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METRIC ANALYSIS OF THE ORIGINAL STANDS OF ROMAN AMPHITHEATER IN TARRAGONA: METHOD AND RESULTS.

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ABSTRACT:

Despite being a well-Known monument, the amphitheatre in the city of Tarragona, included in the World Heritage list by the UNESCO, has only been entirely studied since the late 80s of last century, with their archaeological research limitations and specific characteristics of the moment. This is appreciated on the quality of planimetric documentation. The general planimetry was basically available with their relevant sections in scale 1/100 with enough accuracy. Although with the current scientific parameters is clearly insufficient to use rigorously and obtain a comprehensive architectural knowledge. Own technical limitations of time, and monument innate difficulty caused the obtaining of a limited number of sections, in particular two, with a low level of detail.

This situation leads to deficiencies in reading and interpretation that necessarily involves dubious or erroneous conclusions. Therefore the need for a complete metric documentation is evident because allows us to do a correct analysis. This documentation has been obtained by carrying out a topographic survey using digital photogrammetry, which provides us with more information than merely measure. From three-dimensional model generated we are able to analyze the sections of the stands and draw conclusions about its geometry.

1. INTRODUCTION

Thanks to the awareness of society about cultural and civic values that world heritage represent, currently archaeological activity is a quotidian work in our cities. Moreover, in some cases the historical continuity of urban fact in Western Europe leads to physical coexistence between historical spaces and the dynamism of our contemporary cities. Among these cases we find the city of Tarragona, ancient Roman Tarraco, which compiles all the possible information about their old inhabitants, even before the own genesis of the Roman city. This has established the need to define a working archaeological methodology enabled for all interventions and to have a thorough knowledge of the town, in addition to standardized criteria in architectural representation of the remains, because archaeological data transcends to other specialties: urban planning, architecture or restoration.

We need to propose an archaeological survey methodology based on capturing 3D information to accurately track, from instruments and methods to obtain a geometry which will then be analyzed rigorously. When the elements of cultural and historical heritage of our cities have good graphic and geospatial documentation, we can complete accurately an analysis and to understand how they were built and what modifications suffered throughout their history. It is here where our research has been focused, particularly in the Roman amphitheatre of Tarragona, where aspects of its construction are unknown and now claim to deal with in detail, but this was necessary to have a full 3D model. The geometric shape of the amphitheatres ground has been studied by many authors (Docci & Migliari, 2001) but the elevation plans, i.e. sections of the stands are less analyzed. The study of these sections will be the object of our investigation.

In recent decades, digital photogrammetry and topography, whether in our traditional system of captures or through scanning instruments that enable massive capture, have been the methods that have experienced a major expansion (Remondino et al. 2009). Thus the present topography allows us to capture quickly and accurately a large amount of spatial geo-referenced information, using total stations, GNSS receivers and terrestrial laser scanner (TLS). Photogrammetry enables us to document the archaeological excavations metrically with minimal interruption of fieldwork, saving many hours of working with a classic manual drawing. Furthermore all structures are photographically documented allowing the creation of an historical archive of the different phases.

In the case of needing metric information about plane elements (mosaics, wall paintings, facades ...) we can use to obtain this information a single photograph with perspective corrected (see Figure 1). We only need to identify the characteristic lines of photographic model or knowing the topographical coordinates of the four-points that appears in the image (e.g. nodes of a rectangle). Naturally the elements out of the plane of work will suffer several errors (i.e. depth).

Figure 1. *Trompe l'oeil* rectified in the Cathedral of Barcelona.

If you want to obtain a three-dimensional model of the element to study it is necessary to use the stereophotogrammetry. Today digital photogrammetric systems can get a cloud of points, similar that resulting from TLS scan through process of automatic correlation and only requires the operator involvement in introducing the representative lines of the object such as the edges. From this vector information you can obtain an identical model to the original with incorporated texture as in the example of Subirach's sculpture at the Passion facade of the Sagrada Familia in Barcelona (Figure 2).

Figure 2. Synthetic dimensional model obtained by photogrammetry

Depending on the precision of the results that are necessary to obtain, we must evaluate the use of a methodology and instrumental (Arias et al. 2005). The following sections show the work carried out to achieve a 3D model of amphitheatre that has allowed a metric analysis and draw conclusions about its construction process.

2. THE ROMAN AMPHITHEATRE IN TARRAGONA

The Roman amphitheatre of Tarragona was built in the first third of the second century AD in a small peri-urban hollow, when the city was the capital of largest province of Empire. Although in this place passed a road, with its corresponding funerary area, this construction represented the beginning of the architectural history of a space that, by their nature, kept a continuity of human occupation. With this building the city gave the last great public compound that characterized the urban leisure of roman society. The precise location of the building was due to the proximity to the city, its accessibility and the use of the mountain to cut there part of the stands (Arbulo Ruiz, 2006).

The Amphitheatre is currently one of the most important referents of our past and its classical roots. In 2000 the building was included in the list of Tarragona declared World Heritage by UNESCO. Also is on the list of the 7 Wonders of Catalonia promoted in 2007 by the foundation Capital of Catalan Culture. In the same year, was considered the tenth wonder of Catalonia in a popular vote conducted by the newspaper *El Periodico*. It is one of the museum enclosures most visited of the city, and in 2011 received the amount of 137 318 visitors. It is also one of the preferred areas to host acts of Tarraco Viva, the annual festival of re-enactment and historical dissemination.

Despite this cultural and touristic acceptance, whole the Roman Amphitheatre is difficult to understand by the visitor and the specialist. The building has suffered a strong transformation by architectural reforms or attacks to the original structure, so that the witness who is currently standing is only a small portion of an already disappeared volumetric reality. So, his remains, partially preserved and partially reconstructed, difficult to understand the original body from the point of view of the history of architecture. They become an appropriate challenge where applying new technologies for graphic and digital representation.

We surely know that the building was in use during the 3th century and between the 4th and 5th suffered a progressive decline resulting from the economic difficulties of the city and the increased influence of Christianity, with an opposite position to the traditional Amphitheatre games. In the middle or the second half of the 5th century the building was abandoned and would have availed a small sanctuary in memory of the three tarraconians martyrs, who executed in its sand within the context of persecutions of Christians (Muñoz, 2010).

At the end of 6th century was built a Christian basilica on the sand, commemorating their martyrdom. It was the first important architectural affectation when robbing the stone blocks of the amphitheatre and leaving the skeleton of stand in lime mortar. With the Arab occupation of Iberian Peninsula, the city and its Amphitheatre were abandoned between 8th and 12th centuries. Until 1154 when was built a new church -*Sanctae Mariae de Miraculo*. The new constructions increased architectural the plundering from old structures, while new roads connecting with the upper part of the city and its port area were opened. We do not know how were the following processes of degradation, but sixteenth-century descriptions (Pons d'Icart, 1981) or drawings of Tarragona (Anton Van den Wyngaerde 1563) indicate a very similar conservation level with respect a currently.

In 1568 the see of the Congregation of "Puríssima Sang" was moved to the church of Amphitheatre, and in 1576 the space was occupied by the monastery of Trinitarians. They built new dependencies throughout the area and elevated the levels of circulating hiding the sand and lower ancient buildings. The Trinitarian monastery was maintained in the amphitheatre until 1780 and, since 1792, it was conditioned to accommodate prisoners of war. This new activity was the origin of the prison of Miracle, which was in use until 1908. At the request of the City of Tarragona, in 1910 the Spanish government ceded the ownership of terrain. With the desire to recover the vision of the Medieval church were demolished old structures of the prison (Gisbert, 2012). Unfortunately, old walls did as buttresses of Church and in 1915 there was the accidental collapse of the roof of *Sanctae Mariae de Miraculo*, beginning a period of degradation historical heritage that was not resolved until 1948, when the Provincial Archaeological Museum undertook an intensive archaeological excavation to exhume all remains preserved.

In 1964 the Ministry of Education financed the activities of Artistic Heritage Brigades that, between 1967 and 1973, carried out the reconstruction of a part of the monument defining the currently appearance. During the 80s there was the reconstruction of building and the development of a scientific project, led by the Archaeology School Workshop of Tarragona (TED'A, 1990), that allowed to make the first topographic survey of the site. Since then, the historic site is managed by the Historical Museum of the City of Tarragona. The result of this historical evolution is the preservation of the architectural plan plus a segment of ima and media cavea, and the start of summa cavea. Not have a complete section of the stands and the twentieth century restoration not respected the original geometry of the monument, providing the feeling that this is on a smaller scale than the original.

3. METHODOLOGY

The development of a more detailed and complete graphical documentation project using new techniques of capture allows an analysis that had not yet been carried out. It should be noted that the available archaeological planimetry was made in the last century, with instrumental typical of the time. Afterwards the Tarraco Archaeological Planimetry project revised this mapping using global positioning with reference system ED50 and cartographical projection UTM 31N (Macias et al. 2007). Until this project, new technologies like as digital mapping, digital photogrammetry, 3D CAD models never had been applied. In short the computerization of the archaeological record and analysis of archaeological data is a novelty for the amphitheatre of Tarragona

3.1 Working method

The works detailed below corresponds to the original Roman amphitheatre in Tarragona at scale 1/100. This survey was made by photogrammetric techniques with the support of classic topography. Among the different techniques that can be used to obtain geometric and graphical information of archaeological elements to the scale above mentioned, the most appropriate, due to its quality / cost ratio is close range photogrammetry. In these works the classical topography is generally used to give the necessary control points in the process and to complete some areas by topographic surveying.

The main characteristic of these techniques is the way to achieve photogrammetric documentation: from photographs made with standard cameras that have been calibrated by the operator to allow the restitution with the required accuracy. To face up to photogrammetric restitution, field and office tasks are necessary. First, a photographic coverage of the amphitheatre that would ensure a proper scale and stereoscopic vision. To give a homogeneous coordinate system for all models an aerotriangulation was made, and finally, stereoscopic models were obtained and from them we are able to generate the model.

3.2 Shooting

To achieve a good stereo model is necessary to have a sufficient overlap between the different photo in each strip and between strips. In the case of the amphitheatre a minimum longitudinal and lateral overlap of 60% and 30%, respectively, was considered adequate. Moreover, to make possible to work with different distances in order to obtain a complete model different focal has to be used.

After analyzing the different options we chose to use conventional cameras. They were calibrated previously to obtain their internal parameters. The cameras used in this case were the Canon PowerShot Pro1 and Nikon D70. The focal length used are f = 7mm for short distance, f = 30mm for details and textures and f = 70mm for long distances.

The shooting was distributed as follows:

Front facade: 3 strips using in the lower and intermediate a focal length of 70mm and 7mm in the upper one. In total 22 pictures were taken.

Side facade: 2 strips using a focal length of 30mm in the lower and 7mm in the upper one. In total 5 pictures were taken.

Back facade: 3 strips using in all of them a focal length of 7mm, in the centre was also used a focal of 30mm in 2 photographs. In total 40 pictures were taken.

Grille: In this case it was a detail which was covered with a single strip with a focal length of 7mm.

In total 167 photographs were taken of which 70 were used for the restitution and the obtaining of the model.

3.3 Aerotriangulation

To establish a topographic network was necessary before the aerotriangulation process. The coordinates of control points identifiable in the photos were obtained from the bases of this network. That would allow us to obtaining support points. This information allowed us to georeference models. This network consisted of two traverses connected with each other. They were related with the reference system established by the Catalan Institute of Classical Archaeology (ICAC) during the project "*Planimetría Arqueológica de Tarraco*" since two bases of the traverses made up of the ICAC network.

The software used for the aerotriangulation process was the Image Master of Topcon. First the relative orientation was made by measuring homologous points (from 15 to 25) between adjacent images. Then we proceeded to make the absolute orientation of each of the images from the control points whose coordinates were obtained during the topographic survey. Thus images were related and the model was obtained. Finally, the block adjustment was calculated. After this process it was checked that the parallaxes were less than 1 pixel and the residuals for the coordinates of the control points did not exceed 2 cm.

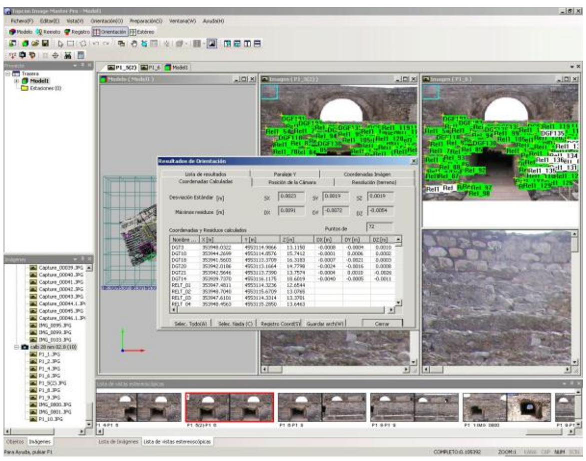

Figure 5. Creation of the models

3.4 Restitution. MDT

Finally, the restoration was made to obtain a three-dimensional vector model, which is the basis of subsequent graphical representations.

The scale chosen for the representation of the model is 1:100. The value of this scale, as the cartographic case, determines the photographic shooting. The drawn vectors have a double function, on one hand a vectorial model is obtained and on the other hand these are used as broken lines in the automatic correlation process that allows us to achieve a spatial model with a resolution of 5 cm.

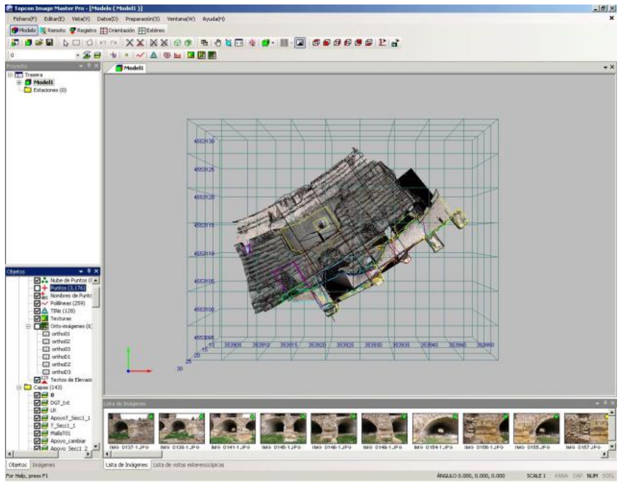

Figure 6. Cloud of points obtained by correlation and break lines

3.5 Mapping and orthophotography

This continuous and complete model of the steps and the back facade could be coloured from the oriented photographic images. In this way a synthetic and realistic model was achieved and from it several derived products such as sections, ground plants, elevations, isometrics, etc.

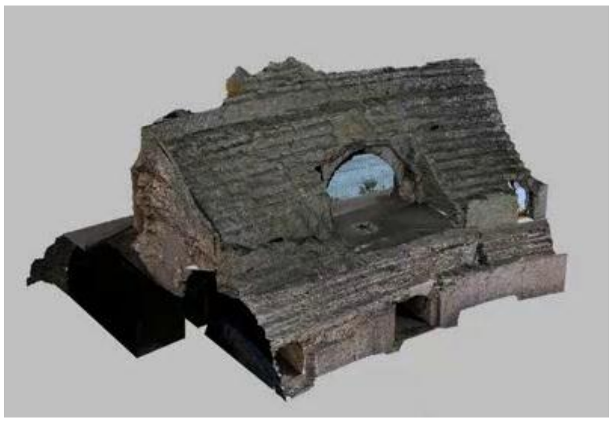

Figure 7. Textured model.

4. RESULTS

This 3D photogrammetric model has generated a documentary corpus and several geometric studies that approach to the knowledge of the monument. For the first time there is sufficient reliable data to successfully analyse a number of fundamental issues for understanding the amphitheatre, both in terms of its geometry and calculations regarding their ability to viewers. Furthermore, we can study many issues that had gone unnoticed. But in this paper we focus on the analysis of the sections obtained from the 3D model. We generated four transversal sections and one longitudinal more, with the aim to define the profile of the stands, because by the high rate of erosion and various actions of restoration and consolidation was distorted its original appearance (Figs . 8 and 9). Section 1 crosses through the first series of preserved vaults (Fig. 10.1), section 2 crosses the support walls of the vaults (fig. 10.2), section 3 passing through the axis of the authorities tribune (fig . 10.3) and section 4 passes by restored area in the 60s of last century (Pl. 10.4). Finally, a longitudinal section crosses in separation point between summa and media cavea where there is a change of inclination of the vault (fig. 11).

Figure 8. Position of the cross sections

Figure 9. Position of the longitudinal section

Figure 10. Cross sections

Figure 11. Longitudinal section

The analysis of these sections allow to develop a new interpretative proposal about the stands of maritime facade (fig. 12) and this would presumably be the scheme developed around the perimeter, even in area where the building was cut in the rock. On the other hand, the comparison of these sections shows a divergence considerably between the original part and the stands rebuilt in 60s (compare 10.1 and 10.2 compared to 10.4). There is no coincidence in the design of the vaults or with the profile of the stands. For example is displaced almost 1.30 meters the separation wall between ima cavea and media cavea (fig. 13). This is because of /due to a documentation error of architectural restoration, when confusing the last row of the ima cavea with the remains of the separation wall. There is also a discrepancy in the size and number of stairs in the restored part.

Figure 12. Theoretical sections.

Figure 13. Overlap the sections between the original and reconstructed areas.

Metric analysis of the original part identifies a cavea divided into three parts by corridors -praecintiones. The dimensions are given in Roman feet because this is the unit that was planned and built the monument. A Roman foot (*pes correctus*) is 0,296 meters. Thus 15 p are 4.44 meters. As was common in Roman entertainment buildings, the ima cavea, media cavea and the summa cavea, were separated by walls that formed the railing of the first row of seats. Ima cavea would have approximately 15 p. wide, with three rows of 3 p. wide and about 1.5 p. tall. His current height is between 1.2 and 1.3 p. , as an effect of natural and anthropogenic erosion. A distribution of heights of 1.5 p. fits the general scheme, and also maintains a coherent with the metric system used in the overall design of the stands. After we should add the measures of the stone seats, about half a foot in height, which were reused in the walls of the Visigoth basilica. In the upper of the three cavea could be one praecintio about 3.5 p. wide, slightly raised and which facilitated the distribution of viewers. The media cavea would be about 6 p. above the ima cavea level and would consist of 8 rows of about 2.5 p. wide and 1.5 p. height. At the top would be another praecintio about 6 p. wide. The summa cavea is difficult to define because only preserves two rows. It is about 5 p. above the media cavea and the only way to deduce its size is from the intersection of the overall width of the building with the stands slope documented in the 3D model.

The current width of the stands is about 20.5 meters (70 p.) and its tilt angle is around 32 degrees. These measurements allow us to hypothesize a suma cavea of 20 p. wide and 50 p. above of the level of sand. From the theory of seating section of 2.5 and 1.5 p. (fig. 14) the summa cavea would have six rows of seats more an upper praecintio. This aspect represents a change in relation to capacity studies currently.

Figure 14: theoretical section with heights

This theoretical section coincides with original stands, but not in pulpitum area (Figure 15), where you can see the remains of two lower rows and it is difficult to define the ima cavea. Although we have to imagine some elements that separated the authorities respect the other spectators, nowadays any evidence o barrier is preserved. The height of vault of pulpitum is higher than media cavea and there was only upper circulation corridor.

Figure 15: theoretical section of pulpitum area

The photogrammetric survey has also performed inside the support vaults of stands, which has allowed us to know how the substructure of the amphitheatre was. The vaults that support the ima and media cavea have been documented, and also the start of the summa. Furthermore, in alignment with the axis pulpitum there is a low vault that communicates the sand with the outside of the building and it was not able to be documented photogrammetrically.

These vaults have been subjected to consolidation and reconstruction works that alter the original geometry and difficult to define them precisely. However, we have established that the ima cavea was supported by vaults of 10 p. wide, a maximum 12 p. height and the separation would be about 8 p. The media cavea repeats the same system, but with slightly higher vaults, 17 p. (Figure 16.1). The summa cavea is sustained by a raised vault regarding the media cavea (4,4 - 5 p.), but the restoration of the 60s in this area not allow us a better definition. Anywhere from outside allows to us deduce the maximum height of these upper vaults, but approximately, it would have around 30 feet height. In relation with the pulpitum there are changes on the vaults system. The bottom is a low vault, which is located approximately 9 feet of lateral. The vault is 23 feet wide and about 12 feet tall. The vault that covers the pulpitum is 8 feet away from the other. It is the largest and highest of all and the only visible from the stands. It measures 25 feet wide with a maximum of 19 feet height (Figure 16.2).

Figure 16: Cross section with heights (1) and constructive proposal (2)

5. CONCLUSION

When documenting a historic building the biggest concern was traditionally achieve maximum quality of both geometry and precision of architectural detail. With the development of massive capture data systems (basically digital photogrammetry and laser scanner); the equality of graph paper and architectural reality is sufficiently precise to speak of the generation of digital "clones". In other words, near perfect copies of reality. And that has been the main objective of most of the projects of architectural heritage documentation: obtain an increasingly efficient and economical these copies. There is no doubt about the documentary value of these digital products, which are mnemonic elements to interpreter in anywhere and at any time. But the graphic documentation is much more than a purely descriptive element and in fact can not be an activity that justifies itself. Making a planimetric survey often constitute a hard work and their cost will have to be offset by the benefits to be obtained from their posterior exploitation.

This article does not focus exclusively on the genesis of the obtaining process of a digital model, but also in the conclusions that can be made from a specific monument. The original area of the stands of amphitheatre in Tarragona has been the subject of a digital photogrammetric survey in the framework of two Finals Degree projects of Surveying Engineering and Geodesy. These have created a digital model useful enough for archaeological analysis. The model has allowed us detailed geometric study with a restorative proposal that define architectural section formed by three bodies -the cavea- separated by praecintiones. The ima cavea would consist of three rows of seats, the media cavea of eight and the summa cavea of six. We must to take into account the original stone blocks and, for this reasons, each of seats would have a 3 p width and a 1,5 p height.

In addition, the maximum height of the stands could measure about 50 p. by 70 wide. If we add the theoretical width of upper praecinto, more the ashlars from the lining of the facade is concluded that its separation from the sand would be nearly 80 p. These height and width values can hardly be coincidental because their relationship is too close to auric proportion. Also it has been demonstrate how architectural reconstruction done in the 60s was made without taking into account any previous study. Consequently the reality was distorted as his section does not match with the original.

The architectural section of pulpitum area is other singular element where the media cavea completely disappears while the ima cavea almost spans the entire section. This arrangement is logical because was a distinct architectural treatment to create a privileged field of vision to the authorities. From the constructive point of view, we have identified the rhythm of separation of the vaults of support of the stands. They are regularly distributed with a constant width of 10 feet, except pulpitum area where their singularity forced to develop vaults with a greater width.

Finally data obtained from the photogrammetric model analysis allow us a better knowledge of this monument. It is an important step forward but insufficient for a global understanding. Despite this is an essential methodological phase within the scientific process. So, a future study of the amphitheatre in Tarragona, with the results of work here presented, will define the plain of building originally and its constructive logic.

6. REFERENCES

Arias, P.; Herráez, J.; Lorenzo, H.; Ordóñez, C. (2005): "Control of structural problems incultural heritage monuments using close-range photogrammetry and computer methods", Computers and Structures 83, 1754-1766.

Balletti, C., Guerra, F., Pillon, M., & Sartorelli, L. (2007). The Grumentum's arena: measure, geomtry and shape. XXI International CIPA Symposium. Atenas.

Docci, M., & Migliari, R. (2001). Architettura e geometria nel Colosseo di Roma. Matematica e Architettura - Metodi analitici, metodi geometrici , 13-24.

Forte, M. 2005; proceedings of the 2nd Italy-United States workshop, Rome, Italy, November 3-5, 2003, Berkeley, USA, May.

Ghiretti, A. (2008). L'Anfiteatro romano di Durazzo. Studi e Scavi 2004-2005 - Verso l'individuazione della geometria dell'Anfiteatro. A Annuario della Scuola Archeologica di Atene e delle missioni iraliane in oriente, Volume LXXXIII, Srie III, 5 - Tomo II - 2005 (p. 776-782).

Gisbert, M. 2012: Els presos i el port de Tarragona. Història de 92 anys de treballs forçats (1792-1884), Tarragona.

Golvin, J. (1988). L'amphitheatre romain. Essai sur la Théorisation de sa forme et de ses fonctions. Paris.

Macias, J. M., Fiz, I., Piñol, L., Miró, M. T., Guitart, J. 2007: Planimetria Arqueològica de Tarraco, Atles d'Arqueologia Urbana de Catalunya 2, Treballs d'Arqueologia Urbana 1, Documenta 5, Tarragona.

Muñoz, A. 2010: «La memòria de Sant Fructuós en la basílica de l'Amfiteatre de Tàrraco» a: Gavaldà, J. M.; Muñoz, A.; Puig, A. Pau, Fructuós i el cristianisme primitiu a Tarragona: actes del congrés de Tarragona (19-21 de juny de 2008), Biblioteca Tàrraco d'Arqueologia 6, Fundació Privada Liber, Institut de Ciències Religioses Sant Fructuós, Tarragona, 381-396.

Pons d'Icart, Ll. 1981: Libro de las grandezas y cosas memorables de la metropolitana insigne y famosa ciudad deTarragona, Llibreria Guardias, Tarragona.

Remondino F., El-Hakim S., Girardi, S., Rizzi A., Benedetti S., Gonzo L. 2009: «3D Virtual reconstruction and visualization of complex architectures - The 3DARCH project», International Archives of the Photogrammetry, Remote Sensingand Spatial Information Sciences, Vol. 38 (5/W1), Trento, Italy. http://www.isprs.org/proceedings/XXXVIII/5-W1/pdf/remondino_etal.pdf

Ruiz de Arbulo, J. 2006: L'Amfiteatre de Tarraco i els espectacles de gladiadors al món romà, Biblioteca Tarraco d'Arqueologia II, Tarragona.

Ted'a 1990: L'amfiteatre romà de Tarragona, la basílica visigòtica i l'església romànica, Memòries d'excavació 3, Tarragona.

Wilson Jones, M. (1993). Designing Amphitheatres. MDAI (R) (Mitteilungen des Deutschen Archaologischen Instituts: Römische Abteilung) (100), 391-442.