2023 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Rome, Italy, October 19-21, 2023

The Roman amphitheater of Venosa (Basilicata, southern Italy): 3D survey and reconstruction

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***Abstract* – The Roman amphitheater of Venosa (Potenza, southern Italy) is one of the experimental sites chosen as part of the IDEHA project (Innovation for Data Processing in Heritage Areas) in the Basilicata region, of which the CNR ISPC was scientific coordinator. This contribution presents the new results of the research more closely linked to the technical and constructive aspects of the monument, achieved starting from the instrumental survey performed with integrated techniques of laser scanning and digital photogrammetry. The metric data collected was integrated with those no longer visible that emerged during the archaeological excavation campaigns, which took place in 1841, 1925 and then in the 1980s and from a careful reconnaissance of the collapsed architectural elements present *in situ*. Despite the poor conditions of the wall structures, subject to centuries of abandonment and spoliations, it was possible to develop a reconstructive proposal for the amphitheater, with the creation of a three-dimensional model in which they critically merged all the collected data.**

I. INTRODUCTION

The Roman amphitheater of Venosa in Basilicata (southern Italy) is one of the experimental national sites of the IDEHA project (Innovation for Data Processing in Heritage Areas) coordinated by the Institute of Cultural Heritage Sciences of the National Research Council. The structure was built in the 1st century AD in the easternmost sector of the ancient city, a peripheral area originally affected by residential districts, and subsequently it was the object of restoration and consolidation in the 2nd century.

From a geological point of view, the area on which the amphitheater is founded is characterized by the upper part of the Pleistocene regressive sequence, that testifies the last phase of the sedimentary history of the Bradanic foredeep [1-3]. This geological unit is characterized by sandy-gravelly regressive Deposits, whose thickness varies from 20 to 130 m and consist of sandy and gravely bodies (or mixed), including marine and/or continental litofacies, reportable to depositional delta and coastal systems and continental systems (plain alluvial), places among them in relationship of continuity (gradual passage) and/or disconformity (erosive contact).

The cemented conglomerate deposits therefore constituted the rigid substrate for the foundations of the amphitheater, which in part were also supported on the masonry foundations of pre-existing structures.

The first archaeological investigations dated back to 1841 [4], followed by those of 1935 [5] and more recently in the 1980s [6]. Unfortunately, very little remains of its magnificence today, as the site after centuries of abandonment became an open-air quarry for the recovery of building materials: a fate common to many other ancient monuments of Venosa. Furthermore, many of the evidences visible today have been the subject of heavy restoration work since 1935, which in some cases consisted in the *ex novo* construction of the same masonry structures (Fig. 1).

In this study the results of a part of the project are proposed, those more specifically related to the documentation of the remains of the monument, obtained with a 3D survey campaign based on the cross use of the laser scanner and Image-Based techniques. This has provided the basis for the development of a reconstructive hypothesis of the amphitheater, of which a three-dimensional model has been elaborated capable of condensing all the archaeological data inside it, including those currently not visible but documented by previous excavation campaigns. (ML, FG, IF)

Fig. 1. Roman amphitheater of Venosa: S-E aerial view.

II. FROM THE METRIC SURVEY TO THE 3D MODELLING

A. The metric survey through integrated methodologies

The starting point for a precise structural analysis of the archaeological evidence was the planning of a survey campaign, capable of producing an accurate 3D digital reproduction of the visible structures of the amphitheater. The metric survey was based on acquisition methods already tested in previous research projects [7-9], with the combined use of the 3D laser scanning and the aerial digital photogrammetry techniques, in order to obtain models with a different level of detail.

The terrestrial survey was performed using a Leica P20, a time-of-flight topographic laser scanner, with an acquisition capacity of approximately 120 m of radius and a speed of 1 million points per second. For total coverage of the amphitheater it was necessary to make 53 scans: 47 with preset values aimed at surveying more complex and close-up portions (spacing 3.1 mm, quality 3 and time 13:30, on a 10 m dome radius), and the remaining 6 to cover larger portions of the site but with minimal archaeological evidence (spacing 3.1 mm, quality 4 and time 26:59, on domes with a 10 m radius). The matching of the point clouds was performed manually with the Leica Cyclone software (v 8.1.1), with a final cloud of 320 million points then exported in .pts format (12 Gb) (Fig. 2). The file was then imported into Geomagic (Studio 2003) with a decimation of 50% and processed for the calculation of the mesh of about of approximately 10 million of polygons, then exported in .obj format (90 Mb).

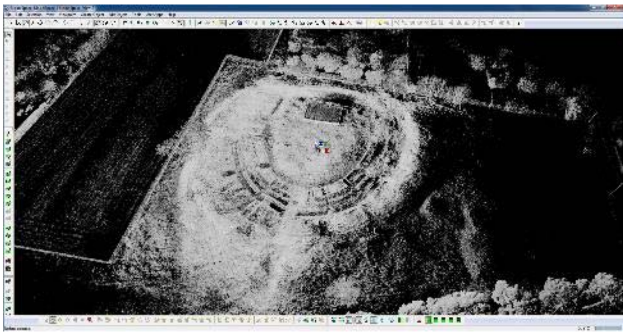

Fig. 2. Roman amphitheater of Venosa, point cloud from laser scanner: Leica Cyclone software (v 8.1.1) screenshot.

The photogrammetric survey campaign, aiming at the large-scale documentation of the site, was carried out with aerial acquisitions performed using the DJI Mavic 2 Pro UAV, equipped with a high resolution RGB camera (20MPx). The surveyed area, covering approximately 16,000 m2, has a relatively flat morphology with minimal variations in altitude not exceeding 4 m. The flight operations were preceded by the positioning of six Ground Control Points (GCP) identified by specific targets (80 x 80 cm), detected by an Emlid Reach RS2 GNSS multi-frequency receiver with RTK differential corrections directly from the Hexagon SmartNet network. The area was acquired with two flights at a height of 30 m AGL (Above Ground Level), the first–with a nadiral camera and the second with a double grid with a camera positioned at 30°, for a total of 310 RGB photos. The flights were automated and planned with PIX4Dcapture, defining parameters of altitude, speed, shutter speed of the camera and lateral/frontal overlapping percentage, according to the desired resolution (Fig. 3).

A second dataset of 436 photos aimed at more detailed documentation of the wall structures was carried out with two further double grid flights at a height of 10 m AGL. All the images were then processed with Agisoft Metashape Pro® with the following steps: alignment of the photos and creation of the sparse point cloud; insertion of the GNSS coordinates on the relative markers on the ground; photo alignment correction based on known GNSS coordinates; creation of the high density cloud; creation of the three-dimensional model with texture; creation of the DEM and the nadiral orthophoto.

The 3D Image-Based models, perfectly scaled and oriented, were-merged in the same 3D space with the .obj model obtained from the laser scan, and used to set up the reconstructive study. On them, imported and perfectly aligned in the digital work environment, the reconstructive study was set up with a perfect overlap functional to the immediate recovery of all the metric information concerning the planimetry and the elevation, especially for the walking surfaces in the different sectors. (FG)

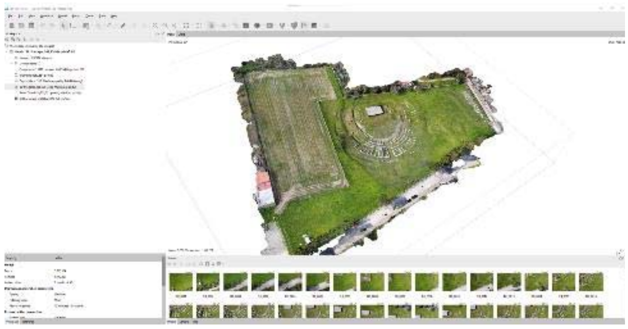

Fig. 3. Roman amphitheater of Venosa, 3D textured model from aerial photogrammetry: Agisoft Metashape Pro® screenshot.

B. The 3D modelling process

The elaboration of the 3D reconstructive proposal was carried out in the Maxon Cinema 4D R21 environment with hand-made modeling techniques and the support of the V-Ray 5 render engine [10-12]. Given the amphitheater plan, which can be duplicated in symmetry along its axes, the 3D modeling initially involved a quarter of the monument, using the 1:1 scale models obtained from the 3D surveys as a reference (Fig. 4).

The modeling process took into consideration all the constructive aspects and the deductions of a technical-structural nature deriving from the cross-referencing of the published data, with the unpublished data emerging from the *in situ* reconnaissance of the archaeological evidence, such as wall structures and individual architectural elements in collapse. It represented an important phase of refinement and improvement of the reconstructive hypothesis, which contributed to the definition of the architectural form of the monument, both from a structural and typological point of view. The result produced can be defined as a "knowledge model" [13], which summarizes all the information collected, clearly open to future changes deriving from the possible acquisition of further new data. The total number of polygons in the final model of the amphitheater is approximately 22 million, for a total weight of 1.7 Gb in the native .c4d format. The textures used for mapping the meshes are photographic based and optimized in Photoshop (CS6): a total number of 32 .jpeg images were used for a total weight of 100 MB. All this aims to propose an overall 3D representation in which the interpretations of the collected data converge, in an attempt to make both the overall architectural development and that of the various interior spaces better understandable. (IF, FG)

Fig. 4. Roman amphitheater of Venosa, virtual reconstruction on digital photogrammetry model: Maxon Cinema 4D R21 software screenshot.

III. STUDY OF THE ARCHAEOLOGICAL EVIDENCE AND ELABORATION OF THE 3D RECONSTRUCTION PROPOSAL

The first step was to integrate the update plan, with what is no longer visible but was documented in the previous metric surveys (Fig. 5a-c). The structures cover more than half of the volume of the amphitheater, so by mirroring the remains it is possible to recompose the general plan (Fig. 5d). From it, the overall dimensions are obtained with a good approximation, recognizable in a major axis oriented NW/SE of about 104 m and in the minor one of 84 m, in the *arena* reduced to 57 m and 38 m. From the comparison with the other known amphitheaters, we can see as the Venosa one is a monument of medium-sized, implanted on a slight hillside slope in the NE suburb of the city, with foundations in the natural ground in the western portion, and on an embankment in the eastern one: the latter was probably made with the soil removed for the construction of the *arena*, located about 2.4 m lower than the external walking surface.

The *cavea*, divided into 80 wedges, has a width of 23 m and consists of three parts: the peripheral portion 12 m wide with the external pillars and the radial walls, the internal one 4 m wide close to the *arena* characterized by masonry embankments, and the middle sector 7 m wide with the three contiguous annular corridors, each 2 m wide in the first phase. Regarding the construction techniques, the double order of external pillars is in *opus quadratum*, while the remaining masonry structures (the radial walls, the spine walls of the annular corridors and those of the embankments) are in *opus reticulatum*.

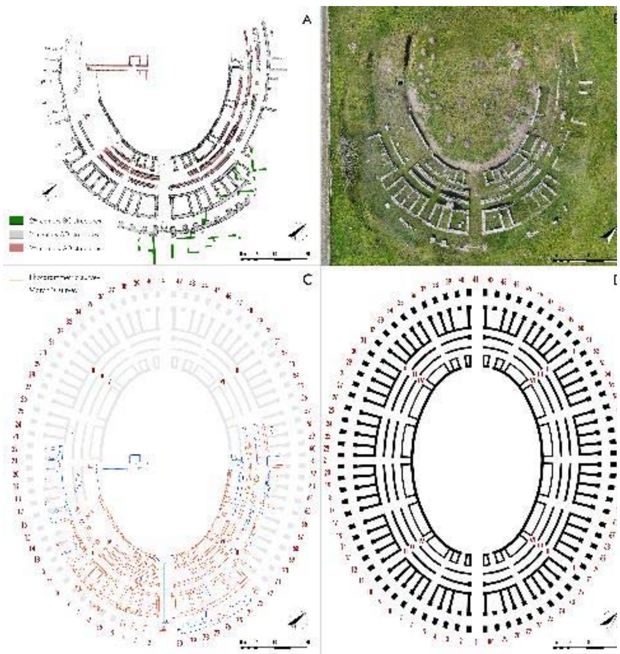

Fig. 5. Roman amphitheater of Venosa: A) 1980s archaeological excavation plan; B) 2021 nadiral orthophoto; C) merge of the 1980 and 2021 metric surveys; D) hypothetical reconstruction of the original plan.

The external ambulatory have a double ring of pillars originally surmounted by arches, the external rectangular ones and the internal quadrangular ones, which trace a peripheral annular corridor about 2.7 m wide having the walking surface about 2.4 m higher than to the central arena, as indicated by the remains of some thresholds still present between the pillars (Fig. 6a-b).

Between the radial walls there are wedge-shaped rooms, distributed along the oval in groups of four -with the exception of those flanking the major axis-, divided by descending corridors about 2.7 m wide at the outer end and 1.2 m in the internal one. These last stop at the surrounding wall of the *arena*, also known as the *podium*, interrupting the continuity of the masonry embankments: the steps for access to the *ima cavea* were located in these recesses.

Fig. 6. Roman amphitheater of Venosa, collapsing architectural elements: A) base block of an external pillar; B) arch wedge; C) cavea seat; D) molded base of half pilaster referable to the second order; E) shelf of the velarium; F) Corinthian style capital of half pilaster.

The two main entrances are along the major axis to the amphitheater which lead directly into the *arena*: the southern one is the only one investigated, has a constant width of about 4 m and was originally extended outside by a clay road [14] (Fig. 7).

It is configured as a large ramp that begins its descent before the external pillars, resulting in correspondence with these already 80 cm lower: the difference in height is given by the threshold of the main entrance, on which there are the holes for the hinges of the gate. This implies the original existence of a connection between the ramp and the floor of the external ambulatory, which in the reconstructive hypothesis is resolved with some steps following the example of the amphitheater of Lecce. [15-17]: the same solution was proposed for the three internal annular corridors, all placed on the same level.

Also on the sides of the main entrance, between the external ambulatory and the internal annular corridors, are two large rooms occupying the space of two wedges of the *cavea*: their entrance was probably from the external ambulatory with two arched openings.

Ascendent ramps would be symmetrically arranged in the third wedge of each grouping of rooms: their pavement consists of a thin layer of conglomerate laid directly on the ground.

Fig. 7. Roman amphitheater of Venosa: the southern main entrance seen from inside the arena.

The three central corridors in a concentric ring, each 2 m wide, have a common walking surface 0.7 m higher than the arena. In the wall facing of the outermost one there is a stringcourse in small blocks 1.5 m high, used for the reconstruction of a short section of the barrel vault. The other two annular corridors on both sides are wall coverings in *opus mixtum* dating back to the 2nd century, which reduce the passage to only 1.2 m. It is believed that this intervention was useful to contain events of instability of the vaults which at that point supported the seats of the *media cavea*, through an internal brick counter-vault which assisted in the dissipation of loads and stresses.

The masonry embankments supported the seats of the *ima cavea*, with the various blocks lying directly on the compacted ground. Their annular development is interrupted by the stairwells, which originally led to the first ring of *vomitoria*, but also by small wedge-shaped rooms near the main entrances, connected both with the innermost corridor and with the arena. The size and position lead us to interpret them as *carceres* (rooms for keeping animals destined for the *venationes*).

The *arena*, enclosed by the *podium* wall covered with white marble slabs, was the lowest point of the whole monument and therefore required drainage systems. For this purpose there is an underground rainwater disposal channel, which has its mouth in a small well located on the edge of the arena near the main southern entrance: it has a slight slope of 4.5° and extends along the main axis, to then presumably flow into a sewer branch. At the center of the arena are four hypogean environments attributable to the 2nd century construction phase.

Starting from these data, a reconstructive proposal of the elevated structures can be developed also considering the collapsed architectural elements on the site, such as the seating blocks of the *cavea*, easily recognizable by a shape similar to a right-angled triangle and essential for estimating the slope of the *cavea* (Fig. 6c). In the in situ elements the surface of the riser is *between* 36 and 41 cm and the seating surface is between 90 and 85 cm deep: this leads to an average slope of the steps of about 30° (Fig. 8).

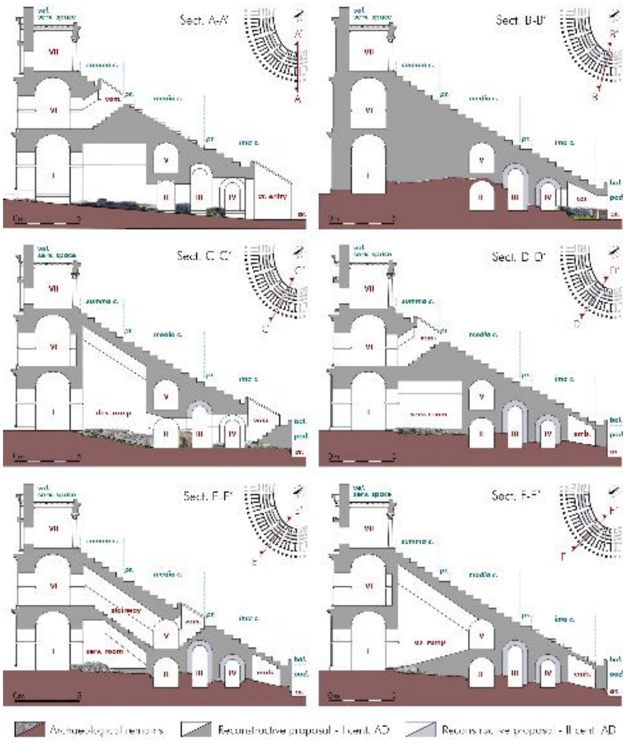

Fig. 8. Roman amphitheater of Venosa: cross sections of the reconstructive proposal.

By attributing an average height of about 2.6 m to the podium wall [18], and establishing with it the starting point of the *cavea*, it is possible to reconstruct the sectioned profile of the amphitheater and the structural function of the three internal annular ambulatories. The two innermost corridors, in fact, must have had increasing heights to support the *cavea* seats after the first sector with the embankments. The resulting space between the extrados of the remaining corridor and the *cavea* suggests the existence of another perfectly aligned annular corridor of similar dimensions, accessible from the ascending ramps. In this corridor it is reasonable to suppose the accesses to the *vomitoria* of the *media cavea* on the internal side, and on the external side the stairs leading to the upper external ambulatory of the amphitheater, from which it is probable there were the accesses to the *vomitora* of the *summa cavea*. In the portion of the radial partitions, the seats were thus supported by conoidal oblique vaults. Based on the inclination and width of the *cavea*, the external facade of the amphitheater almost certainly presented two orders of arches in *opus quadratum*, decorated with a series of pilasters aligned along the pillars (Fig. 6d).

The amphitheater was closed at the top by a crowning wall: the only surviving architectural elements are the shelves of the *velarium*, still recognizable among the ruins due to the rectangular recess in which the wooden poles were inserted to support and stretch the curtains. These large stone corbels are 105/106 cm long, 47 to 55 cm wide and 40 to 54 cm high, but with similar recesses 30 cm long, 22/23 cm wide and 14/14 deep 16 cm (Fig. 6e).

In the reconstruction proposal a third ring of pilasters decorates and strengthens the external side of the crowning wall, on which are virtually repositioned quadrangular capitals in the Corinthian style carved on three sides, still present among the ruins (Fig. 6f). The existence of the *velarium* need special spaces for handling, maintenance and conservation of the sails, generally located above a *porticus* in *summa cavea*, which for purely indicative purposes was modeled in the final reconstructive proposal (Fig. 9).

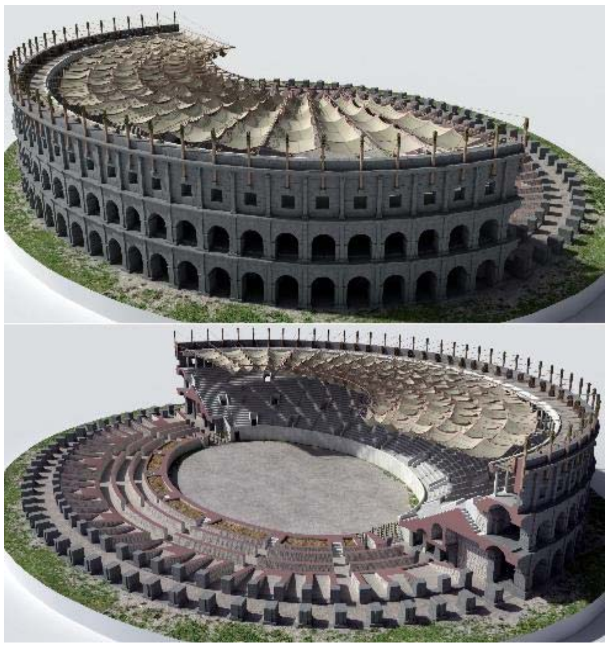

Fig. 9. Roman amphitheater of Venosa: cross section of the final 3D reconstructive proposal.

Regarding the estimate of the maximum spectator capacity of the Venosa amphitheater, thanks to the 3D model it was possible to calculate a total number of about

10,300 spectators, obtained by dividing the linear extension of the seats by 45 cm, corresponding to the width of a single position.

In conclusion, the proposed reconstructive elaboration, while remaining anchored to the elements that emerged, intends to represent a further step in the understanding of a monument that still needs to be fully investigated, remaining open to additions or modifications deriving from the possible discovery of new elements from future investigations archaeological. (IF).

REFERENCES

[1] P.Pieri, M.Tropeano, L.Sabato, M.Lazzari, M.Moretti, "Quadro stratigrafico dei depositi regressivi della Fossa bradanica (Pleistocene) nell'area compresa fra Venosa e il Mar Ionio". Giornale di Geologia 1998, pp. 318-320.

[2] M.Lazzari, P.Pieri, "Modello stratigrafico-deposizionale della successione regressiva infrapleistocenica della Fossa bradanica nell'area compresa tra Lavello, Genzano e Spinazzola", Mem. Soc. Geol. It., 57 (1), 2002, pp. 231-237.

[3] M.Lazzari, "Il comportamento tettonico e sedimentario del bacino d'avanfossa Bradanica durante il Pleistocene inferior". Volume in memoria di Alfredo Jacobacci "Evoluzione delle conoscenze geologiche dell'Appennino Apulo-Campano e Tosco-Umbro-Marchigiano. Mem. Descr. Carta Geol. It., LXXVII, 2008, pp. 61-76.

[4] S.Aloe, "Scavi nell'anfiteatro di Venosa", Bullettino Archeologico Napoletano, Roma 1842, pp. 12-13.

[5] G.Pesce, "Venosa (Potenza). Scavo dell'anfiteatro e restauro della cosidetta «Casa di Orazio»", Notizie degli Scavi di Antichità, 1936, pp. 450-460.

[6] M.L.Marchi, "Venosa. Nuove acquisizioni archeologiche. Saggi nell'area dell'anfiteatro", in Salvatore M. (a cura di), "Basilicata. L'espansionismo romano nel sud-est d'Italia. Il quadro archeologico. Atti del Convegno. Venosa, 23-25 aprile 1987, Venosa 1990, pp. 17-21.

[7] L.De Giorgi, I.Ferrari, F.Giuri, G.Leucci, G. Scardozzi, "Integrated Geoscientific Surveys at the Church of Santa Maria della Lizza (Alezio, Italy)", Sensors 2021, 21(6), 2205.

[8] G.Leucci, L.De Giorgi, I.Ditaranto, F.Giuri, I. Ferrari, G.Scardozzi, "New Data on the Messapian Necropolis of Monte D'Elia in Alezio (Apulia, Italy) from Topographical and Geophysical Surveys", Sensors 2019, 19(16), 3494.

[9] F.Gabellone, I.Ferrari, F.Giuri, P.Giuri, "Architectural survey and analysis of the costal tower of S. Maria dell'Alto in Nardò (Lecce, Italy)", Proc. 2019 IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage (Florence, Italy, December 4-6, 2019), pp. 254-258.

[10] F.Gabellone, I.Ferrari, F.Giuri, M.Chiffi, "3D technologies for a critical reading and philological presentation of ancient contexts", Archeologia e Calcolatori 28.2, 2017, pp. 591-595.

[11] F.Gabellone, I.Ferrari, "Reconstruction of Villino Florio's wooden ceiling using 3D technologies", Archeologia e Calcolatori 28.2, pp. 587-590.

[12] F.Caruso, F.Gabellone, I.Ferrari, F.Giuri, "New reconstructive proposal for a critical reading of the archaeological documentation of Syracuse in Greek times", Virtual Archaeology Review, 6(12), 2015, pp. 19-28.

[13] I.Ferrari, A.Quarta, "The Roman pier of San Cataldo: from archaeological data to 3D reconstruction", Virtual Archaeology Review, 10(20), pp. 28-39, 2019.

[14] M.L.Marchi, M.Salvatore 1997, "Venosa", Roma 1997.

[15] C.M.Amici, "*Iter* progettuale e problemi architettonici dell'anfiteatro di Lecce", in F.D'Andria (a cura di), "Metodologie di catalogazione dei Beni Archeologici. Conoscenza e Tecnologie, Quaderno 1-2", Lecce-Bari 1997, pp. 181-198.

[16] R.Persico, G.Leucci, L.De Giorgi, S. D'Amico, E.Colica, "A multidisciplinary study on the Roman amphitheatre of Lecce, Southern Italy", Proc. 10th International Workshop on Advanced Ground Penetrating Radar, Held at Near Surface Geoscience Conference and Exhibition 2019, (The Hague, Netherlands, September 8-12, 2019), 2019NSG.

[17] F.Gabellone, I.Ferrari, F.Giuri, M.Chiffi, "The contribution of the 3D study for new reconstructive proposals of Lecce in Roman age", Proc. of the 1st International Conference on Metrology for Archaeology (Benevento - Italy, October 21-23, 2015) Benevento 2015, pp. 534-538.

[18] J.G.Golvin, "L'amphithéâtre romain: essai sur la théorisation de sa forme et de ses fonctions", Paris 1988.