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THE VIRTUAL RECONSTRUCTION OF THE LAKE FUCINO'S EMISSARY

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Abstract **– The Lake Fucino's emissary represents one of the most important hydraulic construction realized in antiquity. Unfortunately, little remains of the original structure of the Roman emissary, obliterated by the Torlonia building and the definitive drying of the lake. This article presents its virtual reconstruction, in order to understand survey and technological issues met by Romans and to visually offer reconstruction theories, interpreting a partially lost evidence of the Roman technology. The engineering resource becomes the means for a deeper comprehension of archaeological questions, combining the tools of engineering and archeology.**

I. INTRODUCTION

The application of technologies for 3D reality-based reconstruction allows a deeper comprehension of heritage sites and artifacts. This is particularly true when only few or none traces of the original work, still exist in modern age. Generally, 3D reality based technologies are used to reconstruct ancient monumental buildings, focusing on their aesthetic and historical value. With this work, 3D technologies would be used to illustrate relevant technological issues of ancient constructions whose value concern more the technological side than other values. In these cases, the aim of using virtual reality is in clarifying the functionality of the ancient structures.

This is the case of the emissary of lake Fucino in the Abruzzo region, Italy. The emissary of lake Fucino, realized by Romans between 41 and 52 B.C., arouses admiration since it was built and it can be rightly considered one of the most important hydraulic works in antiquity, even if its functionality ceased during Middle Age because of the tunnel's collapse.

The greatness of the Fucino's emissary is in its length, about 5650 m, a record unmatched until the nineteenth century. The tunnel construction required to solve unusual problems with new technologies. This emissary was replaced in the nineteen-century, when the old Roman emissary was obliterated by the construction of a modern tunnel. The new emissary was made following the track of the old one, its section has a different shape, more suitable to withstand the different pressures of the soil, and capable of greater water flow. The new gallery is much larger than the Roman one and the ancient emissary was completely erased.

Only the section beneath Mount Salviano still retains traces of the old emissary, excavated by hand in the rock that intersects the new one, excavated with mines. Only the Roman passages remained basically untouched, as well the descents also used during the nineteenth-century works.

Alexandre Brisse and Léon De Rotrou, the last witnesses of the Roman construction before its final demolition, make a description of the old emissary published in two books and in an atlas with plates describing in detail the old tunnel. Other elements concerning the Roman emissary can be inferred by analyzing the few remains of this hydraulic construction and its descriptions made by Raffaele Fabretti and Carlo Afan De Rivera.

The main goal of the here presented study about the ancient Fucino's emissary is in understanding the specific technologies used to plan and realize it. The nineteen-century documentation of the Fucino's emissary and the currently evaluable archaeological material are difficult to analyze. To comprehend this hydraulic work and its technologies, all the documentary sources require to be collected in a single representation, which must include the territorial geography and the few archaeological remains such as wells and the other auxiliary structures. The aim is not only to show the exteriority of the construction, but also to evidence the complex functional connections among the wells, the tortuosity of the main tunnel's path, the secondary tunnels network and the territory's orography, together with the subsoil. The 3D geometric relations among all these components retain the technological reasons of such a complex work.

Since a lot of the technologies used to realize the emissary concerns the capability to use geometry, a 3D virtual reconstruction of the Roman work is a powerful resource to infer the knowledge regarding the methods Romans used to realize such a complex task. Advanced techniques for 3D reconstruction are useful for specifically understanding surveying methods, hydraulic technologies, the constructive phases together with the problems met at that stage, and the functions of the archaeological remains.

The Fucino's emissary represents the opportunity to evaluate the capability of the virtual reality technologies to support the archaeological research of scientific and technological aspects, through the analysis of measured data, combined with documentary and iconographic sources.

II. THE ROMAN EMISSARY: HISTORICAL EVENTS

The Marsica landscape was deeply changed by the drainage of Lake Fucino. This was an endorheic lake and therefore without any natural emissary, subject to great variations in surface and depth. Consequently, the Fucino's waters overflowed on the lands surrounding its shores. This was the main reason why, since the antiquity, local people expressed the need to regulate the Lake level.

Though the lake drying was definitively achieved in the nineteenth century, the idea of intervening on the Fucino in order to control its waters and to exploit the territories brought to light was already expressed by Roman authorities. The drying of the Fucino took shape, only as a project, during the first century BC. Caesar introduced this idea in a broader program that aimed to make new arable land available, through the draining of the Pontine Marshes and, indeed, the Fucino. This project, however, was not realized because of Caesar's death and was taken back a century later by Claudius, who built an artificial emissary to decrease the water level.

This wasn't the first time that Romans and Etruscans proved themselves in the creation of an artificial emissary for a lake: e.g. lake Nemi, 1653 m was built during the 4th century BC, and the emissary of Lake Albano (1400 m) probably around the 4th century BC too. The Lake Fucino's emissary was a more demanding challenge. The complexity of this work required the use of the best practices in tunnels construction and innovative technologies for that time. Since there are no written records, it is difficult to retrieve the knowledge used to survey and to build this hydraulic construction.

The emissary was completed in AD 52 and its use continued with Claudius' successors. Trajan and Hadrian took care of the restoration and maintenance of the emissary, as evidenced by historical and epigraphic sources. Later, due to disinterest, along with natural events such as earthquakes, the Roman tunnel lost its function as an emissary.

The first to show a renewed interest in Lake Fucino and its waters was Frederick II, in 1240 ca. However, every project concerning the emissary was interrupted by his death and there are no reliable reports/records of any kind of practical realization of this project. In the meantime, problems related to the endorheic nature of Fucino occurred again, when the level of water increased uninterruptedly from 1787 to 1816, with the lake reaching to 35 m deep.

The Kingdom of Naples, however, seriously considered such a project only with Carlo Afan De Rivera, the military engineer who in 1824 was appointed Director of Public Works of the Kingdom of the Two Sicilies. The lack of funding slowed down the work and then, the death of Afan De Rivera in 1845, temporarily put an end to the Bourbon attempts to resolve Fucino's problem. The definitive solution occurred with the involvement of Prince Alessandro Torlonia, who thought of modifying the project, following a radical solution by replacing the old emissary with the construction of a modern tunnel.

The new tunnel is much larger than the Roman one and due to its construction, the ancient emissary was completely erased.

III. METHODOLOGY

A. Sources and documentation

Despite being one of the most challenging hydraulic work carried out in ancient times and involving the application of new technologies, the Fucino's emissary remains quite unknown. Unfortunately, its current status is radically modified and few original parts remain, because of its almost complete demolition carried out to realize the Torlonia's tunnel. This circumstance doesn't help to increase knowledge about the Fucino's emissary. To investigate what remains of the tunnel, it is necessary to collect and coordinate in a single representation data that can be directly measured in site and the ones coming from sources and documentation.

Aside from the classical sources (such as Plinius, Tacitus and Cassius Dio), the first documentation available, following a chronological order, was in the descriptions of the Roman emissary made by Raffaele Fabretti [1] and Carlo Afan De Rivera [2]. The last one reported his works to recover the layout of the outlet, carried on in 1836 with the aim to use again the original Roman emissary. It is as an important source especially because A. De Rivera describes the methods used for the underground excavation and the machines needed for it, together with the solutions adopted and descripted in his work that probably didn't diverge too much from the ones used in antiquity. It gives also a very precise description about working environment and condition. A very useful source is also the G. Agricola's treaty, *De re metallica* [3]. It can be used as comparison especially for wells and tunnels function, as well for working techniques and machinery. Some knowledge about the equipment used for the Roman works can be understood in a bas-relief found during the nineteenth-century emissary construction. Further elements can be also inferred by analyzing the remains of this hydraulic construction.

The most detailed source is the work published by A. Brisse and L. De Rotrou [4], who directed the works for building the modern tunnel, the last witnesses of the Roman emissary before its final demolition. Their description of the ancient construction is presented in two volumes and an illustrated Atlas, which also contains the technical description of the modern works to drain Lake Fucino (fig. 1). Detailed charts describe the tunnel's path and its longitudinal section, along with the wells and secondary tunnels. In addition, the Atlas presents a series of detailed plates with the sections of the Roman gallery, one every ten meters.

All these sources contribute to give a reconstruction hypothesis about the original method used to design a project and about the use of proper machineries for lifting and transporting materials.

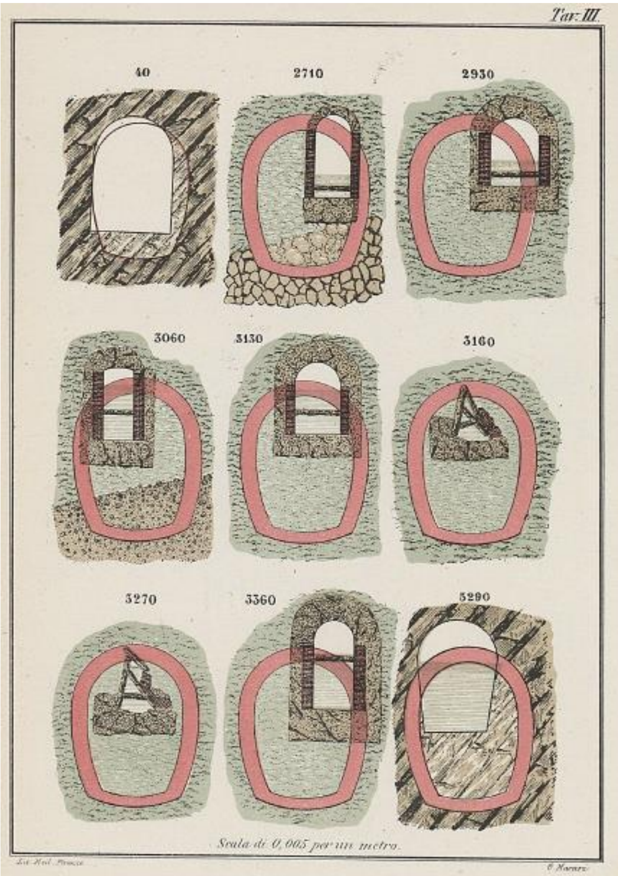

Fig. 1. Drawings sections of the Roman emissary compared to the modern one as illustrated in [4].

B. Virtual Reconstruction

The choice of a representational genre influences the ability to generate new interpretations and hypotheses. Usually, the amount of information that archaeologists handle is inherently large and complex. In this case, the volume of data is mainly given by written sources, a documentation provided by the last witnesses of the Fucino's emissary. Through 3D reconstruction, it is possible to have visually represented different and various reconstruction theories, interpreting an evidence of the roman technology that is not existing anymore.

It is possible to visualize some of the questions related to the emissary's structures and the surveying technology used, only by having a 3D model at disposal. The comprehension of the complex functionality of the tunnels system, with their orientation in the space, can be facilitated by the modern virtual reality systems. This instrument helps to analyze and understand the technologies and methods used by the Romans, also for revising the technical assessment made by the Torlonia engineers. The latter, in fact, considered the issues concerning the quality of the roman project and of the emissary construction affected by errors.

Various tools have been used to provide a valid virtual reconstruction of the ancient hydraulic construction.

The most important information concerning the territory topography comes from IGM cartography (1:25000) and aerial photographs. These were the basis for the digital terrain reconstruction, an area located between Fucino lake and Liri river. The drawing representing path of the tunnel described in the Torlonia atlas [4], once digitalized, has been added to the modern 2D representation of the territory by acquiring topographic points on site. An image processing software has been used to erase maps and digital image distortions. It was also necessary to use 2D drafting software, for providing dimensional relation among the different maps used as basis for this work.

In order to produce the digital terrain model, using software for 3D modeling, the information represented in 2D maps were spatially located. Then the 3D path of main tunnel was modeled, according to De Rotrou and Brisse work. In the Torlonia Atlas the tunnel is described by its plan representation, the heights of its bottom and by 600 sections, one every 10 meters. Then, all the 40 wells and the secondary tunnels were modelled.

Textures and rendering tools were applied to 3D models, using a specific software for rendering and 3D animation. Textures related to wells and material construction has been determined based on the study and analyses of cladding in use at that time for similar construction. Just for few parts, as in *cunicola* entrances, it still exists nowadays parts of the original roman cladding. The textures in the section of the complete hydraulic construction are aimed to show the geological strata whose location and extension conditioned the tunnel's realization and they are necessary to explain the reason of tunnel's failure (fig.2). Indeed, the main collapses of the tunnel happened when it crosses geological stretches of clay and sand. These textures are symbolic and they are taken from the Torlonia Atlas [4].

The result of this work was alongside with the production of a film documentary, which describe and summarize the history of this construction, from the origin to present day. It has an educational purpose, and it is nowadays used to introduce visitors to site visits, but it's still useful to fully understand the technologies behind this hydraulic construction.

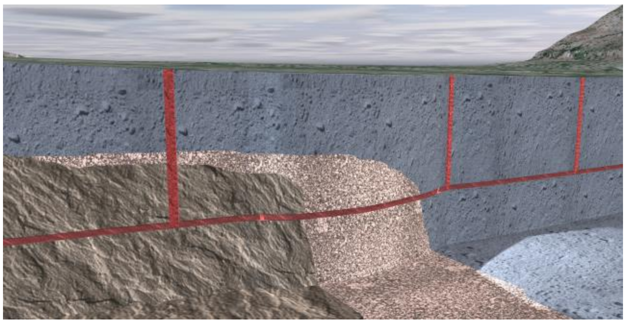

Fig. 2. In this picture is reproduced Palentini Plain, in proximity of the point where Roman tunnel suffered the greatest damage. At this point, as reported in [6], the Torlonia's tunnel suffered similar problems.

V THE VIRTUAL RECONSTRUCTION: RESULTS.

Claudio's work consists of the construction of an opencast collecting canal to convey Fucino's waters towards a system of tanks (the so-called Incile), and the excavation of an underground tunnel (the emissary), whose itinerary crossed Mount Salviano, Palentini Plain, and finally ended in the Liri River.

It's very likely that the original Roman plan didn't involve the draining of the entire lake, as otherwise happened with Torlonia's works. Claudius aimed to regulate the water level of the lake maintaining, therefore, a part of the basin. To do so, the entire activity needed to be planned upon a careful leveling, establishing the position where the path of Liri river was lower than Fucino Lake. Once that the direction was set up and the length measured, the quota of the lake and Liri's outlets were fixed, setting the inclination needed for the emissary to operate.

Once set both the starting and final points, the main tunnel had to be built following a path far from straight. This is illustrated by the reconstruction in the fig. 3, which shows the topography of the area and the itinerary of the emissary. In this way it is possible to understand the technologies used to plan and execute the works, especially as regard the topography technique adopted [5].

In order to construct the main tunnel a system of wells and secondary tunnels (*cunicola*) were planned and then realized. The system made of wells and secondary tunnels served to increase the spots where the horizontal tunnel excavation started. Once the well was dug to a deemed appropriate depth, the tunnel excavation started, proceeding on the two opposite fronts (Fig. 4).

The probable functions of these wells are different:

- Served as different start points for digging the emissary, divided into several segments, being at the same time a direction's reference;
- Facilitated tunnel's ventilation during excavation's

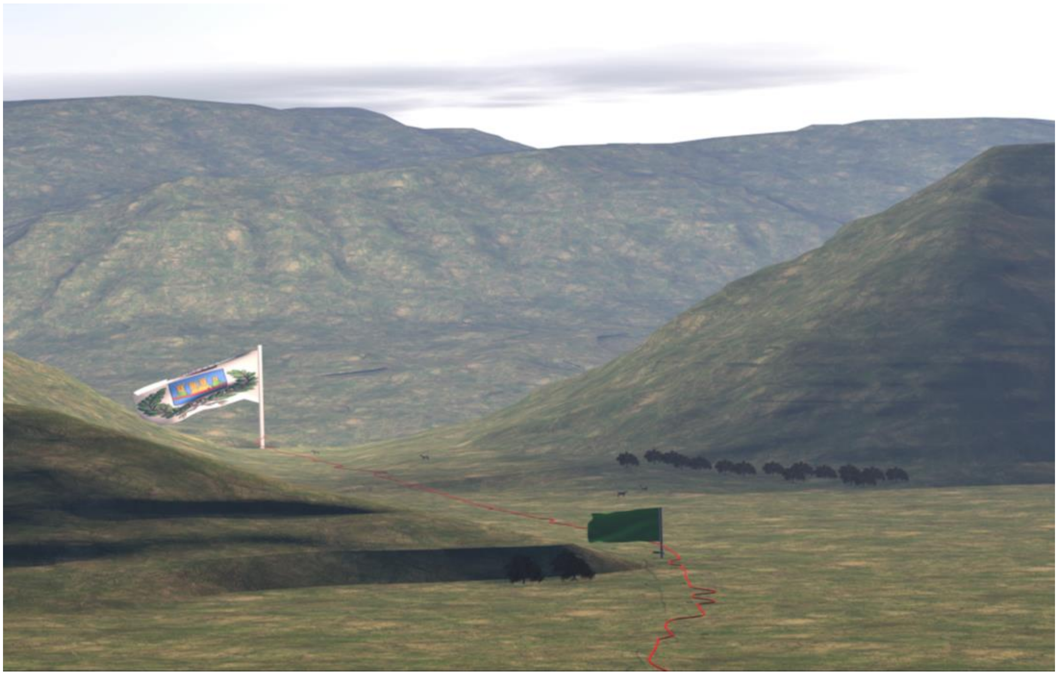

Fig.3 Virtual reproduction of the territory overlapping the path of the artificial emissary, as measured by Brisse and De Rotrou. The picture, which illustrates the tunnel's section on Palentini Plain in Capistrello, highlights the tortuosity of the path. The flags represent the final point in Capistrello and the turning point where the tunnel bend to overcome an obstacle.

work;
• Formed the fastest way to introduce building materials and dispose of water and resulting material.

Fig. 4. Virtual reconstruction of the Roman emissary under construction. The buckets are a reproduction of the ones fund during Torlonia's excavations. The bucket is now part of the Torlonia Collection of Antiquities of the Fucino area, hosted in Celano, Museo d'Arte Sacra della Marsica e della Collezione Torlonia di Antichità del Fucino, Italy. The wheelbarrows are inspired by De Re Metallica.

The excavation of the wells took place in areas of different soil consistency, so some could suffer unsustainable side pressures. It was therefore necessary to arm them with wooden or wall armor, and both systems were found and documented by the engineers involved in Torlonia's work (fig 5).

Fig. 5. Virtual reproduction of the centering used in the Roman works. It is based on the structures found by Torlonia's engineerings, as described in their publications.

At least 40 wells were built in a square section (fig. 6) and of variable depth, together with the tunnels. 29 of these wells are positioned on the side where the town of Capistrello is located, and 11 beyond the mountain Salviano, on the eastern slope. The depth of the wells is variable from 19 m to the deepest well (number 22), the last on the side of Capistrello, which reaches 122 m in depth. The wells on the western side of Mount Salviano have a depth generally greater than 80m.

The wells had wooden scaffolds like the ones represented in the virtual reconstruction in the fig. 6.

Fig. 6. Reproduction of the Roman wells scaffolding, found intact during the nineteenth century works.

The *cunicola* were tunnels sloping towards the main gallery, replacing the vertical wells, mainly positioned on the two sides of Mount Salviano. The underground passages found on Salviano's slopes are seven and constitute the expedient used to deal with one of the most difficult segment of the project. So, they have a function similar to the wells, plus they were used to transport excavation materials and as an entrance for workers and means.

The section under Mount Salviano, where the tunnel is dug into the compact rock, it crosses a section of rocky debris mixed with pebbles. Here the Romans ran into great difficulties and needed to make a deviation from the preset path, probably because of landslides. The emissary then crosses a long stretch of clay and sand, where the Roman gallery suffered, in the centuries following its realization, the collapse of many tunnel's parts.

The tunnels located on the side of the lake are Cunicolo Imperiale, Cunicolo del Ferraro, and Cunicolo Maggiore. The latter is the most monumental, with an entrance made on three arches in vertical succession. It is the last descender on the east side of Salviano and is connected, transversely, to the Ferraro's tunnel (fig. 7).

After the Mount Salviano, there are three descents, sequentially excavated and intercepting well 22, called Salviano 1, Salviano 2 and Salviano 3, or Calderaro tunnel. Not far away there is another tunnel, the Salviano 4, connected to the well no. 21 through a short deviation.

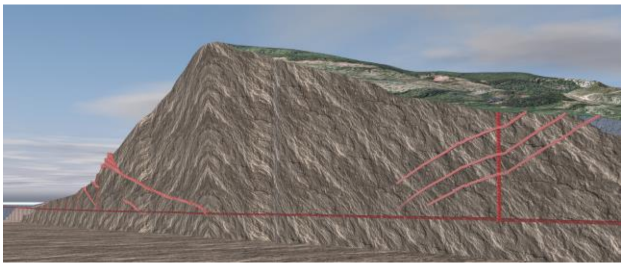

Fig. 7. Section of the emissary beneath M. Salviano and the tunnel system. The virtual sections of the emissary are

achieved following the tunnel path. Geological stratifications are reproduced as reported in [1]. Orography is taken from IGM planimetries.

The final tunnel will result in an impressive work by the length of approximately 5,650 meters.

The exit of the emissary is on a bend of the Liri River, in a narrow gorge in Capistrello town. It is a monumental exit surmounted by an arch of great height, made of masonry in *opus incertum* and in *opus reticulatum*.

The old Roman emissary was almost completely erased by the new one build by Torlonia. In fig. 8, the two version of the tunnel are compared.

Fig. 8. This picture confronts the Torlonia emissary with the Roman tunnel, represented near one of the roman well. It can be seen the difference in heights between the two tunnels and the width of the respective sections.

V. CONCLUSIONS

The virtual reconstruction of the Fucino's emissary here illustrated aims to investigate and to study the Roman hydraulic work and the technologies involved in its realization.

Virtual reality is a support to the understanding of the survey's techniques used in the project, the knowledge of digging technology, the construction of the main tunnel and the *cunicola*. The virtual reality applied to cultural heritage is usually used for architectural or landscape reconstruction contexts. In this case, the application is closer to the original use of 3D techniques (Computer Aided Design) used as a tool for functional analysis of artefacts rather than for their historical or artistic representation. The here presented work is similar to a reverse engineering process that extracts knowledge and design information from ancient sources, documentation and drawings of the Roman emissary's archaeological remains. In this case, virtual reality was used in order to complete the missing data and reconstruct the model of an ancient hydraulic construction achieving the reconstruction of its original functionality and understand how Romans worked.

The 3D geometric model could be used to analyze the ancient construction from different technical point of view: for instance, by using numerical fluid dynamic models, with regard to water flows, but also for understanding the *cunicola* and wells function regarding the air flows that is necessary for the survival of the workers who built the construction.

In this way, the engineering resource becomes the means for a deeper understanding of archaeological questions, combining the tools of engineering and archeology and thus promoting the development of the knowledge of ancient technology.

V. ACKNOWLEDGEMENTS

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