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The Amphitheatre of Avella: from its origin to digital

Marco Limongiello[1], Alfonso Santoriello[2], Giovanni Schirru[2], Raffaella Bonaudo[3], Salvatore Barba[1]

[1] *Department of Civic Engineering, University of Salerno.*
mlimongiello@unisa.it; sbarba@unisa.it
[2] *Department of Sciences of Cultural Heritage, University of Salerno.*
asantori@unisa.it; schirrugiovanni@gmail.com
[3] *Superintendence of Archaeology, Fine Arts and Landscape of the districts of Salerno and Avellino*
raffaella.bonaudo@beniculturali.it

***Abstract* - This study is a collaboration between the Superintendence of Archaeology, Fine Arts and Landscape of the districts of Salerno and Avellino, particularly the Avella's Archaeological Office, and the departments of Sciences of the Cultural Heritage and Civil Engineering of the University of Salerno, to serve the purposes of protection, research and enhancement of the Avella's monument. The paper deals with the photogrammetric survey of the ancient Amphitheatre of Avella (Italy) made by an UAV aircraft, which weighs under 2 kg. The ultimate goal is the realization of georeferenced orthophotos. Two capture modes were compared each other: firstly, a traditional photogrammetric flight with overlap of about 75%, consequently a less established video acquisition. The generated 3D models are verified metrically through 6 GCP (Ground Control Point) placed on the arena floor. The results show that video techniques, although characterized by further margins of error, have the advantage of speed of acquisition and secure overlap between the frames, allowing to monitor the cultural heritage with an extreme ease of operation.**

I. THE AMPHITHEATRE OF AVELLA: STRUCTURAL AND TECHNICAL ANALYSIS

The Amphitheatre of Avella is located in the South-East corner of the ancient Roman city walls, on the inside, and the major axis's orientation which is South West-North East varies from the ancient orthogonal city grid. Part of the building uses the walls (the south-eastern corner), and another part (the West side) uses the natural slope. On the West side, part of the embankment retaining wall in *opus reticulatum* is preserved and built as a substructure of the summa *cavea*. In the South sector, the monument is supported by vaulted structures in *opus caementicium* [1]. The Amphitheatre of Avella consists of a "full structure", according to the definition given by Golvin [2]. The main feature of this type of buildings is to use the natural conditions of the ground, so the *cavea* is entirely or partly dug into the ground or rock. If the natural depression or the slope is not sufficient, the bleachers are huddled in embankments contained by annular supporting walls.

The absence of radial walls supporting the *cavea* gives an imposing appearance to the structure [3]. The arrangement of the Amphitheatre externally consists of two semi-circular structures connected by right angle walls, and internally, by an oval-shaped structure, the arena, which dimensions are 63.6 x 34.3 m. Otherwise, the general dimensions document a building smaller than the Amphitheatres of Pozzuoli and Pompeii although the overall dimensions can be distorted by poor conditions of the outer area of the northern and eastern sectors (Fig.1).

The Amphitheatre has two monumental gates with vaulted galleries in *opus caementicium* on opposite sides of the major axis: *Triumphalis* gate toward the city, and *Libitinensis* gate, both paved with stone slabs. Near the two main entrances are two smaller galleries called *vomitoria,* which allow access to the *cavea*.

Fig.1. Avella's Amphitheatre: panoramic view.

In the southern sector, these galleries are not aligned in a perfectly symmetrical way like on *Triumphalis* gate because on its West side are two arches (Fig.2) The closest to the gate is not just a simple entrance but it allows to reach a vaulted room of quadrangular shape. A similar structure is recognized in the East of the other main entrance tunnel. Here the gallery's vaulted ceiling is largely collapsed, but at least one of the two lateral arches giving access to the *cavea* (the one to the East) is still intact. These rooms can be interpreted as *carceres* and act as service areas for performances since the Republican Amphitheatres do not have underground service facilities, as those of the imperial age [4]. Along the West side there's a third smaller gate where, near the podium, has been the privileged seat of the monument consisting of a simple and wide bench, called *subsellium*, which was reserved for judges or most important people (Fig.1). Immediately behind the podium, locate a narrow corridor that allowed the audience to move into the *ima cavea*. In front of the minor gate, on the East side, there is a rectangular room with jambs and limestone threshold where survive traces of an aedicule. The small rooms built in the podium near the main entrances were used as *spoliaria*, a service area where corpses were assembled. The archaeological record indicates that the others openings in the podium were stables for beasts which date back to the fourth century A.D. In the western sector, the annular wall of the substructure of *media cavea* is internally abutted against another wall which varies to the South. Given the pressure of the outer embankment in this area, it might be thought that there is a reinforcing wall to counterbalance the external pressure, furthermore the latter's technique seems different. This foundation wall of the *cavea* (Fig.3, wall A) is considered part of the original structure as it follows the only elliptical geometrical line towards the north and consists of small and yellowish blocks of tufa arranged in a *quasi reticulatum* pattern. The most interesting data in this area is the outer annular wall, which diverges from the course of the previously described wall following the course of the vaulted structure of the *Triumphalis* gate (Fig.3, the wall B).

Fig.2. Southwestern sector: vaulted galleries of the Porta Triumphalis.

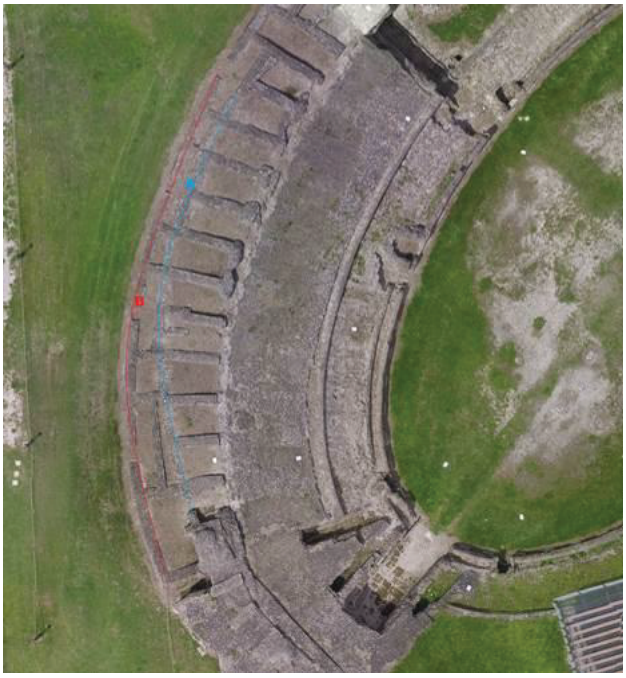

Fig.3. Southwestern sector: two phase's walls (A-B).

The external curtain of this structure does not survive but, by analogy with the Amphitheatres of Pompeii or Nola, it is possible to imagine that was characterized by blind arches coated with *opus reticulatum* or plaster imitating marble. The structure consists of large radial vaults made with reticulate facing crosslinked to the outer annular wall, described above, to form a forepart added to the original facade of the monument. It is possible to assume, in account to this structure and outer wall, that there was a second building phase in this area shortly after the first implant given the technical similarities. It could be a simple structural correction during construction or a late correction immediately after the construction. However, taking into account the comparison with the structures of the Pompeian Amphitheatre, where the course of the buttressed outer wall (which deviates significantly from the arena bend) recalls the situation found in the plan of the Avella's building, it can be assumed that the structure could keep in the outer part a *maenianum* in *summa cavea*. It most likely took the form of an open gallery on the top from which branched flights of stairs allowed to achieve the highest seats. Above the substructures of the South-West side of the monument, on the level of the *summa cavea*, were found two bases of staircase, both gradients towards the West and situated a few meters away from each other. The structure and position of this stairways show a strong analogy with the access staircases to the Pompeian Amphitheatre's porch constituting most likely two of the many entrances to the upper sector of the *maenianum* [5]. The analysis of the structure and construction techniques confirm the complexity of the transformations undergone by the monument in the various phases.

Fig.4. Southwestern major gate: straight wall basis on the west side.

Particularly, in the gallery of the south-western major gate, the West wall has its basis at a higher level than the other wall (the East one), which basis has a slanting profile and connects the external plan of the monument with the internal plan of the arena. The straight trait of the West wall seems related to the oldest phase: it can be assumed that the arena floor was higher than the current, perhaps slightly less than the decking surrounding the monument (Fig.4)

Later, it would be necessary an arena excavation for a depth of about two meters. Such intervention may be linked to the creation of a new sector obtained at the expense of the original arena surface, making it necessary to build manifold around the podium to allow the flow of rain water, actually found in western area of the arena. It can also be noted that the *cavea* has no annular or radial partition walls with the exception of a division wall between the *ima* and the rest of the *cavea*. This annular wall defines an oval area of 74.5 x 44.6 m, which corresponds most likely to the arena of the first phase, which had to be significantly higher than the current.

Despite the restorations do not allow a clear reading of the details of the original construction technique, the use of *quasi reticulatum* vestments consisting of tuff blocks of about 5 cm per side is visible particularly in the wall of the podium overlooking the arena. In monumental gates and rooms adjacent to them, the use of *opus caementicium* is clear; it is covered with a web of yellowish blocks of tufa placed in *opus reticulatum*, distinctly seen along the inner walls of *Triumphalis* gate [7].

The *reticulatum* of the outer annular wall could suggest that the intervention is a decade later than the original structure. However, bear in mind that the reticulated work spread in the last quarter of the second century BC, in the south and central area of the Peninsula, and, gradually supplanted around the middle of the first century BC, is still documented and in some building programs flanked the use of *opus reticulatum* until the end of the century [8]. Given the building features and the overall conditions, the Amphitheatre needs an updated and more complete survey, but it is even more necessary to develop fast inspection techniques, which allow to acquire data that can be easily replicable over time and ensure a consistent and effective monitoring.

II. DATA ACQUISITION

The tests and the renderings carried out on the Amphitheatre of Avella were intended to validate photogrammetric acquisitions from UAV ((Unmanned Aerial Vehicle) which weighs under 2 kg, particularly a DJI Phantom 3 Professional.

The aircraft used is a drone which weighs about 1,3 kg, capable of shooting video in 4K and streaming HD videos on smartphones, tablets and external devices through a special App (DJI Go). The camera is equipped with a Sony Exmor 12.4 megapixel (size 6.3 x 4.7 mm sensor, pixel size 0.00000155 mm) which has a wide-angle lens with focal length 4 mm, F number 2.8 with an aperture and FOV (Field of View) of 94° and it's integrated in the gimbal to maximize the stability of the images during the movement. The DJI position sensors use image data through a monocular lens, and ultrasounds to help the aircraft to maintain its position. The main components of the position's sensors are located on the bottom of the UAV, and include two ultrasonic sensors and a monocular lens. As well as the realization of photos, you can make videos in 4K up to 30 frames per second. The study of the Amphitheatre took advantage of two different methods of acquisition of the frames, a classic flight in manual mode, and also a less established video acquisition: one flight plan that could be called "circular uniform" in relation to the centre of the arena (with constant radius and height), and another "roto-translational" flight plan, a flight with the camera in zenith position with a rotation that increases with the altitude. The images obtained with the first method have a resolution of 12 megapixels, while the video resolution is 4096 x 2160 pixels. Through the photogrammetric flight were taken 75 images with an overlap of about 75% at a constant height of 33m. Otherwise, the video-grammetric nadir flight gained the maximum height of 95 m, while the 360° flight has used the "Point of interest" mode, programmable by the App, keeping a radius of 45 m above the centre of the arena and a constant height of 52 m.

In Figures 5 are shown the trajectories of three separate flights. In order to control the metric error were taken on the arena floor 6 GCP's (Fig.6) by a GPS Topcon Hyper Pro used in static mode with following accuracies in post-processing: H: ± 3 mm + 0.5 ppm V: ± 5 mm + 0.5 ppm.

Fig.5a

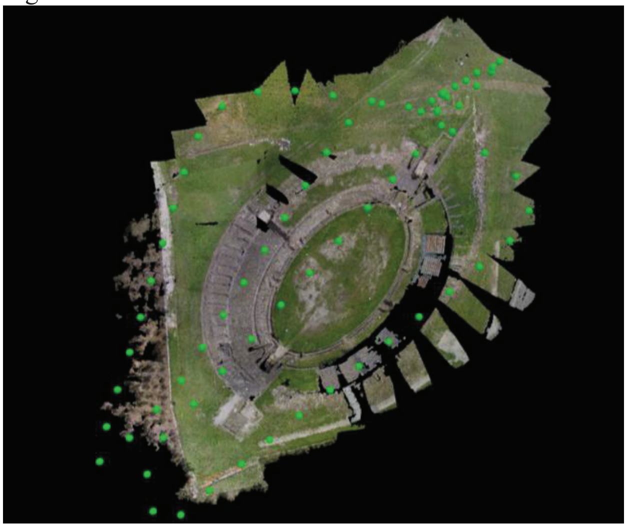

Fig.5b

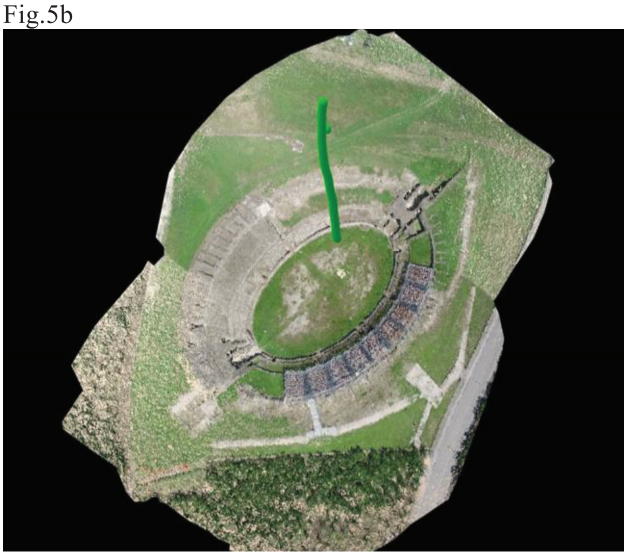

Fig.5c

Figg.5. Acquisitions: a) photogrammetric shots; b) nadir video; c) 360° video.

Fig.6. Distribution of GCP.

III. PROCESSING DATA

The data processing was made by the software Pix4Dmapper (version 2.2.25). The flowchart of Pix4Dmapper is based on 3 steps: Initial Processing (internal/external camera orientation and sparse cloud creation), Point Cloud and Mesh (dense point cloud and textured polygonal model creation) and DSM (Digital Surface Model), Orthomosaic and Index. In this last step, it is possible to generate the orthophotos, according to the resolution requested by the user [9].

In fact, in the latest versions it is possible to insert in input not only images but also video files. Once the video is imported, the user can decide the gap between frames (smaller is the gap, greater will be the images' overlap).

Once extracted the single frames, the image processing is similar to the photogrammetric one. Although, it is necessary to consider that in the processing of a video all the interior parameters of the camera are unknown, so the computational work of internal orientation becomes more burdensome than a traditional aerial photogrammetry. Therefore, in order to obtain an overlap of about 80%, the elaborations that come out from processing video has provided the extraction of 395 frames from the nadir flight and 558 frames from the 360° flight. In all projects developed, the number of automatically detected key points was augmented to 15,000 and at the same time, the number of pairs for each image is 3. With this configuration setting, the software aligns all images in the project that contains only images, 75/75 (100%), while for the processing of videos 154/395 (38%) for the nadir flight and 523/558 (93%) for the 360° flight.

Fig.7a

Fig.7c

Fig.7b

Figg.7. Ortophoto: a) photogrammetric; b) nadir video; c) 360° video.

Tab.1: GCP errors

	Error (m)	P1	P2	P3	P4	P5	P6	Average (m)	Dev. St. (m)
Photo	X	0.012	0.071	0.056	0.012	0.073	0.005	0.0382	0.0318
	Y	0.055	0.097	0.012	0.048	0.102	0.014	0.0547	0.0389
	Z	0.023	0.023	0.004	0.002	0.003	0.030	0.0142	0.0125
"360°"	X	0.179	0.481	0.107	0.063	0.118	0.062	0.1683	0.1591
	Y	0.304	0.049	0.112	0.161	0.107	0.040	0.1288	0.0967
	Z	0.321	0.711	0.133	0.145	0.436	0.093	0.3065	0.2376
"Nadir"	X	0.195	0.116	0.107	0.022	0.084	0.101	0.1042	0.0558
	Y	0.721	0.621	0.112	0.151	0.220	0.364	0.3648	0.2542
	Z	0.243	0.406	0.133	0.020	0.096	0.423	0.2202	0.1669

The GCPs were also used to adjust camera calibration and estimate a mean RMS (Root Mean Square) error.

In the second step, for the construction of the dense cloud, an image scale factor of 1/4 (half resolution on each side) was used. The dense cloud is generated by Bundle Block Adjustment [10] counts the number of 3D points respectively: 387’080 for photogrammetric processing, 77’924 for the nadir flight, 307’837 for 360° flight points. The errors of each GCP are reported in Table 1. It can be observed that the photogrammetric flight always presents the lowest variance from the elaborations of videogrammetry, in which the average variances on the coordinates of the single points have a greater magnitude’s order. Given these applications, the maximum average variance is about 36 cm, calculated on the Y coordinate of nadir flight. It occurs because in this acquisition mode there is almost no baseline between successive camera positions’, therefore it is difficult to make a photogrammetric triangulation.

Figures 7 shows the georeferenced orthophotos obtained; it can be observed that the use of classical photogrammetric technique gives better results both for metric and infographic parameters relatively to the texture production.

IV. FIRSTCONCLUSION

The use of a UAV aircraft that weighs under 2 kg equipped with an integrated camera produced results suited to the metric scale required for the study of the geometry of the Amphitheatre. The use of high-resolution video proved to be an interesting way to develop and pursue, demonstrating the advantage of greater speed of data acquisition and a certain overlap between frames, with appropriate metrical rendering in order to be used for the documentation of study’s site. It is, in summary, an innovative technique to be taken in account, particularly, in the expeditious application of excavations or archaeological heritage’s monitoring.

REFERENCES

[1] W. Johannowski, “La situazione in Campania” in P. Zanker, ed., Hellenisvmus in Mittelitalien. Kolloquium in Gôttingen vom S. bis 9. Juni 1974, Gôttingen, 1976, p. 272, n. 33.

[2] J.C. Golvin, L’Amphitheatre romain: essai sur la théorisation de sa forme et de ses fonctions, Paris 1988, p.42 ss.

[3] P. Gros, L’architecture romaine; du debut du IIIe siècle av.J.-C à la fin du Haut-Empire. I.Les monuments publics, Paris 1996, p. 357.

[4] K.E. Welch, The Roman Amphitheatre: From its origin to the Colosseum, New York 2009, pp.189-190.

[5] M.Iandoli, “L’anfiteatro di Avella: analisi tecnica e strutturale” in La forma della città e del territorio II, Roma 2005, pp. 173.

[6] E. A. Stanco, “Arene Campane: un modello geometrico di progetto” in Orizzonti, Rassegna di Archeologia XII, Pisa-Roma 2012, p. 34.

[7] G. Tosi, Gli edifici per spettacoli nell’Italia romana, Roma 2003, pp. 122-123.

[8] J-P. Adam, L’arte di costruire presso i Romani, Milano 1990, pp. 142-147.

[9] M. Limongiello, B. Jiménez Fernández – Palacios, “Action camera for metric archealogical documentation for narrow space”, in 1°International Conference Metrology for Archaeology, 2015, pp. 274 – 278.

[10] F. Fiorillo, B. Jiménez Fernández – Palacios, R. Remondino, S. Barba, “3D surveying and modelling of the archaeological area of Paestum, Italy”, VAR - Virtual Archaeology Review, vol. 4, No. 8 (2013), pp. 55 – 60.