form of subject–predicate–object expressions (Figure 30). To better manage the creation of the semantic conceptualization, a mixed bottom-up and top-down approach have been used, according to the needs explained below.

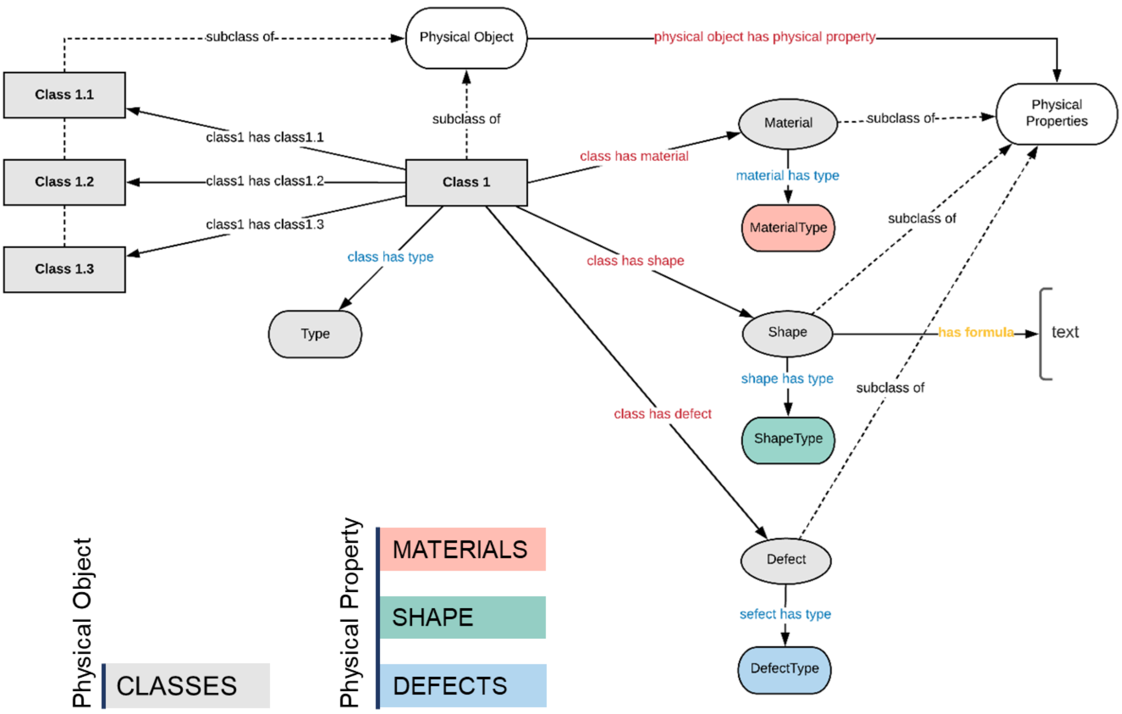


Figure 30 - The conceptualization scheme

A top-down approach was adopted to identify classes and relations between bridge elements, with a focus on their characteristics and geometric shapes. Applying an analytical-technological method, the components of the bridge were identified with the related details and nomenclature; the functional hierarchy of each part relating to the whole was highlighted. To reach this goal, historical treatises and manuals need to be consulted.

During this process, an important reference was the illustrated dictionary (Torre, 2003), that suggests a remarkable and comprehensive classification of most of the concepts related to a masonry bridge instance. Adopting the general classification criteria enlightened in this reference, these items were categorized. Also, several information related to dimensional and geometrical aspects were empathized, i.e., the plan layout and the arch profile of vaults.

Starting from the object Masonry arch bridge, the main classes identified are Spandrel Wall, Pier, Vault, Roadway, Foundation. Each of these classes, conceived as subclasses of a more generic Physical Object class, is characterized by types (different typology of the same class) and lower-level concept categories (other classes that compose the more generic ones). These classes are characterized by Material, Shape and Defect, designed as Physical Property.

The Shape property is slightly different from the others. It is designed to have, among its features, the possibility of adding formulas as a text. This is a key point for elements such as the vault that, as previously mentioned, is one of the most significant elements in masonry arch bridges (Figure 31).

On the other hand, a **bottom-up** approach starting from the chosen case study helped to characterize materials. This kind of approach has been preferred because materials and construction techniques are

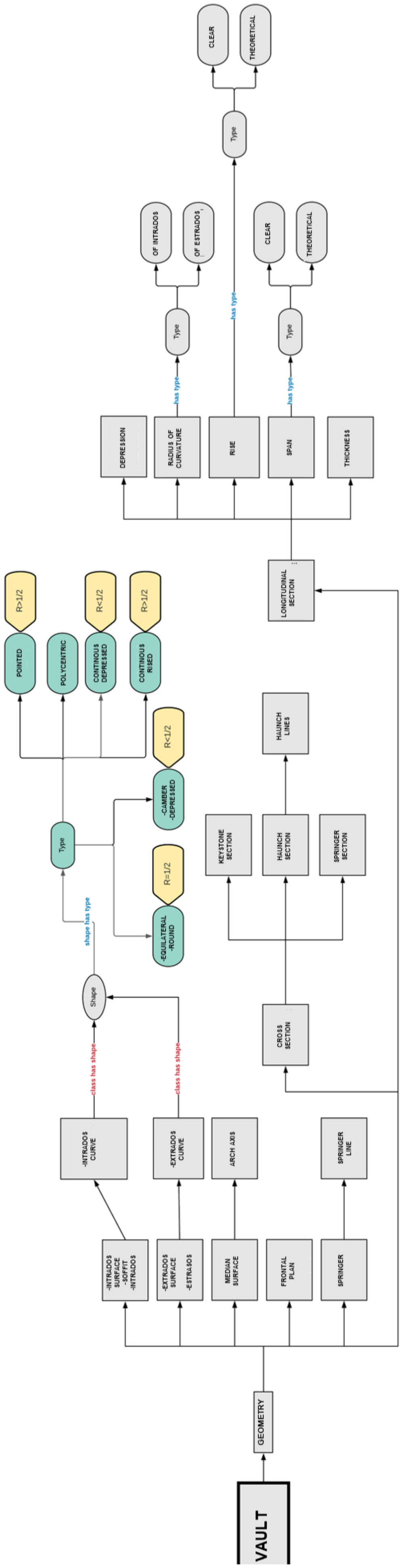


Figure 31 - The conceptualization of the class "Vault"

specific to each area and, at least in this first phase, it was chosen to better focus on previous classes and on the methodological approach in general.

In addition, also the structural aspects and state of conservation issues need to be considered. In doing this, a mixed approach exploiting top-down, and bottom-up approach was followed (Figure 32). As a reference, the authors use both the Italian guidelines for monitoring and managing existing bridges and some inspection sheets, previously produced for the Circumetnea under an agreement with the Department of Civil Engineering and Architecture of the University of Catania.

An aspect that does not emerge from this first conceptualization is related to the position of the objects in space, a crucial point for the application of the ontology in the training of neural networks and in the creation of synthetic datasets. Indeed, for this aspect, the authors are considering a solution to be applied directly to the architecture of the ontology, through the creation of special connected classes, which convey the objects by defining their relative position.

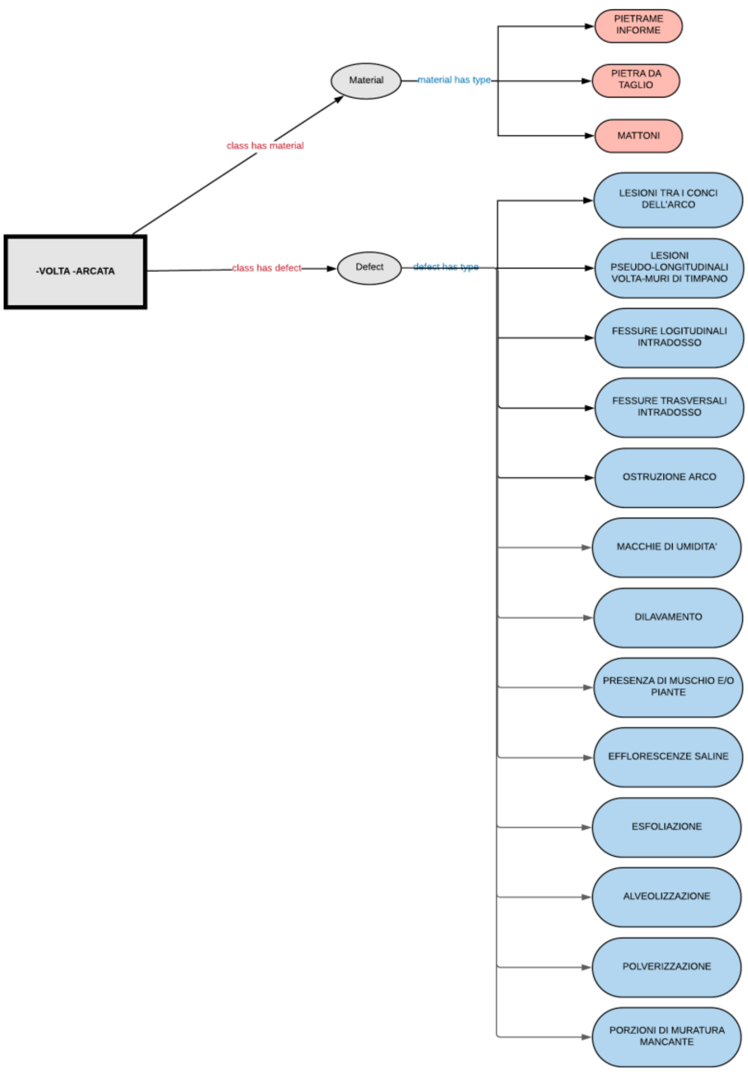


Figure 32 - The conservative issues in vault elements

Chap. 6 Point Cloud segmentation – Research item 3

6.1 MATLAB application for Point Cloud segmentation

In recent years, laser scanning and other survey techniques have become increasingly popular for the documentation and preservation of architectural heritage. Bridges are complex structures that require careful monitoring and maintenance to ensure their long-term structural integrity. However, the analysis of these large and complex point clouds can be a challenging task, requiring advanced computational techniques and software tools. To assist in the analysis and utilization of these point clouds, including modeling purposes, the application of intelligent segmentation procedures can be crucial. The segmentation of 3D point clouds involves categorizing them into distinct regions that share similar characteristics. To achieve this goal, various approaches have been proposed in the past (Che et al., 2019; Grilli et al., 2017; Nguyen & Le, 2013; Zhang et al., 2019).

One approach is to employ machine learning algorithms, such as deep neural networks, to learn patterns and features from labelled point cloud data. These models can be trained to recognize and differentiate different objects or regions within the point cloud ((Bello et al., 2020; Pierdicca et al., 2020; Wang et al., 2020).

Another approach involves utilizing coding techniques, such as voxelization or octree representation, to discretize the point cloud into smaller units. These units can then be analysed and classified based on their local properties, such as density, curvature, or colour (del Río-Barral et al., 2022; Lamas et al., 2021; Poux & Billen, 2019; Tchapmi et al., 2017).

These approaches have shown promising results in achieving accurate and efficient point cloud segmentation, enabling a wide range of applications.

6.2 MATLAB application for Point Cloud segmentation

Starting from the point clouds acquired during the survey campaigns described in Chap. 4, a methodology to obtain the main components of the bridge vaults has been developed. The technique has been developed in collaboration with the Applied Geotechnology Group

CINTECX – Centro de Investigación en Tecnoloxías, Enerxía e Procesos Industriais Universidade de Vigo, Vigo (ES) under the supervision of Belén Riveiro Rodriguez. Based on the technical procedure proposed by (Riveiro et al., 2016a), the bridge point clouds have been segmented and the vaults have been isolated, to directly work on these elements. Specifically, the objective is to obtain dimensional data to speed up the scan-to-BrIM procedures.

The methodology involves several steps, which have been implemented through a MATLAB code. The first step in the methodology is the application of principal component analysis (PCA) to rotate the vault into its main direction.

PCA is a statistical technique that is widely used in data analysis, machine learning, and other fields. PCA works by finding the principal components of a data set, which are the directions along which the data vary the most. These principal components are determined by analysing the covariance matrix of the data set and identifying the eigenvectors of this matrix. The eigenvectors represent the directions along which the data vary the most, and the eigenvalues represent the amount of variance in the data that is explained by each eigenvector. By applying PCA to the point cloud data, the vault can be rotated so that its main direction is aligned with one of the principal components, making it easier to analyse and visualize.

However, the presence of points in the clouds not equidistant between each other resulted in a not accurate rotation of the vault along its longitudinal direction. To overcome this issue,a voxelization of the point cloud was performed. Voxelization is a process that involves converting an object represented by geometric primitives into a three-dimensional grid of voxels (volumetric pixels). Each voxel represents a small volume of the object, and its properties such as colour, material, and texture can be assigned based on the corresponding properties of the original object. A new MATLAB variable class `Voxels` is defined through the function `classdef`, and the points are transformed into voxel elements by means of the function `voxelize` (see Appendix). The voxelized point cloud is shown in Figure 33.

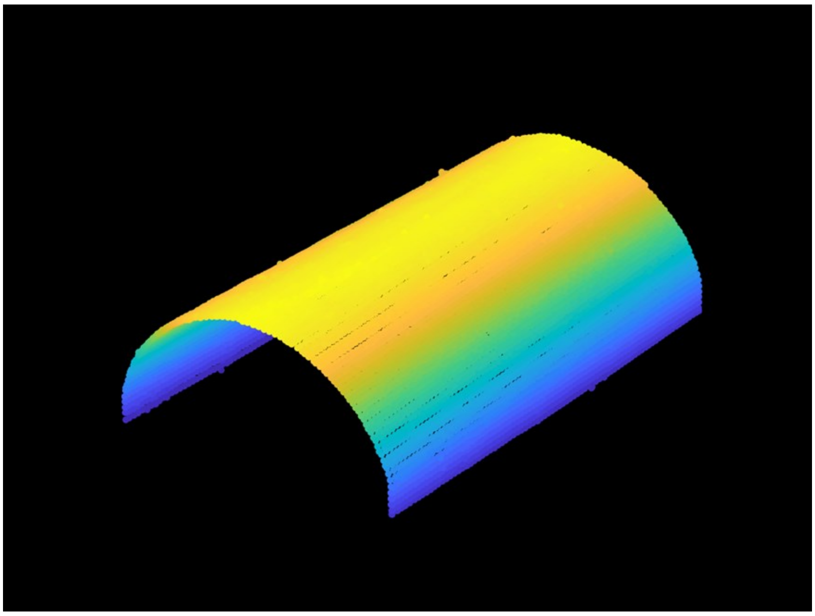


Figure 33 - The vault of the Bridge “Solicchiata” after the application of the voxelization algorithm

To furtherly facilitate an accurate PCA application, the voxelized vault has been flattened, i.e. the vertical component of each voxel has been set to zero. After the application of PCA, resulting in a correctly rotated vault, first the length of the vault is computed and then a slice of the vault is selected, followed by the application of polynomial fitting to the points to obtain a continuous version of the vault slice. This step allows to facilitate the analysis of the geometrical and dimensional characteristics of the vault. Figure 34 shows a vault section automatically extracted by the MATLAB code, defined by the positions of each voxel centroid.

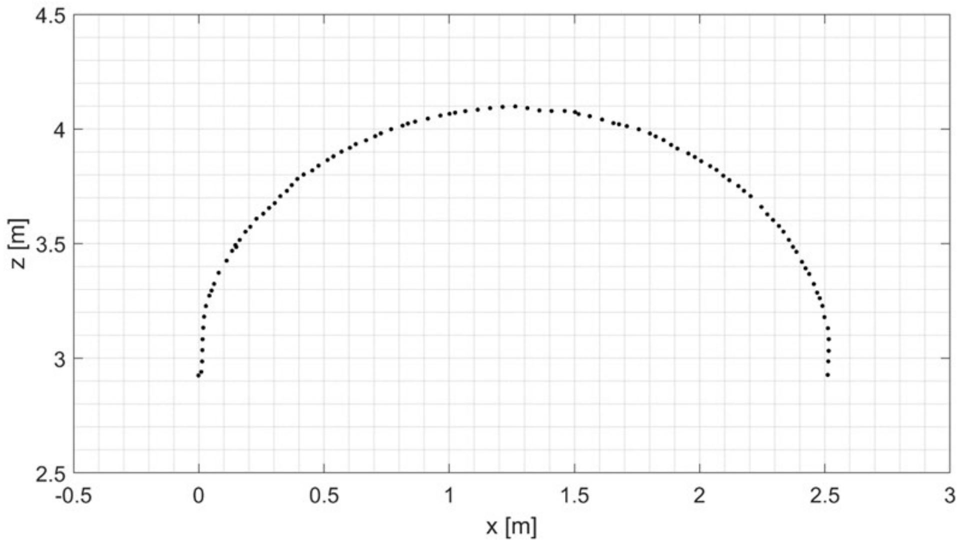


Figure 34 - A vault section automatically extracted by the MATLAB code.

Finally, the main geometrical characteristics of the vault are obtained, e.g., the width of the section, the arrow and the span Figure 35

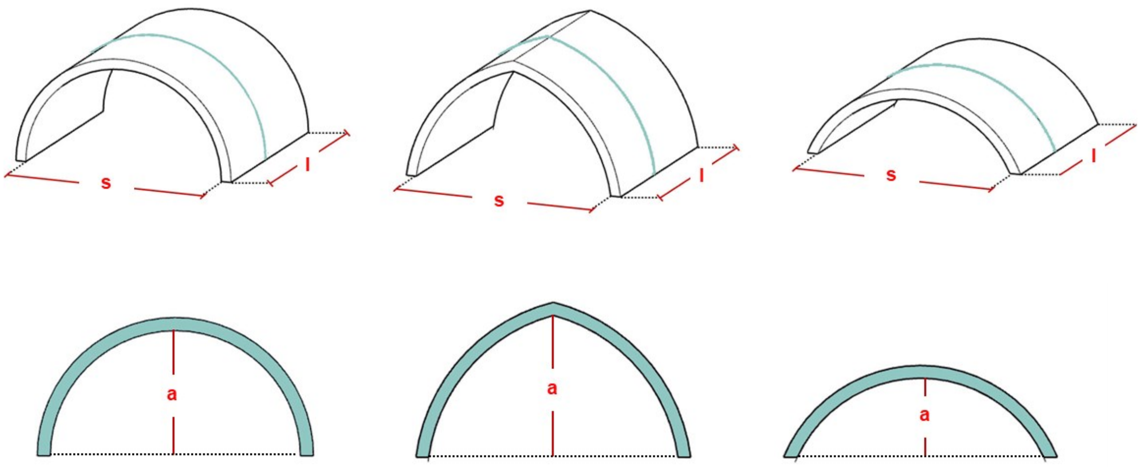


Figure 35 - Geometric characteristic of the vault extracted.

By means of conditional algorithms, the typology of lowering of the vault is defined. Specific thresholds are set for lowered arch, for raised arch and a barrel vault. Furthermore, two circular arcs are fitted in the two halves of the section in order to obtain the two centres of the arcs and depending on the abscissas of the right and left centre coordinates, the vault is classified as "polycentric arch" or "pointed arch", depending on the relative position of the fitted circumferences as shown in (Figure 36).

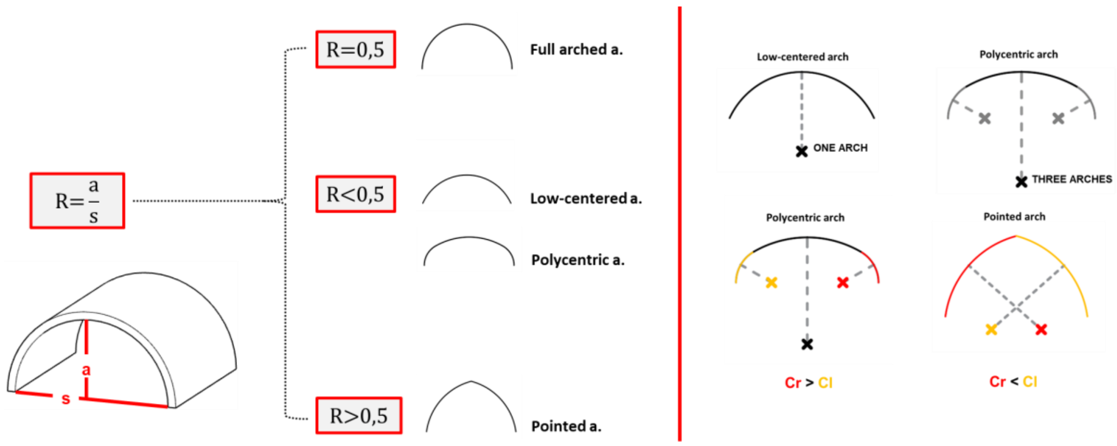


Figure 36 - The criteria for the classification of vault

Figure 37 shows the code flowchart of the abovementioned procedure, with the dimensional thresholds. The implementation of the methodology through a MATLAB code also allows for its easy replication and application in other projects and contexts, and the development of a user interface powered by free MATLAB Runtime Compilers, i.e. usable also by MATLAB non users.

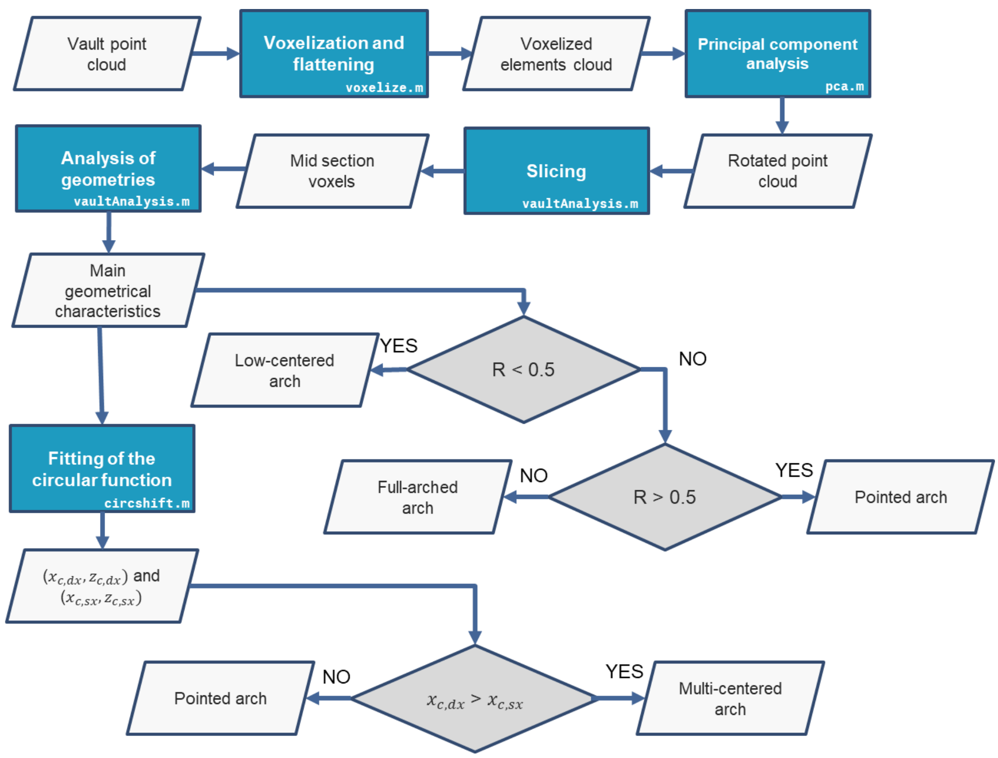


Figure 37 - Flowchart of the proposed methodology

Chap. 7 H-BrIM – Research item 4

7.1 Introduction

Digital technologies undoubtedly provide valuable support in the AEC (Architecture, Engineering and Construction) sector throughout the building lifecycle, from conception, design, construction, management, and demolition. As stated previously, The BIM approach allows the continuous verification of the entire construction process through the creation of a model that is to all intents and purposes a virtual copy of the individual building represented, in which each building component is both described geometrically and from an information point of view, thus allowing full control of the construction process (also from the point of view of site organisation) and maintenance of the building (Pavan et al., 2017). Today, the BIM approach is the most appropriate methodology for designing from scratch, as well as for working on existing buildings. The BIM model can be defined as a semantic 3D database, each building component an element of this database, containing both geometric and alphanumeric information. The relational database underlying the model is made graphically explicit through 3D views, 2D drawings, and schedules. In addition, since these are parametric models, every change in the model has an impact on all the project drawings, which are automatically updated. In the context of this thesis work on the railway buildings of the Circumetnea Railway, BIM issues will be tackled at the scale of the built heritage (HBIM) (Banfi et al., 2017; Continenza et al., 2018; Guzzetti et al., 2021)and at the territorial scale (InfraBIM) (Conti et al., 2020; Dall'O' et al., 2020; Pepe et al., 2020; Previtali et al., 2019) by experimenting with the possibility of a union between the point element constituted by the buildings and the linear element, i.e., the railway line.
Infrastructure is understood as a complex of capital goods that, although not used directly in the production process, provide a series of services that are indispensable for the functioning of the economic system: roads, railway lines, ports, schools, hospitals, etc. In this context, the effectiveness of the logic behind the BIM methodology can provide valuable support in an extremely complex area, both in the design phase and in the maintenance and management phase of infrastructures. In this case, the term Infra-BIM (Infrastructure-Building Information Modeling) is used, meaning the system that manages the information processes of infrastructure construction. Since this definition came into being recently, the terms 'Heavy-BIM', 'Horizontal-BIM' and 'Civil Information Modeling' (CIM) are also sometimes used to distinguish it from the generic BIM used in the field of building construction for point works and vertical structures.
The introduction of BIM for infrastructure causes a paradigm shift in terms of process: the innovation concerns interoperability, i.e., the possibility to exchange data between different information managers. IFCs are not yet available, however, for all the 'intelligent objects that make up the solid road and that are indispensable to realise its complete virtualisation. The relative evolutionary delay of infrastructure parametric models, compared to those widely used

in construction, depends on the evident greater complexity of the former; in fact, digital objects for large-scale works are characterised by heterogeneous relational links with numerous other spatial context models.
The tools and methods that can be used are many and rapidly evolving, as are the processes that should ensure their optimised and standardised use, with guidelines to follow. The first step in this direction is based on certain actions aimed at knowledge, analysis, and monitoring. The digitisation of infrastructures into semantically enriched parametric 3D models involves multiple aspects, ranging from the analysis of the area of influence, to the assessment of interference with other infrastructures (point or networked), to the interaction with structural, architectural and plant engineering works, sometimes even of historical, artistic, and environmental interest. The multidisciplinary approach introduced requires the processing of data belonging to different domains (BIM, GIS, point clouds, IoT, etc.), to enable different uses (such as, for example, structural or energy analyses, but also and above all management and maintenance). It is therefore necessary to manage at the same time ensuring interoperability between information related to the territory by means of GIS platforms that adopt a spatial logic and therefore extend horizontally (shapefiles) considering surfaces or point representations) and data concerning structural or architectural works, which therefore require a 3D description by means of information models.
In view of the above, in order to work correctly in the field of InfraBIM, it is necessary to involve different disciplines, each with its own specific competence, in order to allow the definition of an overall framework capable of guaranteeing the correct interrogation of data over time, for a multidisciplinary use, capable of facilitating the definition of intervention strategies based on up-to-date and quality data. This wealth of information, if correctly utilised, will over time prove essential not only to optimise the design and implementation phases, but will above all provide effective support during operation.

7.2 H-BrIM for bridge health assessment

As a knowledge collector, BIM requires agility in connecting structured databases, whose use is essential dealing with assets of considerable complexity, such as infrastructure and cultural assets. Interoperability research in BIM for architecture, engineering, construction, and facility management is a trend nowadays (Ozturk, 2020). IFC data exchange standard has been primarily designed to describe buildings; the increasing need for full adoption of BIM approach in infrastructure domain (Costin et al., 2018) led to the development of extensions of the IFC scheme, to integrate information and concepts about infrastructures, such as bridges, roads, railways, and tunnels.
Several researchers analysed this open international standard, such as the study of (Borin & Zanchetta, 2020), enlightening its limitations and potentials, thus revealing a mixed scenario.

In general, the IFC scheme is more suitable for managing geometry and structured information than integrating unstructured data or semantic knowledge.

Speaking of bridges, there is a wider interest in concrete or steel facilities, given the high incidence of these typologies around the world (Trzeciak & Borrmann, 2018). There are numerous IFC extensions, that range from those used to enable BIM-based descriptions of structural health monitoring systems in compliance with IFC modeling capabilities (Theiler & Smarsly, 2018) to those collecting domain knowledge of bridge rehabilitation to improve information integration and constraint management (Wu et al., 2021). In the context of structural analysis requirements, (Park et al., 2020) propose an extended IFC-based bridge information modeling method using a process to apply the meshfree structural analysis method to the IFC-based model. (Isailović et al., 2020) presented an approach for point cloud-based detection of spalling damage joined with a method for semantic enrichment of IFC model with damage semantics. (Ismail et al., 2017) improved the semantic quality of BIM models and link specific domain information from various domains with focus on bridge models based on the IFC standards. In (Esser & Aicher, 2019) the Visual Programming Language (VPL) tool Dynamo was used to prepare bridge models from InfraWorks, because neither InfraWorks nor Revit have a native IfcBridge interface yet. Thus, the authors developed an innovative Dynamo library containing nodes to interact and export bridge models into the new IFC 4x2 standard.

In (Simeone et al., 2019) a prototypal application for Semantic-enriched BIM was applied to build heritage case studies.

In the view of the above, an attempt was made to investigate the problems relating to the digitisation and conversion into the open IFC format for a masonry vaulted element forming part of a bridge, as a typical case not included in the international standard definition.

As highlighted in a study carried out by BuildingSmart Italy (Guida All'IFC per i Ponti – BuildingSMART Italia; Basso & Bernardello, 2020), one of the critical issues to be addressed is mainly related to the classification of elements constituting a masonry bridge through the IFC format. This mainly concerns complex geometric elements typical of masonry bridges.

One of these is certainly the vault. Such an element, that can be easily encountered in buildings, especially historical ones, in masonry bridges assumes a unique architectural and structural meaning.

The specific problems encountered for the masonry vaulting can be traced back mainly to finding the correct semantic combination between the actual element and the corresponding class of the standard. By having to use a standard designed for buildings, the vaults in a bridge no longer become the enclosing elements of a room, but become the support of what is present above, making the modelling of the element forming part of the bridge conceptually different from the standard. It is thus easier, for example, to model a vault with the 'roof' command, whose default export class would be IfcRoof. This results in a necessary customisation in the production phase of the IFC model, which is not always processed by the software.

However, after a thorough literature research on the matter and a series of attempt to apply the above-mentioned procedure, it resulted that the feasibility of the procedure was not compatible with the timespan of the present study. Therefore, the presented matter is today an open question that requires further developments.

7.3 InfraBIM

The first objective of the research on the InfraBIM approach, was to build a portion of the Circumetnea railway system within Infraworks, which would comprehend at least one for each element of the rail line (signalman's house, bridges, stations etc.). As for masonry bridges no proper IFC classes do exist, a first attempt to model Circumetnea elements was carried out starting from the signalman's house and the rail line elements, with the aim to start with components with existing IFC classes.

The case study dealt with an issue involving parametric HBIM models arranged along a railway line, a linear infrastructure. The need therefore arises to be able to visualise these objects within their context, which must allow the buildings to be analysed and viewed in their geometric and parametric structure (thus reading all their information). The context itself must be parameterised to become a "virtual container" of information. An attempt was therefore made to understand the possibility of making the buildings on the line interact with the linear infrastructure to which they belong.

7.3.1 Creation of the context model

The line under consideration lies between the municipalities of Piedimonte Etneo and Linguaglossa, located at the foot of Mount Etna. The Autodesk Infraworks software was used to create the basic spatial context. Using the "Model Builder" command on the access screen, it is possible to create 3D models of the territory quickly and easily by defining a specific area of interest for a maximum extension of 200 square kilometres. The georeference system is set as WGS84. Once created, the model describes the terrain orography of the area it refers to, within which buildings, roads and railways are inserted. The models created through Infraworks can be used to contextualise the area of a project, although some elements such as roads, railways and rivers are sometimes represented incorrectly, with overlaps and intersections (Figure 38).

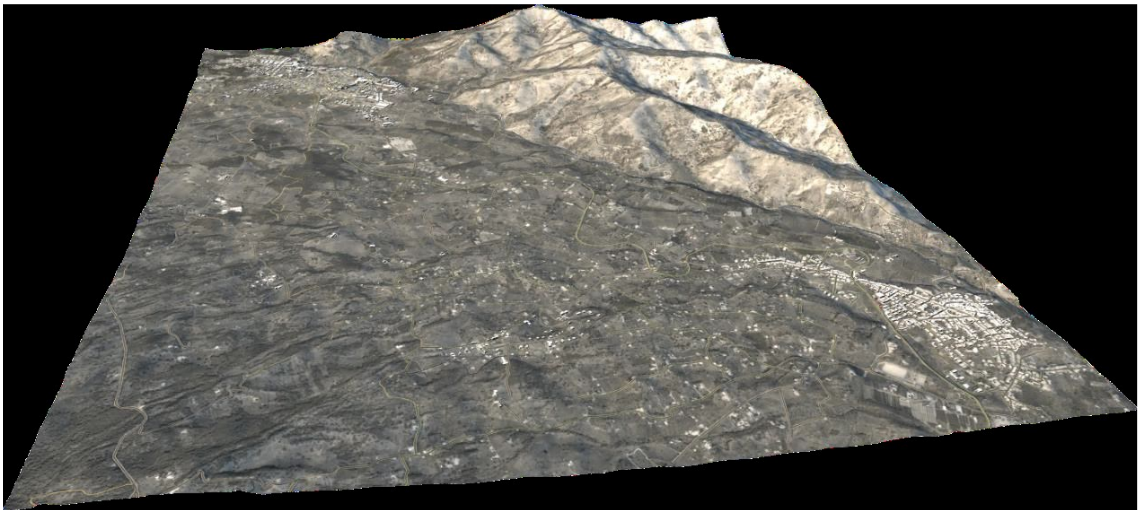


Figure 38 Autodesk Infraworks - Parametrised contextual model of the area between Piedimonte Etneo (CT) and Linguaglossa (CT).

This very often depends on a so-called 'reading error'. In fact, the software bases its operation on the transformation of satellite raster images that are analysed by the programme itself and converted into mesh. It is possible that several aerial photos have problems with their acquisition or that they are simply replaced with newer ones over the years, forgetting to update the database, so that the linear elements of a first reading overlap with those of a second reading.

In these cases, it is up to the operator to intervene to modify the sections, eliminating those that are superfluous and correctly connecting the profiles. It is also possible to create linear elements starting from existing files, for example by importing shapefiles from a GIS program and modeling the section following its track. The raster image from which the topographic surfaces are derived can also serve as a guide to confirm correct operation.

7.3.2 Modeling the railway

In the case under examination, two fundamental steps were followed that allowed us to contextualize the case study as best as possible: we decided to import the path of the existing railway line created in the QGIS database to overlap it with the existing one created by Infraworks, in order to modify the course of the mesh, creating a modeling based on an existing path and correcting areas that present reading inaccuracies.

Subsequently, a point cloud derived from the digital survey was imported into a separate Infraworks file. By isolating the binary component through the commands that allow you to draw the various borders (the central line of the linear element, the margin line, both horizontal and vertical lines), it was possible to obtain the distances and report the information within the model (Figure 39).

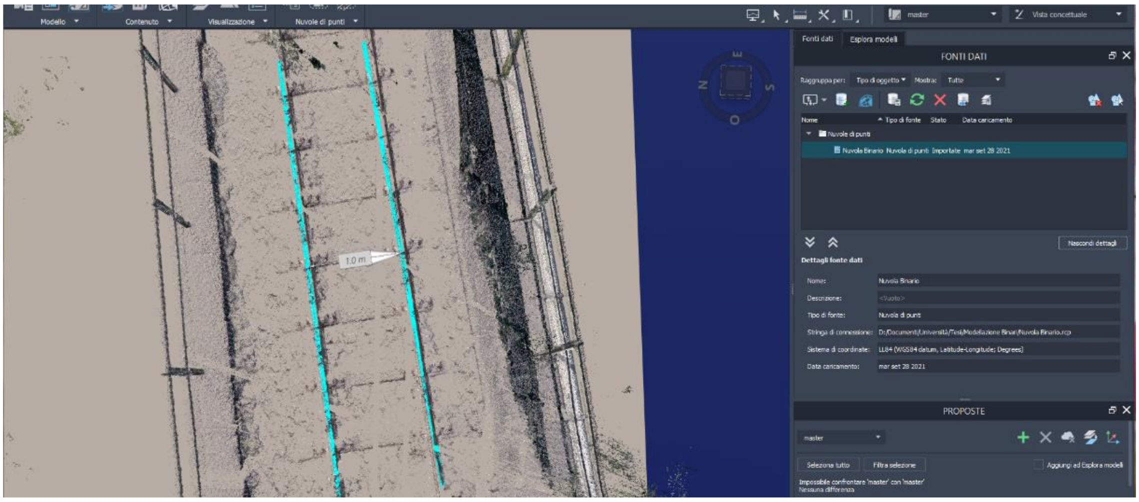


Figure 39 - Importing the cloud into Infraworks and defining the main lines from which to derive distances for reconstruction.

7.3.3 Characteristics of the rails

The software interface allows you to intervene on all types of infrastructure, in the "Railway" tab contained in the "Style Palette," there are already predisposed tracks. By selecting one and clicking on "Duplicate," it is possible to customize a parametric model by inserting the information.

In our case, the information obtained from the point cloud concerning the proper settings of the rail, such as the size of the flange and the height, was inserted. It is also possible to specify the course of the railway with respect to the road by modifying the slope.

In our case, since the FCE is a narrow-gauge railway, the gauge size between the rails is less than 1.4 meters by definition, and specifically is 0.950 meters. The entire route is characterized by the presence of a single track except in the areas corresponding to the stations (of all types), which are important exchange centers for two opposing vehicles. In this case, we will have the presence of two parallel tracks interspersed with a pedestrian transit zone during the boarding and disembarking phases. The distance between the two tracks is one meter.

One of the functions that the software automatically generates is the intersection between the railway and the road, where a railway crossing area is created. However, there may also be imperfections in this case, which is why a third specific family was created for road intersections, by selecting the "Ground line" option contained in Infraworks editor.

7.3.4 Interaction with Autodesk Revit models

After modeling and creating the context, it is necessary to link the railway buildings to the Infraworks file through the "add data sources file" command contained within the "content" tab, which allows you to load many models in almost all available formats.

Once imported, it is possible to define the graphic settings of the model and position it within the context through its reference system, if it has been georeferenced previously, or with the "interactive position" command, which allows the user to position and move the loaded model as desired.

A parametric database has thus been created that contains a number of diversified models that are updated simultaneously with the original data source, using the "reconnect" button available within the data sources. Infraworks is unable to read the texture of the model, which will therefore be displayed with a flat color. Moreover, while it can read the Revit file, it does not display the various families that create the individual models, does not allow interaction, and cannot provide more information.

For this reason, an external tool must be used to read the buildings of interest. Various IFC readers have been analyzed that allow interaction with the object and reading of information. To allow better visualization, the Autodesk viewer contained within Autodesk drive was chosen to be used.

This free portal can connect, through a user profile, all data uploaded or processed through Autodesk products and transfer them to its interior, where they can be shared with other users who can access information, download, and modify them in turn.

The connection with Infraworks occurs easily through the data source configuration of the models, in the "command description" tab, it is possible to insert an HTML code that calls the viewer's link. In this way, once the file is updated, just click on it and Infraworks will execute the command, allowing you to interact with the models through the reader.

Autodesk Viewer allows to perform various operations, including extracting a section to better visualize the content. You can read through the project browser all the families that are part of the model, interact with them, and view their information. It is also possible to explode individual models and measure the distances of individual components. In addition to Revit models, Autodesk Drive allows you to upload folders containing files and documents that are directly linkable to the model. This way, anyone with the hyperlink can access the portal, view, and edit the work (Figure 40). Therefore, it can be useful within a large company like FCE to organize a control and maintenance work of individual buildings through a portal.

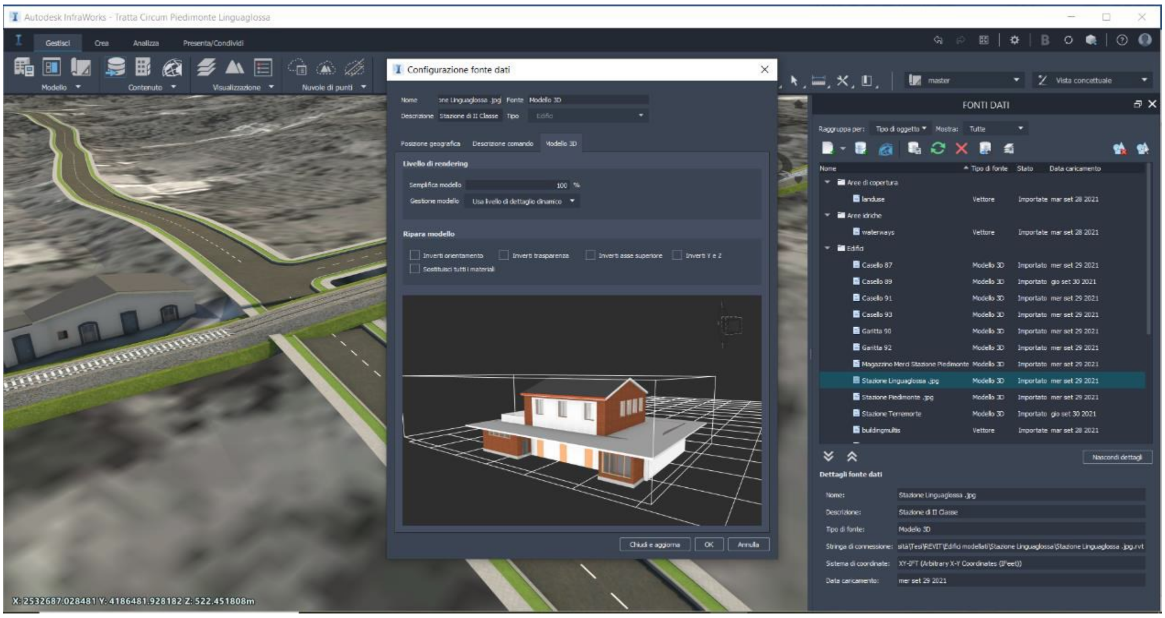


Figure 40 - Autodesk Infraworks - Import of parametric buildings from Autodesk Revit software and placement within the contextual model.

Chap. 8 Conclusions and future developments

This research work has aimed to propose a methodological framework for the knowledge and preservation of masonry arch bridges, which are significant assets of Italian heritage.
The methodology was divided into different phases aimed at acquiring data, developing a computational ontology, and creating informative models of the bridges under investigation.
The **cognitive phase** allowed for the acquisition of knowledge about the geometric configuration, construction techniques and materials of the bridges of Circumetnea through documentary research, visual inspections, and digital survey campaigns. All this information was then used to develop a comprehensive census of the bridges analysed.
Based on all the gathered information, two types of classification sheets have been developed: one for the cataloguing of historical archival materials and another for the classification of bridges identified along the surveyed route. Specifically, both sheets have been created by merging the classification sheets for cultural heritage assets, proposed by ICCD and the sheets for the inventory of existing bridges by MIT, with the aim of appropriately highlighting the historical information associated with masonry bridges.
Furthermore, based on the gathered experience, specific protocols have been established for the surveying of masonry bridges, thereby creating an implementable foundation to guide operators in conducting surveys of bridges with varying dimensions and diverse characteristics.
The **semantic phase** aimed to design a masonry arch bridge computational ontology that could be used as a knowledge base for deep neural network training. The ontology structure was developed based on an in-depth survey of existing vocabularies and taxonomies, as well as technical manuals and treatises. This structure was designed to include information about the semantic structure, construction techniques and typical defects of the bridges and it's created through a combination of bottom-up (starting from the Circumetnea bridges) and top-down (consulting manuals) approaches, adapting to other case studies and demonstrating its versatility and ease of implementation.
The **segmentation phase** focused on speeding up the Scan-to-HBrIM (Historical Bridge Information Modelling) procedure by extracting useful information from the point cloud in an automatic way. This was achieved through the development of a code to extract useful information from point clouds.
Finally, very preliminary results and first evaluations of the integrated **H-BrIM and InfraBIM** approach was presented.

The comprehensive knowledge acquired through the cognitive phase can be used to support maintenance operations, while the semantic phase can facilitate the creation of informative models of the bridges. The segmentation phase can help speed up the modelling process, thus making it more accessible and efficient.

In conclusion, the proposed methodology can contribute to the preservation of masonry arch bridges, which are important historical assets that reflect our cultural heritage. Also, it can help ensure the long-term durability, functionality, and reliability of these works, which are critical components of the road and railway infrastructure. The methodology can also contribute to the development of a broader framework for the maintenance and management of this historic structures, based on digital technologies and computational methods.

Regarding the digital surveying of masonry arch bridges, future developments encompass the verification and potential extension of the protocols outlined in this research. These protocols could be integrated considering additional unspecified parameters, such as accessibility to the various parts of the bridge, as well as parameters from other fields of knowledge. The aim is to generalize and develop guidelines that consider the characteristics and purposes of surveying masonry bridges.

Regarding the semantic part, future developments may involve the refinement and expansion of the suggested preliminary ontology structure proposed. Once fully developed, the ontology can be used for both the creation of semantic-based informative models and the structuring of an intelligent querying systems capable of guiding maintenance and monitoring processes for bridges.

Further exploration is necessary to investigate segmentation systems leveraging deep learning techniques, also deepening the creation of a two-level GAN and the training of the CNN with real and synthetic datasets. Additionally, the implementation of the tool developed in MATLAB could be considered, not only to determine the type of arch generating the bridge vault but also to extract information such as equations for surface generation. The extracted information can facilitate modeling using tools such as Visual Programming Language (VPL).

Additionally, future developments in parametric modeling can expedite scan-to-BIM procedures. Attention should be directed towards the IFC bridge and its potential future advancements. Moreover, special attention would be given to the integration of masonry bridges into the infra-BIM model, striving to achieve optimal interaction between bridge models and the railway model.

Overall, these future developments in digital surveying, ontology and semantics, point cloud segmentation, and parametric modeling hold promising prospects for advancing the field of masonry bridge analysis, documentation and preservation.

Index of abbreviations

AEC	Architectural Engineering and Construction
AINOP	National Information Archive of Public Works
BIM	Building Information Modeling
C2C	Cloud-to-Cloud
CIM	Civil Information Modeling
CNN	Convolutional Neural Network
CRM	Conceptual Reference Model
CTR	Regional Technical Map
DEM	Digital Elevation Model
DL	Deep Learning
FCE	Ferrovia Circumetnea
GAN	Generative Adversarial Network
GDS	Ground Sampling Distance
GIS	Geographic Information System
HBrIM	Historical Bridge Information Models
ICCD	Central Institute for Cataloging and Documentation
IFC	Industry Foundation Classes
IGM	Istituto Geografico Militare
IOP	Public Works Identifier
Infra-BIM	Infrastructure-Building Information Modeling
LIDAR	LIght Detection And Ranging
NDT	Non-Destructive Testing
QGIS	Quantum Geographic Information System
PCA	Principal Component Analysis
SFM	Structure From Motion
SS	Strada Statale (State road)
SLAM	Simultaneous Localization and Mapping
TLS	Terrestrial Laser Scanning
UAV	Unmanned Aerial Vehicle
VPL	Visual Programming Language

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