The Pozzuoli (Naples, Italy) Flavian Amphitheatre cisterns: a basic experience in 3D modelling with LIDAR

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Abstract

Thanks to an agreement with the Phlegraean Fields Archaeological Park, the Cocceius Association has been carrying out research into the Pozzuoli Flavian Amphitheatre water management system. Rain water was collected from the *cavea* and stored into a number of cisterns. These fed small fountains at the ground level; waste water was then collected by a complex system of underground drainage channels on two levels, still functional. Furthermore, an aqueduct branch provided fresh water to the underground Amphitheatre level under the *arena*. Up to thirteen cisterns were identified, mostly symmetrically spaced within the Amphitheatre structure. The research analyses the cistern characteristics: volume, intakes, out-takes, manholes, lining, corner moulds, debris fillings, etc. In this scope, a test survey was performed on the Amphitheatre cisterns with an iPhone 14 Pro and the Scaniverse app. The paper reports on the experience garnered in such a survey session. Both general and specific matters are dealt with. Specific matters are relevant to the survey process in the context of the Amphitheatre cisterns, while general matters are relevant to the general context of surveying in confined spaces with an iPhone Lidar. As a result, the test provided attractive 3D models, with a very favourable time/result ratio and an interesting cost/result ratio. The results are useful in a preliminary cavity characterization and in research demonstration / exploitation. However, attention must be paid to issues like: survey path planning, effects of overlapping, sensor range, lighting, effects of survey suspension / resuming on model acquisition, surface rendering, device power consumption.

Keywords: Roman hydraulics, Roman amphitheatre, water management.

Introduction

The Flavian Amphitheatre in Pozzuoli (fig. 1) is among the largest known Roman amphitheatres. Between the late Republican age (1st century BC) and the early Imperial age (late 1st century BC – 1st century AD) *Puteoli* was the main commercial harbour in the Roman economic system. Furthermore, the nearby lakes in the Phlegraean Fields hosted the Tyrrhenian fleet harbour. In the late Republican age, an amphitheatre was erected in an area just outside the main Roman settlement in *Puteoli*, on the road to *Neapolis*. Few decades later, in the Flavian age, the growth in population dictated the construction of a new, larger amphitheatre, alongside the older one. At the beginning of the Christian era, the Flavian amphitheatre was the location of the martyrdom of Saints Januarius and Proculus. Presently, the amphitheatre is a monument open to public, under the management by the Phlegraean Fields Archaeological Park. It is renowned for the underground spaces located under the arena, which are particularly well preserved.
In the course of a comprehensive research on the amphitheatre water management system, a number of cisterns were identified and characterised. As a beginner experience in 3D modelling, cistern models were produced, so as to ascertain advantages, drawbacks and best practices in 3D data acquisition. As a first step, only the data acquisition phase is considered; the post-processing phase is left to further tests.

Materials and methods

The amphitheatre *cavea* is supported by masonry structures defining 72 radial sectors (*cunei*). The whole amphitheatre is divided into four symmetrical quarters, each composed of 18 sectors. A main annular corridor divides each sector, with respect to the *arena,* into an outer and an inner section. Forty outer sections include stairways connecting to the ground level. Spaces between ground level and the stairways were designed to hold water tanks. Rain water was collected on the *cavea* and thence by drains into clay pipes and to the cisterns. Pipes supplied drinking fountains at ground level. Waste water then entered underground drainage channels to a main sewer located under the amphitheatre major axis and then to the sea. The drainage system is still partly functional. In Medieval and later times, the *arena* and the *cavea* were cultivated as a vineyard, while the spaces under the *cavea* were used as living quarters for farmers.

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Fig. 1 – Location of Pozzuoli and the Flavian Amphitheatre in the Phlegraean Fields (digital terrain model by Campania Region GIS, modified).

Some cisterns retained their original function, while others were filled with debris.

The whole Flavian Amphitheatre is a little researched monument. Its recovery started in 1839 (Bonucci, 1839). Charles Dubois, a French art historian and archaeologist, reported about the Amphitheatre structure. He included a plan that shows some cisterns (Dubois, 1907, pp. 316, fig. 33), mentions eight cisterns and provides information about the one nearest to the then access to the Amphitheatre (Dubois, 1907, pp. 334-335).

In 1955, Amedeo Maiuri, Superintendent to antiquities in Campania, published a book on the Flavian Amphitheatre (Maiuri, 1955). He mentioned the cisterns and the fountains they supplied. A cross-sections shows the water collection, storage and drainage systems (Maiuri, 1955, p. 37, fig. 9), together with a cistern (fig. 2).

We identified up to 13 cisterns (fig. 3), even if we are still not able to enter two of them (brown circles in fig. 3). Seven cisterns are composed of two chambers, while four consist of a single chamber and the last two of four chambers. The typical two-chamber cistern size is 3 m width and 7.5 m length (fig. 4). Height is variable, due to sloping roofs under staircases and the earth and other debris that has filled the cisterns over the years, the maximum cistern height is about nine meters.

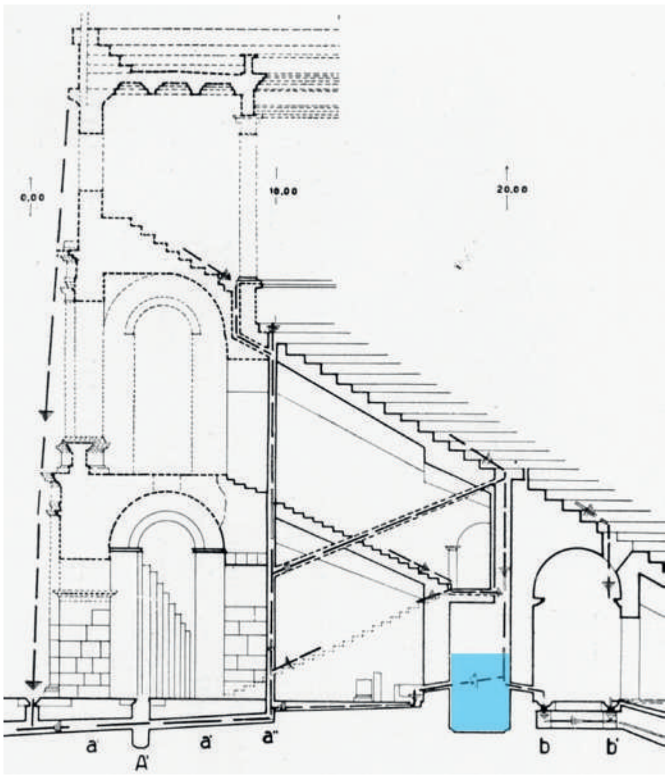

Fig. 2 – Cross-section of the Amphitheatre structure and drainage system (from Maiuri, 1955, modified).

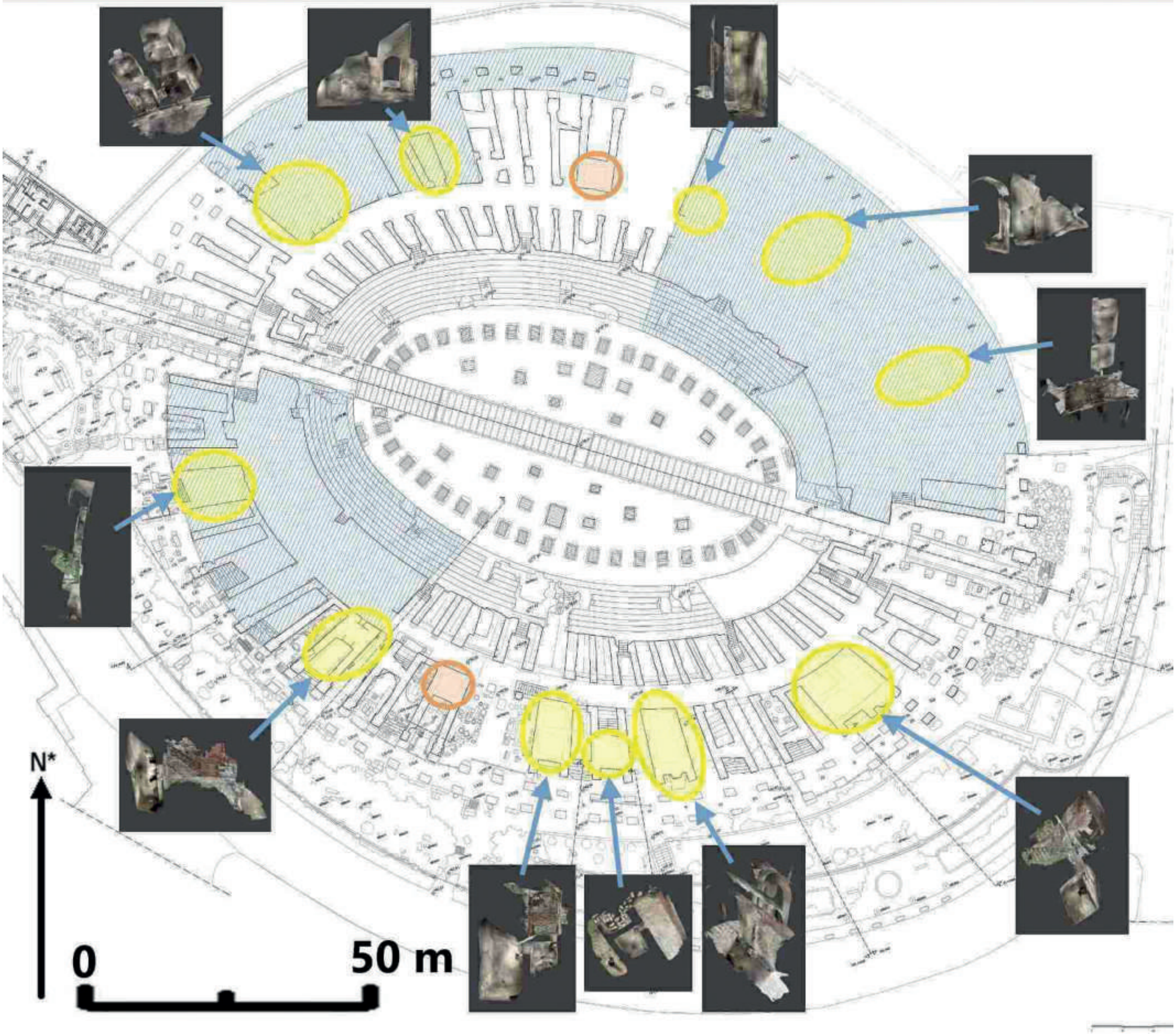

Fig. 3 – The Amphitheatre cistern locations (plan by the Phlegraean Fields Archaeological Park, modified).

The Phlegraean Fields Archaeological Park recently commissioned a laser scanner survey in the Flavian Amphitheatre. However, the cisterns and the underground drainage systems are awkward sites to deploy a laser scanning device, so they were not scanned.
Recently, the LIDAR sensor in Apple iPhones raised interest in the archaeological and speleological community. Some tests were performed (Fiorini, 2022). They showed that the overall quality is not comparable to traditional techniques (e.g. laser-scanning, photogrammetric, photographic) as far as small to medium-sized items (e.g. marble capital) or masonry walls are concerned. However, poorly lit, confined spaces can be surveyed in a fairly efficient way with respect to other techniques.
In order to check advantages and drawbacks of the Apple LIDAR sensor in the archaeo-speleology field, we performed a number of tests in the Flavian Amphitheatre cisterns. Data acquisition was performed with an Apple iPhone 14 Pro, with IOS V16.2, 256 GBytes RAM, and the Scaniverse application V2.1.4, with *Large object* scan size and *Area mode* processing. The acquisition procedures were kept as simple and naive as possible, in order quickly to gather information about procedure troubles and technology drawbacks in a real archaeological confined spaces context. Access to some cisterns was possible only by vertical manholes or horizontal passages from the top; in the past, inhabitants of the site opened passages on side walls at middle height or at the bottom. Access is now possible by climbing up or crawling in side passages, or by lowering down a ladder from the top. This means in some cases the surveyor must suspend acquisition, climb up or down and then resume the scan. If, due to the accumulated debris in some chambers, the ladder cannot be moved to reach the next chamber, the surveyor must scan the next chamber from the connection passage.

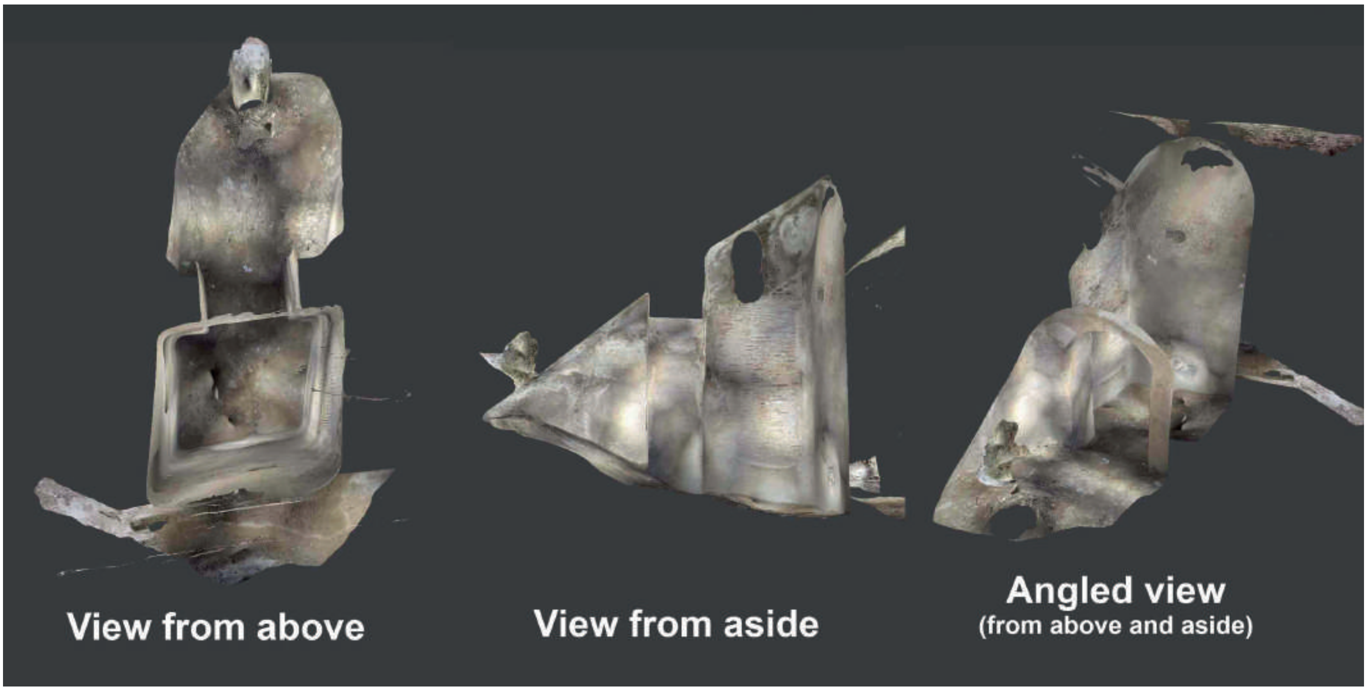

Fig. 4 – A two-chambers cistern example scan.

Fig. 5 – Issues in scan results: device shadows (top), iron gates and missing scan areas (bottom).

Fig. 6 – Irregular vegetation and square vertical cistern access (from above).

Fig. 7 – Cistern measurements.

Results

Apart from the two inaccessible cisterns, all known cisterns were scanned. The highest scanned cistern measures 8.55 meters. Scan time is short; it ranges from one to five minutes, according to the cistern structure and to the need to suspend and resume scan. All eleven cisterns were scanned in a single four-hours session, as separate scans; the LIDAR sensor is quite power hungry, but the iPhone battery is able to manage many long scans. Similarly, even big scans with saved raw data, which produce more than one Gbyte data, are feasible for the device memory.
The resulting scans are affected by several issues:
1. some areas high on the walls and on the roof were not scanned; in *Large object* scan size, the LIDAR sensor range reaches a maximum of 5 m distance, so higher cistern areas were out of range;
2. some small areas in the lower cistern portions were not scanned; this is due to a poor and hurried path planning, that missed some hidden areas, especially where stone blocks, wooden planks or iron gates (fig. 5, bottom) are present inside the cistern or where the scan was performed from an access window, without entering the cistern;
3. often, shadows are visible on the cistern surfaces (fig. 5, top); we relied only on helmet-mounted lighting, so the processing phase often picked up the phone shadow itself;
4. the surface rendering quality is not uniform; of course, quality depends on range, where farther surfaces show coarser renderings; however, even the phone movement speed and occasional jumps may cause bad rendering;
5. in some cases, a surface overlapping showed up; this happened when a duplicated scan was performed, especially when a suspend-climb-resume procedure was applied;
6. in some places, vegetation grows over the unroofed structures; scan quality is particularly affected by vegetation, which is extremely irregular in shape and surface (fig. 6).

Discussion

In summary, the iPhone Pro LIDAR technology allows surveyors to collect 3D survey data in a very quick way, with a non-cheap but affordable expense. The overall result is an attractive representation of a cavity, suitable for presentations and project exploitation/dissemination.
Measurement accuracy can be evaluated by comparison between the linear measures provided by the scanning application and direct on-site measurements with traditional methods. Point selection in Scaniverse is not an easy matter: the user must be careful in double-checking the correct position of the selected points. Checks on several chamber side measurements showed that the difference between LIDAR measures and traditional ones is within few centimetres, that is, accurate enough to satisfy typical caving requirements.
An advantage in the iPhone LIDAR technology is in the chance to easily obtain measurements in inaccessible areas. Figure 7 is a plan view of the second chamber in a two-chamber cistern. If it is not possible to enter and climb down into the chamber, the surveyor can look into the chamber from the connection passage (at the bottom in fig. 7). Both the far wall width (3.43 m) and height (5.33 m) can be measured only by triangulation methods or directly on the 3D model.
However, in order to get a good quality result, the surveyor should apply several procedural expedients, so as to avoid or mitigate the above-mentioned issues:
1. *maximum range*: where cavity length or width are an issue, a proper path planning can help in scanning excessively long and wide areas. If the issue is in cavity height, a sturdy stick can be employed;
2. *unsurveyed areas*: a careful device path planning is mandatory, based on cavity morphology and on past experience, so as to cover all hidden or unfavourably-positioned areas;
3. *lighting*: in order to get a fairly uniform surface lighting, a device-mounted illuminator must be used, while

the surveyor helmet illuminator must be switched off; furthermore, the device should move at a fairly uniform distance from the surveyed surface;
4. *uniform rendering*: again, the device should move at a fairly uniform distance from the surveyed surface and with a uniform speed; jumps, trips and sudden moves should be avoided; as far as possible, the scanning device should be moved perpendicularly to the scanned surface; the use of a camera gimbal or stabilizer should be considered;
5. *overlapping*: a careful path planning should avoid duplicate scans of the same area; furthermore, a suspend-resume sequence should care not to move the device position; possibly, overlapping areas can be cropped out in post-processing;
6. *green areas*: vegetation rendering performs better in *Detail processing mode*; this means a separate scan should be planned, to be connected in post-processing.

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Bibliography

Bonucci C., 1839, *I Reali scavamenti nell'Anfiteatro di Pozzuoli,* Poliorama Pittoresco, 4: pp. 65-66. Napoli.
Dubois C., 1907, *Pouzzoles antique (historie et topografie)*. Fontemoing, Paris, 452 pages.
Fiorini A., 2022, *Scansioni dinamiche in archeologia dell'architettura: test e valutazioni metriche del sensore LIDAR di Apple*. Archeologia e calcolatori, 33 (1): pp. 35-54. doi 10.19282/ac.33.1.2022.03.
Maiuri A., 1955, *Studi e ricerche sull'anfiteatro flavio puteolano,* Macchiaroli, Napoli, 155 pages.