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3D LIDAR MODELING WITH IPHONE PRO IN AN ARCHAEO-SPELAEOLOGIC CONTEXT. RESULTS AND PROSPECTS

1. Materials and methods

In order to check the advantages and disadvantages of the Apple LiDAR sensor (Fiorini 2022) in the archaeo-spelaeology field (Ferrari 2023; Madonia *et al.* 2023), we performed a series of tests in different underground and/or confined structures of archaeological interest so as to guarantee diversified documentation to understand the effectiveness of the instrumentation. The data acquisition was carried out during 2023 using an Apple iPhone 14 Pro, with IOS V16.2, 256 GB of RAM, while the application used was Scaniverse V2.1.4, with scanning in Area mode and processing in Area mode (Ferrari 2023).

Although the technology limits are effectively illustrated in several contributions relating to different research areas (Luetzenburg *et al.* 2021, 2; Spreafico *et al.* 2021, 421-422; Fiorini 2022, 50-51), the LiDAR scanners installed on iPhones have actually showed specific limitations in some cases such as small decorated objects (for example marble capitals) and when certain environment dimensions are exceeded, where the overall quality of the scans obtained is not comparable to traditional techniques (e.g. laser scanning, photogrammetry, photo rectification, etc.). However, when these devices are used in very particular environments, such as confined spaces, of relatively small dimensions, in which the iPhone is placed at distances between approximately 1 m and 5 m compared to the position of the detected structure, the acquisition capacity of the device is promising and with limited deviations compared to traditional techniques.

Therefore it was decided, taking advantage of the projects that the Authors are carrying out within some of the most evocative sites in Campania, such as those pertaining to the Campi Flegrei Park and the ABAP Superintendence for the Municipality of Naples, to test the scanning quality of the Apple LiDAR sensor in various confined environments that to date had not been the subject of specific archaeological studies. The choice to operate in environments of different sizes and morphologies is also aimed at obtaining a set of useful examples in a context, namely artificial cavities, which to date, even in the speleological field, have not yet found a correct codification in this sense. These are two archaeological sites which are different from each other in terms of time of construction, morphology, size and difficulty of access but which fall within that category of environments/structures where the operating conditions are challenging: 1) Flavian amphitheater in Pozzuoli

(Campi Flegrei Archaeological Park); 2) Augustean aqueduct of Campania in the Fuorigrotta-Coroglio section (falling under the authority of SABAP-NA).

2. Case study 1. Cisterns in the Flavian amphitheater in Pozzuoli

The Flavian amphitheater in Pozzuoli (Fig. 1) is one of the largest known Roman amphitheaters (Bonucci 1839; Dubois 1907, 315-340; Maiuri 1955). Built in the Flavian age (mid-1st century AD) to replace the older lesser amphitheater, it has a masonry structure organized into four symmetrical sectors. The sectors are in turn made up of 18 wedges for a total of 72 radial subdivisions. It is an extremely complex building, constantly modified over the centuries, in which the water management and storage was of the most importance. The water, in fact, was collected from the upper levels thanks to an extensive canalization system and it was fed into cisterns –thirteen in all have been identified – positioned at the base of the *cavea* in strategic points with respect to the water courses (Maiuri 1955, 35-40; Ferrari 2023, fig. 3) (Fig. 2). From the morphological point of view, the cisterns are divided into three groups by size and morphology (Tab. 1).

The typical size of a two-chamber cistern is 3 m wide and 7.5 m long (Fig. 3), while the height varies, both due to the covers, which follow the slope

Group	Type	Number
1	Single chamber	4
2	Double chamber	7
3	Quadruple chamber	2

Tab. 1 – Cistern groups in the Flavian amphitheater in Pozzuoli.

Fig. 1 – The Flavian amphitheater in Pozzuoli (photo G.W. Ferrari).

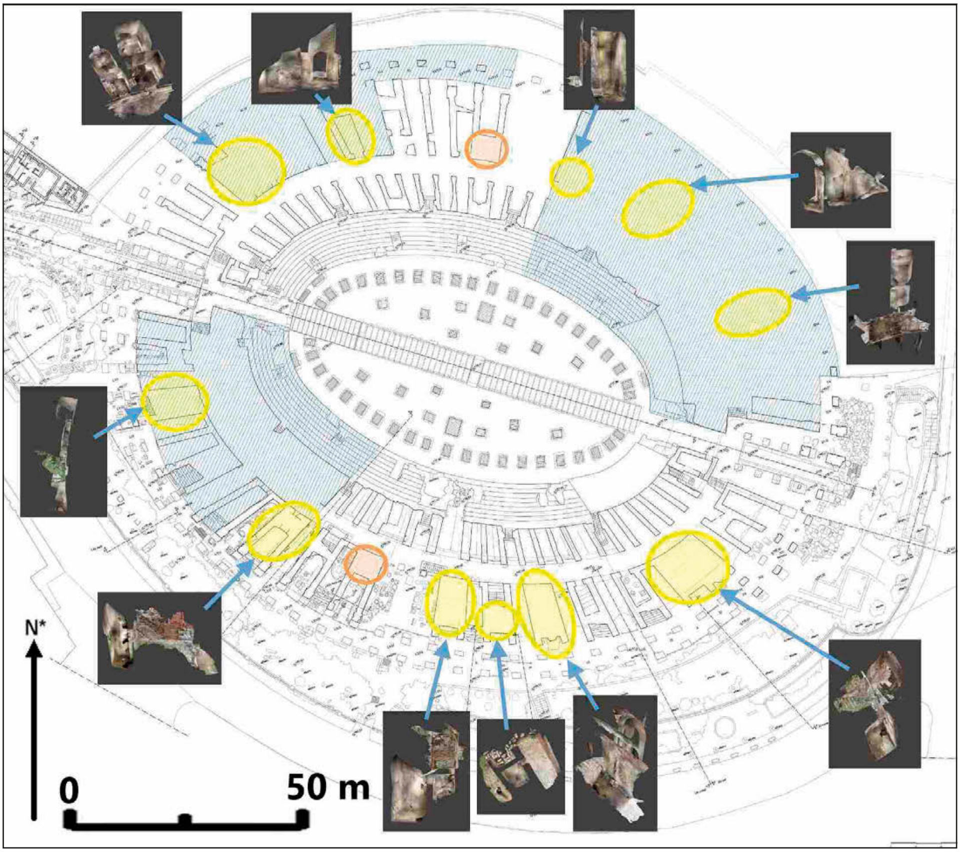

Fig. 2 – Cistern positions in the Flavian amphitheater in Pozzuoli (from Ferrari 2023, fig. 3).

of the access ramps to upper levels, and to the fact that they are still partly cluttered with earth and other debris. The maximum height of the cistern is approximately 9 meters. The difficulties in accessing the cisterns, partly already known in the past (Maiuri 1955, 37, fig. 9), prevented an accurate survey to the point that even today they were not adequately documented or accurately surveyed. As part of this investigation, the cisterns were first identified and characterized and then the individual 3D models were created in a single session on February 28th 2023. The collected scans allowed to check advantages, drawbacks and best practices for 3D data acquisition. The scan procedures, hindered both by the accumulation of debris and by the size of the accesses to the different chambers, lasted approximately four hours thanks to the acquisition speed guaranteed by the LiDAR sensor, trying to create

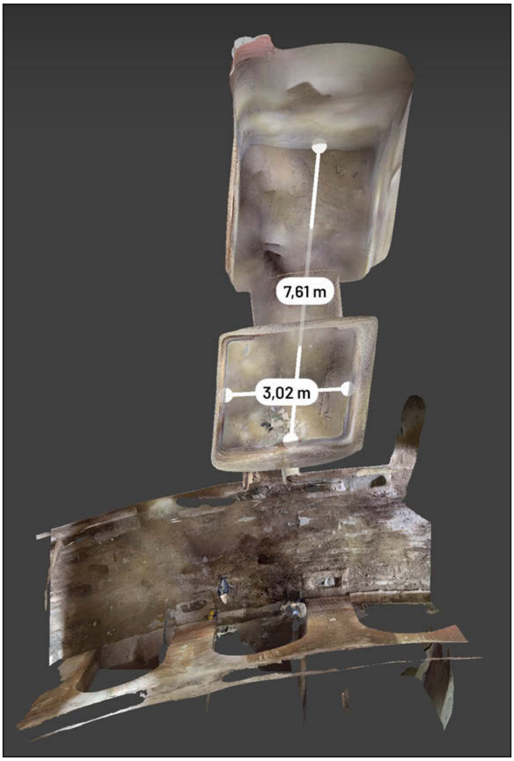

Fig. 3 – Top view of a two-chambers cistern and a main *ambulacrum* section in the Flavian amphitheater (Cocceius Association).

acquisition paths as simple as possible in order to quickly collect information in a real confined spaces archaeological context.

3. Case study 2. Augustan aqueduct of Campania in the Fuorigrotta-Coroglio section

This section was identified at the beginning of 2023 (De Simone, Ferrari 2024) and belongs to a side branch of the Augustan aqueduct of Campania, directed towards the area where the monumental villas of Nisida and Pausilypon stood (Ferrari 2019). The Augustan aqueduct of Campania is one of the most complex engineering works of Roman antiquity and represents one of the best examples of this particular type of hydraulic infrastructure. Unfortunately, it is still little known and researched on. The course of the aqueduct developed mainly underground and only some sections are currently known, mostly

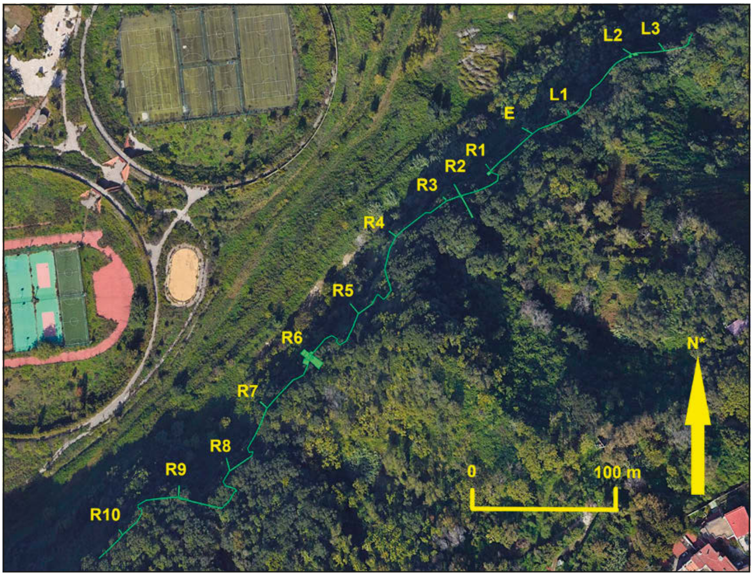

Fig. 4 – Augustan aqueduct side branch section near the Bagnoli reclamation area, with the identified adits (from De Simone, Ferrari 2024, fig. 4).

concentrated in the Neapolitan and Phlegraean areas (Catalano 2003, 2007; Ferrari *et al.* 2018, 71-78). This great ancient infrastructure was built at the end of the 1st century BC to supply fresh water not only to the military port of *Misenum*, but also to a wide portion of what was one of the most populated areas of late-republican Roman Italy, part of Regio I, between the slopes of Vesuvius and the Phlegraean area, as well as some large agricultural centers of the Campania plain. The list of supplied cities is reported in an inscription from 324 AD, found near the Serino springs in 1938 (Sgobbo 1938, 35-97). The main line is approximately 105 km long, reaching approximately 135/140 km with side branches (Keenan-Jones 2010a, 2010b).

This large ancient infrastructure represented an excellent test bed for the creation of models and surveys with LiDAR in underground environments of limited dimensions, since the typical width of the channel in the Phlegraean area is equal to or less than 64 cm (Ferrari, Lamagna 2015). The identified segment is located halfway up the tufaceous ridge of Posillipo, in the municipality of Naples and belongs to a branch that detached itself from the main axis (Serino Springs to *Misenum*) at the Crypta Neapolitana western entrance, and headed towards the Capo Coroglio area. The overall length of the currently explored segment is approximately 800 m, with all the branches and service tunnels identified (Fig. 4), and this qualifies it as the longest, and

Fig. 5 – Augustan aqueduct at Bagnoli: 3D model of R9 adit, with a superposed channel section (Cocceius Association).

probably also the best preserved, section currently known of the Augustan aqueduct (De Simone, Ferrari 2024).

In addition to being of enormous importance about the reconstruction of what must have been the organization and layout of the ancient work in the territory it crossed, this condition also allows us to closely observe the organization of the ancient construction site in relation to the creation of a very complex hydraulic system. Since access to the aqueduct takes place from within the Bagnoli reclamation site, the operating methods were conditioned by the constraints linked to the site itself. It was therefore necessary to operate with particular efficiency and caution. In a first phase, a graphic survey was carried out with a traditional speleological technique, with the use of a compass, clinometer and laser distance meter. In parallel, photographic and video documentation was collected. Only later, in August 2023, was an iPhone scan performed of some sections of particular morphological interest, including the intersection between the R9 service tunnel and the course of the aqueduct (Fig. 5) and the junction point between two excavation teams, particularly tortuous, between accesses R7 and R8 (Fig. 6).

4. Discussion

As already indicated in other contributions (Fiorini 2022; Ferrari 2023) the iPhone Pro LiDAR technology allows you to collect 3D survey data very quickly, with a cost that is not cheap but is accessible also to non-professional entities or to professional archaeologists who can benefit from it enormous advantage for the work activity. The accuracy of the measurements can be assessed by comparing the linear measurements provided by the scanning application with direct on-site measurements taken using traditional methods. Checks on various measurements have shown that the difference between LiDAR measurements and traditional ones is just a few centimeters, i.e., precise enough to satisfy the typical needs of archaeo-spelaeology. However, to obtain a good quality result, the surveyor must apply several practices or expedients, in order to avoid or mitigate the drawbacks mentioned above:

1) maximum range: if cavity length or width is an issue, proper path planning can help scan areas that are too long or wide. If the problem is with the height of the cavity, an extension can be used;
2) lighting: to obtain uniform illumination of the surface, an illuminator mounted on the device is useful, while the illuminator of the surveyor's helmet must be turned off;
3) uniform speed: jumps, trips and sudden movements must be avoided; as far as possible; the use of a stabilizer support should be considered;
4) overlap: careful route planning should avoid double scans of the same area; possibly, overlapping areas can be cropped out in post-processing;

Fig. 6 – Augustan aqueduct at Bagnoli: top view of the junction between two digging teams, between adits R7 and R8 (Cocceius Association).

Fig. 7 – Scan with an illuminator/power bank support in an underground aqueduct channel (photo G.W. Ferrari).

5) vegetation: the modeling of areas covered by vegetation is problematic due to the extreme irregularity of the surfaces; scanning in Detail mode is more effective; this involves performing scans with different point densities, to be merged in the post-processing phase;
6) power consumption: the LiDAR sensor requires a significant amount of power. With a fully charged iPhone battery it is still possible to scan for at least a couple of hours. A manual support with illuminator for the iPhone has proven to be particularly useful (Fig. 7); it can also act as a power bank for the device and it allows you to operate for a whole day of acquisition.

Regarding the usefulness of the method in particularly demanding areas, it was possible to survey tunnel sections almost completely blocked by sediments, with free space reduced to less than 40 cm, in which the caver is forced to crawl. In the archaeological field, therefore, the use of this technology allows you to work in 'extreme' operating conditions, guaranteeing reliable documentation for all those contexts (hypogea, cisterns, channels, ancient aqueducts, etc.), which usually do not fall within normal activities of archaeological research, due to the obvious access difficulties that these structures very often pose. This is a documentary gap that in the past was resolved by relying exclusively on speleologists, the only ones capable of accessing these contexts, but accustomed to different documentary standards compared to archaeological ones. Furthermore, the possibility of obtaining 3D modeling at relatively low costs is certainly useful in the context of the valorisation itself, given that it allows, quickly, to obtain captivating and easily usable results for communication towards users of cultural heritage.

Therefore, while waiting to be able to resolve some of the limitations set out above, there remains the need, already advanced in other contributions

(Fiorini 2022, 50-51) to continue the experimentation and to proceed with the codification of a precise procedure to be used in order to get the best from this instrumentation.

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ABSTRACT

For some years now, both in the archaeological and speleological fields, experiments have been carried out with portable MLS (Mobile Laser Scanner) or HMLS (Hand-held Mobile Laser Scanner) scanners that use LiDAR (Light Detection and Ranging) technology. This choice is due to their basic characteristics such as ease of use, reliability, efficiency and (a fact not to be underestimated) low costs compared to traditional indirect survey systems. These characteristics have made these tools extremely popular, especially since this technology can be used by owners of Apple devices, which has made it available for its tablets and smartphones, thanks to the ever-increasing sensor miniaturization. On the basis of some encouraging data presented in an archaeometry paper (Fiorini 2022) and from direct experiences in various underground sites proposed by several Italian caving groups, the authors have decided to test the device performance in the context of exploration and research on artificial cavities in the archaeological field which, very often, due to size and constraints, do not allow the use of other devices. Through the presentation of some case studies, it was possible to show the advantages and the limitations in the use of this technique in the archaeo-spelaeological field.