

#### **Original Study**

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# The Performances at the Theatre of the *Pythion* in Gortyna, Crete. Virtual Acoustics Analysis as a Support for Interpretation

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**Abstract:** The location of the so-called "small" Roman theatre of Gortyna (Crete), precisely at the back of the temple dedicated to Apollo *Pythios*, suggests a clear correlation of this monument with religious rituals. We may suppose that the theatre was used in particular during the *Ludi Apollinares* (*Pythia*), namely games and a festival dedicated to the God Apollo (held for the first time in Rome in 212 BC) or during the iso-Olympic *agones* as witnessed by the epigraphic sources of the imperial age. However, we have to consider also the possibility that the "small" theatre of Gortyna could have housed civic ceremonies or other activities related to the life of the *Koinon ton Kreton*, the federal assembly of all the Cretan cities which had its seat during the imperial times right in the space of the sanctuary. This paper aims to verify the typology of performances and activities that could take place in the theatre of the *Pythion* (namely if it was more suitable for music or speech) through virtual acoustics analysis. The study of the acoustics' quality has provided significant support to formulate hypotheses about the primary function of the theatre of the *Pythion* at Gortyna.

Keywords: Roman theatre, Ludi Apollinares, sanctuary of Apollo Pythios, 3D model

### 1 Introduction

The sanctuary of Apollo *Phytios* in Gortyna (fig. 1) has captured the interest of several scholars during the years because it was located near the centre of the city and it has a quite long history. The temple dedicated to the God Apollo was already documented in the VI century by Stephan from Byzantium. The archaeological excavations started only many centuries after, thanks to the interest of Comparetti and Halbherr, at the end of the XIX century (Halbherr, 1890). In particular, they were collecting the inscriptions of the Greek laws, dated to the archaic period, written on the blocks that were forming the temple. In the midst of the XX century, Colini decided to investigate the area of the remains of the monument and after he reported his observations (Colini, 1974). A very detailed study about the temple was carried out by Ricciardi who dedicated a large part of her research to the survey of the remains and the analysis and interpretation of the architectural structures (Ricciardi, 1986). Recently, the University of Padua, together with the Italian School of Archaeology in Athens, focused part of their interest in the area of the sanctuary, since they

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were excavating the theatre located immediately at the south-west corner of the temple. The archaeologists aimed to verify the physical connection between the temple and the theatre. Also, they investigated the visible area of the sanctuary to clarify the chronological sequence, including the *heroon* and the "votive" column placed respectively at the north-east corner and in front of the temple. These investigations brought new results about the function of the *heroon* and the column, but it has not been possible to enrich with new information the story of the three phases of the temple. The archaeological excavations carried out by the University of Padua confirmed the three construction phases of the temple: a first one dated to the archaic period between the VII and the VI century BC, a second one dated to the Hellenistic time, and a third one dated between the I and the III century. The end of the attendance at the temple is attributed to the great earthquake of 365 AD, which also destroyed the nearby Roman theatre (Bonetto, Bertelli, & Colla, 2015; Bonetto et al., 2017).

The Roman theatre placed at the south-west corner of the temple, right behind it (fig. 1), was built in the II century and it had two construction phases. Onorio Belli, Italian traveller and Physician, already documented the theatre at the end of the XVI century through a plan and a short description (Beschi, 1999). A few centuries after (between XIX and XX century), one of the archaeologists of the Italian Mission in Crete, Antonio Taramelli, began systematic investigations in the area occupied by the theatre and he left a plan and a section of the cavea of the building (Taramelli, 1902). Major excavations were carried out by the University of Padua for about ten years, since the beginning of the XXI century. The accurate and thorough examination of the area and its remains enabled the archaeologists to reconstruct the history and the structure of the theatre. The numerous archaeological campaigns and their results, together with plans, sections and hypothetical reconstructions, are described in detail in several articles (Bonetto, Bressan, & Francisci, 2006; Bonetto et al., 2008; Bonetto et al., 2011; Bonetto & Francisci, 2014) and in a forthcoming monograph about the theatre of the *Pythion* (Bonetto et al., in press). The geometry of the theatre is characterised as follows: the cavea is composed of two sectors divided by an ambulacrum, and each sector has 12 rows of seats (each seat measures 0.4 x 0.65 meters), its diameter is about 51 meters; the diameter of the orchestra is about 12 meters; the scaenae frons is rectilinear with three openings and about 24 meters long; two *aditus* lead to the stage directly from the outside; the distance between the retaining walls of the cavea and the scaenae frons is about 5 meters. The theatre of the Pythion could probably host up to 2000 spectators.

In Roman times, it was quite common to build theatres next to temples. The construction of the first permanent theatre in Rome in 55 BC, was justified by Pompey maintaining that his theatre was actually a monumental stair to the temple of *Venus Victrix*. Probably, the theatre of the *Pythion* was utilised during the ceremonies dedicated to the God Apollo, which used to take place in the near temple. In ancient times, the main ceremonies dedicated to the God Apollo were two: the *Pythian Agones* and the *Ludi Apollinares*. In 582 BC Greeks established the so-called *Pythian agones* officiated at the sanctuary of Apollo in Delphi, and for the first time in 212 BC, the *Ludi Apollinares* were celebrated in Rome. The *Pythian agones* were characterized by feasts, sacrifices to the God, athletic competitions and by musical contests. The latter was born "as a single musical competition called *Kitharodic* contest" (Perdicoyianni-Paléologou, 2017). The *Ludi Apollinares* used to last eight days: two reserved for games in the circus and six dedicated to theatrical representations (Scullard, 1981). Probably, the theatre of the *Pythion* could have been used to host the meetings of the *Koinon ton Kreton* as well: the federal assembly of all the Cretan cities which likely had its seat, during the imperial times, right in the space of the sanctuary, as it is demonstrated by several inscriptions (Chaniotis, 1999).

This paper aims to understand what kind of performances could be held in the theatre of the *Pythion*, according to its acoustics qualities. Was it suitable for enjoying music or for listening to people talking? Was it built to celebrate the *Pythian agones* (characterised by musical contests) or the *Ludi Apolllinares* (mainly characterised by plays)? Moreover, did the members of the federal Cretan union have their discussions in the theatre of the *Pythion*, or maybe in a better place, more suitable to listen to talks? The virtual acoustics analysis can help archaeologists to answer these questions. Since the theatre is not fully preserved, taking acoustics measurements in situ would not be helpful. The best solution is to reconstruct a3D model of the monument and to utilise proper software to calculate acoustics values. Odeon Room Acoustics is the

software used in this research, also employed in previous studies dedicated to the investigation of the acoustics of ancient theatres. Till now, the virtual acoustics analysis has been mainly used to examine the acoustics characteristics of ancient theatres (Evola, Giallo, Iannace, Marletta, & Sicurella, 2010; Iannace, Maffei, & Trematerra, 2011) but also in order to plan modern reuses of some of these monuments (De Gregorio, Iannace, Maffei, & Masullo, 2007). In this study, the resulting values obtained through virtual acoustics analysis are essential to understand if the architecture of the theatre of the *Pythion* was more suitable for talks rather than music performances, or vice versa.



Figure 1. Aerial view of the area of the sanctuary of Apollo Pythios at Gortyna (from Google Earth).

# 2 Methodology

The first step consisted in collecting all the information that enables the reliable and accurate reconstruction of the original aspect of the theatre of the *Pythion* at Gortyna. The 3D model of the monument used to perform the virtual acoustics analysis was created in AutoCAD by the researchers of the Department of Cultural Heritage of the University of Padua, based on the most recent discoveries during the last archaeological excavations. Then, the 3D model was imported in the software Odeon Room Acoustics after few modifications: to be precise, its architecture has been simplified to facilitate the calculations of the software, as suggested in the user's manual (Christensen & Koutsouris, 2015). The function of Odeon Room Acoustics is to virtually measure the impulse response of a receiver when a source is emitting a sound. The impulse response is characterized by three components: the direct sound, the early reflections and the late reflections. The direct sound is that one that directly reaches the ears of a listener, travelling in a straight line from the source, and it arrives first than the other components. Early reflections come from the sound hitting obstacles (such as walls, ceiling, floor, large objects) that reflect the received acoustic impulse; these are the first reflections that arrive after the direct sound, they cannot be distinguished by the ears, but if they arrive within 20 milliseconds after the direct sound, they improve the subjective

intensity of the sound. Reflections that arrive after the early reflections are defined late reflections: they contribute having the pleasant perception of the vastness of a room and enjoying a full experience of the sound, but when reflections keep arriving for a long time, we have a reverberant sound that invalidates the comprehension. This happens because a long/repeated time of reflections makes a sound longer than it should be and when a second sound (that can be the second syllable of a word, for instance) is emitted, the first sound is still audible, so that the two sounds are not identifiable and distinguishable, thus they are not comprehensible. Therefore, the impulse response contains sufficient information to judge the quality of the acoustics of a room, according to different acoustics parameters. Five parameters were considered to understand if the acoustics of the theatre respected the rules for a good comprehension of the speech or for enjoying music. The five parameters taken into account are: reverberation time (RT) and early decay time (EDT) that are related to the reverberation of the sound; clarity (C80) and definition (D50) that are related to energetic criteria; speech transmission index (STI), connected to spoken intelligibility. The reverberation time is the time a sound takes to decrease by 60 dB after the sound stops; the ideal reverberation time for the comprehension of the speech is around 1 second, while in an ideal space for music it should be around 2 seconds (Spagnolo, 2014). The early decay time is represented by the first 10 dB of decay which are important for the subjective perception of reverberation. The EDT indicates the diffusion of the sound: in an ideal environment it should be the same as RT, but it is usually a little lower and the level of disparity between them is a signal of good or bad diffusion of the sound. Previous researches about well-known and well-preserved theatres (Aspendos, Epidaurus, Jerash) demonstrated that usually, in open-air theatres, the difference between RT and EDT is between 0.2 and 0.4 seconds (Gade & Angelakis, 2006). The clarity represents the comprehension of single sounds within a complex signal; we may have more appropriate acoustics for speech when the value of C80 is equal or greater than 3 dB, while for a good listening of music we should need values under 3dB (Spagnolo, 2014). The definition indicates the level of clarity of the speech, the ease for the listener to understand the message of the speaker; the desirable value of D50 for a speech should be higher than 0.50, for music it should be lower than 0.50 (Spagnolo, 2014). The speech transmission index establishes the quality of spoken level objectively; values of STI between 0.60 and 0.75 are good, higher than 0.75 are excellent (Spagnolo, 2014).

Once the 3D model is imported in Odeon Room Acoustics, there is a procedure that needs to be followed to obtain reliable results from the acoustics measurements. First of all, it is important to set the right options in "room setup", according to the characteristics of the 3D model that has to be analysed; in particular: impulse response length, number of late rays, max reflection order, impulse response resolution and transition order. The following and crucial step was to assign the correct material to each surface of the 3D model. The absorption coefficients of the materials influence much of the energy of the sound that propagates in the area and consequently influence the quality of the acoustics. The materials applied, as suggested by Bonetto (Bonetto et al., 2006, 2008, 2011; Bonetto & Francisci, 2014), Taramelli (Taramelli, 1902) and Sanders (Sanders, 1982) are: bricks (analemmata, ambulacrum's wall, ima cavea's wall, vomitoria's vaults, basilicas, scaenae frons), limestone (ambulacrum's floor, vomitoria's walls, floor and front of the stage, architectural decorations of the scaenae frons), opus caementicium (orchestra's floor and the rise where the stage rests on), wood (doors of the scene building and of the proscaenium), and wood and bricks together (roof above the stage). Moreover, Odeon Room Acoustics allows assigning the "audience" material, which has been applied to the seating area to take into account the presence of spectators. The scattering coefficient was set as well, between 0.5 and 0.7, to perform an accurate analysis. Another fundamental step is the placement of sources and receivers (figs. 2 and 3). An omni-directional source approximately placed at the centre of the stage, 160 cm above the floor, simulated the average height of a person (the actor); an overall gain of 60 dB was assigned to it, corresponding to the decibels reached by the human voice. A grid of 19 receivers (one every 2 or 3 rows of seats) was placed in the cavea: they were distributed in 3 lines, 75 cm above the seats to simulate the average height of a seated person (spectators). An additional grid was also set (1 receiver each meter, 75 cm above the corresponding seats) to obtain a map of the distribution of the resulting values of the acoustics parameters. This grid is useful to verify and evaluate the homogeneity of the resulting acoustic values in the full area of the cavea.

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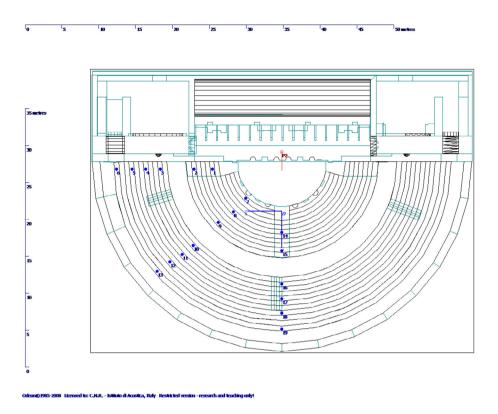


Figure 2. Top view of the 3D model of the theatre of the Pythion at Gortyna with source (red point) and receivers (blue points).

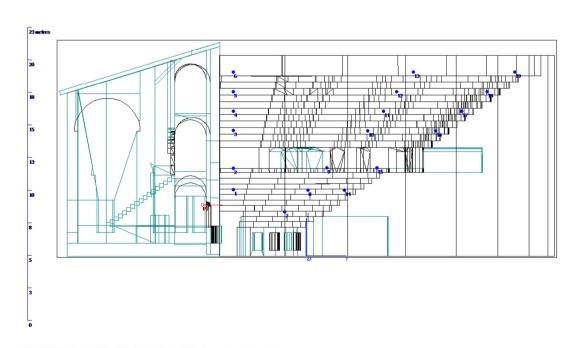


Figure 3. Side view of the 3D model of the theatre of the Pythion at Gortyna with source (red point) and receivers (blue points).

Moreover, the auralisation (the convolution of the impulse response with an anechoic file) was performed. The auralisation produces audio files that sound as they would have sounded if the audios were recorded in situ. Thus, it helps to judge the quality of the acoustics through subjective perception, listening to the auralised audio files. The anechoic file has been recorded in one of the audio room at the laboratory of the Institute of Sensors and Acoustics O.M. Corbino by Dr Paola Calicchia. The file contains a monologue performed by Martina Giovannetti, under the supervision of Dr Cristina Pace, from "The Trojan Women" by Euripides (about 4 minutes long)<sup>1</sup>.

#### 3 Results

The acoustic values achieved through the virtual acoustics analysis are here shown through a table and a map of the distribution of the STI's values. The examined range of frequencies is between 125Hz and 2000 Hz because these are the frequencies that are easily perceived by the human ear to comprehend speech. In table 1, the average values obtained by the resulting values of all the receivers placed in the cavea are shown for each considered frequency.

The reverberation time seems peculiar: it is high at low frequencies (more than 2 seconds) so that it looks suitable for music performances, but it decreases at high frequencies (more than 1 second) suggesting a good comprehension of a talk. This discrepancy of reverberation time between low and high frequencies is singular, as we can understand if we consider previous studies (Berardi, Iannace, & Maffei, 2016; Lisa, Rindel, & Christensen, 2004; Manzetti, 2017, 2018). The reverberation time alone does not allow to say if the theatre of the *Pythion* was more suitable for talks or music. The values of the early decay time are around 1 second (between 0.6 and 1.1 seconds). Since the EDT indicates the subjective perception of the reverberation time, we may suppose that its homogeneous values around 1 second suggest a room for plays rather than for music. Another singular aspect is the considerable difference in the values of RT and EDT (between 0.57 and 1.52 seconds), while, as it was afore-mentioned, generally in ancient open theatres the difference between RT and EDT is around 0.2 and 0.4 seconds.

As shown in table 1, the average values of the clarity are above 3 dB, as would be appropriate for understanding spoken performances. Table n. 1 also shows that the average values of definition are suitable for the comprehension of talks since they are above 0.50. The values of speech transmission index, as visible in the map of distribution (fig. 4), are between 0.65 and 0.80 (in the colour scale; black corresponds to 0.58, orange to 0.97), which means a good and excellent comprehension of the spoken language. Understandably, higher values of STI are recorded in the first rows of seats since they are closer to the source. The lower values of STI recorded in the last two rows of the first sector of the cavea are probably due to the reflections coming from the wall of the ambulacrum, located right behind these seats.

<b>Table 1.</b> Average values of all the receivers for the resulting values of RT, EDT, C80, D50 and difference between the average	
values of RT and EDT.	

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz
RT	2.45	2.3	1.71	1.38	1.09
EDT	1.09	0.78	0.61	0.59	0.57
Difference between RT and EDT	1.36	1.52	1.1	0.79	0.52
C80	3.55	6.34	8.24	8.5	8.76
D50	0.58	0.72	0.8	0.8	0.8

**<sup>1</sup>** For audio files see the supplementary materials.

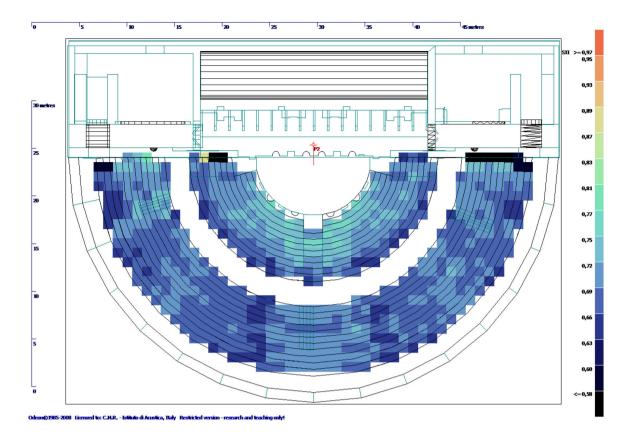


Figure 4. Grid of distribution of the values of STI.

Considering the results for all the chosen acoustics parameters, we can suppose that the theatre of the *Pythion* in Gortyna was built to host plays and talks. Besides, this hypothesis is also confirmed by the auralised files, which have a clear sound and the performed monologue is easily understandable.

Similar acoustics analyses conducted for other Roman theatres, such as the ones in Aspendos, Jerash (Rindel & Lisa, 2006), Ostia (Gugliermetti, Bisegna, & Monaco, 2008), Pompeii (Iannace et al., 2011) achieved similar results, in particular for clarity, definition and speech transmission index. The values obtained for these theatres (included the object of this study) are consistent with the idea that the Roman theatres were built with the purpose to host mainly plays, rather than music performances (more common in the Greek theatres), since these values indicate a good comprehension of the speech. The singular values of reverberation time within the theatre of the *Pythion*, which at low frequencies seems to be too high for a good comprehension of speeches, might be due to the theatre's shape since it is pretty enclosed and enveloping. However, the high value of reverberation time at some frequencies does not seem to worsen the sound of words or to impede their understanding, as the auralised files demonstrate. Nevertheless, this aspect needs to be further investigated.

#### 4 Discussion

The results of the virtual acoustics analysis demonstrate that the theatre of the *Pythion* was a space where talks and spoken performances could be easily and clearly understood. Thus, we may suppose that this was the main function of the theatre and that it was built for this purpose. It is important to remember that both ancient Greeks and Romans had a vast knowledge about sound and its behaviour, as it is still witnessed nowadays by the excellent acoustics of some well-preserved theatres (as Epidaurus) and by the words of Aristotle (Hicks, 2015), Aristoxenus (Macran, 1902), Plutarch (Einarson, 1956) and Vitruvius (Morgan, 1914). Hence, according to the results from the virtual acoustics analysis, we can affirm that the theatre

of the Pythion might be used to host plays (ludi scaenici) luckily organized during the Ludi Apollinares. In particular, we know that during these celebrations, the *fabulae praetextae*, were represented and these were plays narrating Roman events and histories. The theatre seemed not to be suitable to host musical contests, which were one of the main activity during the Greek celebrations, the Pythian agones. We may suppose that the area of the sanctuary of Apollo Pythios, at least since the II century (when the theatre was built), was used for the Ludi Apollinares. This means that in Gortyna, capital of the Roman province of Crete and Cyrenaica, the Roman traditions were probably more affirmed than the original Greek ones. It might be possible that there were musical performances or contests as well, but maybe in the circus, as it was happening in Rome. The theatre of Marcello, next to the temple dedicated to Apollo, was indeed used for plays during the Ludi Apollinares, while music performances were held in the Circus Maximus, as witnessed by Servius (ad Aeneidis, 8.110) who described an old man that, during the ceremonies dedicated to Apollo, kept dancing in the circus. Moreover, the attested comprehension of talks, through virtual acoustics analysis, supports the hypothesis that the theatre of the *Pythion* could be the seat of the assembly of the Koinon ton Kreton, as already suggested (Bonetto et al., 2017). The conclusions drawn about the possible activities held at the theatre of the *Pythion* encourage to further investigate the probably significant events that took place in such space and the connection between the theatre and the temple. Besides, they suggest the strong presence of Roman traditions in Gortyna and they hence encourage to better analyse the role of Rome in the capital of the province of Crete and Cyrenaica, above all in comparisons with the Greek culture. The results of the virtual acoustics analysis will be enhanced by the following analysis of the impulse responses derived from additional sources in at least two more positions on the stage (at the sides) and the seating area, in order to confirm or rethink the formulated hypothesis.

This study seeks to understand the typology of performances or activities held in the theatre of the *Pythion*, but it also underlines the importance of acoustics in archaeology. The analysis of the acoustics of such spaces that were considered important for communication, can reveal hidden aspects of buildings and consequently of the architecture and habits of the ancients. Besides, the virtual acoustics analysis is very helpful in archaeological contexts that are not fully preserved: it provides the possibility to obtain information that would not be possible to obtain otherwise, enabling the analysis in a 3D environment. This paper shows that the acoustics analysis can be employed not only to acquire more data about ancient buildings, such as the objective values of acoustics parameters, but it can be also used to formulate more in-depth and accurate hypotheses in archaeology.

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#### **Abbreviations**

RT: reverberation time EDT: early decay time

C80: clarity D50: definition

STI: speech transmission index

## References

- Berardi, U., Iannace, G., & Maffei, L. (2016). Virtual reconstruction of the historical acoustics of the Odeon of Pompeii. *Journal of Cultural Heritage*, 19, 555–566.
- Beschi, L. (1999). Onorio Belli a Creta: Un Manoscritto Inedito Della Scuola Archeologica Italiana Di Atene (1587). Atene: Scuola Archeologica Italiana di Atene.
- Bonetto, J., Bertelli, A., & Colla, M. (2015). New researches at the sanctuary of Apollo Pythios at Gortyn. In *Proceedings of the* 3rd Meeting, Rethymno, 5-8 December 2013, (Vol. A, pp. 529–536). Rethymnon: Faculty of Letters Publications, University of Crete, Ministry of Culture and Sports Ephorate of Antiquities of Rethymnon.
- Bonetto, J., Bertelli, A., Colla, M., Brombin, E., Bernardi, L., Gallucci, G., ... Metelli, M. C. (2017). Gortyna (Creta). Nuove ricerche presso il santuario di Apollo Pythios (2012-2015). *Annuario Della Scuola Di Atene e Delle Missioni Italiane in Oriente, XCIV*, 37–58.
- Bonetto, J., Bressan, M., & Francisci, D. (2006). Gortyna (Creta). Lo scavo 2004 presso il teatro del Pythion. *Annuario Della Scuola Di Atene e Delle Missioni Italiane in Oriente*, 82(3), 713–750.
- Bonetto, J., Bressan, M., Francisci, D., Bueno, M., Segata, M., & Ghedini, F. (2008). Lo scavo 2005 presso il Teatro del Pythion. *Annuario Della Scuola Di Atene e Delle Missioni Italiane in Oriente, LXXXIII*, 649–672.
- Bonetto, J., & Francisci, D. (2014). Il teatro del Pythion di Gortina: Storia di un teatro romano a Creta. In *Proceedings XVIII International Congress of Classical Archaeology*, (Vol. 1, pp. 941–944). Merida: Museo Nacional de Arte Romano.
- Bonetto, J., Francisci, D., & Mazzochin, S. (in press). *Gortyna IX. Il teatro del Pythion. Scavi e ricerche 2001-2013*. Atene.
- Bonetto, J., Ghedini, F., Bressan, M., Francisci, D., Falezza, G., Mazzochin, S., & Schindler Kaudelka, E. (2011). Gortyna di Creta, teatro del Pythion. Ricerche e scavi 2007-2010. *Annuario Della Scuola Di Atene e Delle Missioni Italiane in Oriente*, 87(3), 1087–1098.
- Chaniotis, A. (1999). The epigraphy of Hellenistic Crete. The Cretan Koinon: New and old evidence. In *Atti Del XI Congresso Internazionale Di Epigrafia Greca e Latina. Roma, 18-24 Settembre 1997*, (Vol. 1, pp. 287–300). Roma: Università La Sapienza Editore.
- Christensen, C. L.& Koutsouris, G. (2015). *Odeon Room Acoustics Software, Version 13, Full User's Manual*. Retrived from: https://odeon.dk/download/Version14/ODEON\_Manual.pdf
- Colini, A. M. (1974). Intorno al Pythion di Gortina. Antichità Cretesi. Studi on Onore Di Doro Levi, II, 129-135.
- De Gregorio, L., Iannace, G., Maffei, L., & Masullo, M. (2007). *The modern use for acoustical performances of the ancient Roman theatre of Beneventum*. Presented at the 19th international congress on acoustics, 2-7 September, Madrid.
- Einarson, B. (1956). Plutarch's Moralia in fifteen volumes. London: Heinemann.
- Erdogan, S. (2006). ERATO Project Symposium. Audio visual conservation of the architectural spaces in virtual environment. Proceedings. Istanbul, Turkey: Yildiz technical University.
- Evola, G., Giallo, G., Iannace, G., Marletta, L., & Sicurella, F. (2010). Le caratteristiche acustiche del teatro Greco-Romano di Taormina attraverso misure sperimentali e simulazione numerica. In *Atti Del 37º Convegno Nazionale Dell'Associazione Italiana Di Acustica, AIA*. Presented at the Associazione Italiana di Acustics 37º Convegno Nazionale Siracusa, 26-28 Maggio 2010, Siracusa.
- Gade, A. C. & Angelakis, K. (2006). Acoustics of ancient Greek and Roman theatres in use today. *The Journal of Acoustical Society of America*, 120(5), 3148–3156.
- Gugliermetti, F., Bisegna, F., & Monaco, A. (2008). Acoustical Evolution of the Roman Theatre of Ostia. *Building Acoustics*, 15(2), 153–168.
- Halbherr, F. (1890). Relazione sugli scavi del tempio d'Apollo Pythio in Gortyna. Monumenti Antichi Dei Lincei, 1, 9-76.
- Hicks, R. D. (2015). Aristotle de Anima: With Translation, Introduction and Notes. Cambridge University Press.
- Iannace, G., Maffei, L., & Trematerra, P. (2011). The Acoustics Evolution of the large Theatre of Pompeii. In *Proceedings of The Acoustics of Ancient Theatres Conference*. Presented at the Patras. Patras.
- Lisa, M., Rindel, J. H., & Christensen, C. L. (2004). Predicting the acoustics of ancient open-air theatres: The importance od calculation methods and geometrical details. *Baltic-Nordic Acoustical Meeting, 8-10 June*. Presented at the Mariehamn. Mariehamn.
- Macran, H. S. (1902). The Harmonic of Aristoxenus. Edited and Translated into English. Oxford: Clarendon Press.
- Manzetti, M. C. (2017). Reconstructing ancient theatres according to virtual acoustics analysis. In *Proceedings of the 2nd Conference on Computer Applications and Quantitative Methods in Archaeology. Greek Chapter (CAA-GR) Athens, December 20th-21st 2016* (pp. 81–87). Athens: National and Kapodistrian University of Athens.
- Manzetti, M. C. (2018). Experiencing an Ancient Performances in a Roman theatre. In *Archaeoacoustics III More on the Archaeology of Sound: Publication of Papers from the Third International Multi-Disciplinary Conference* (Vol. 3, pp. 122–126). Myakka City, Florida: The OTS Foundation.
- Morgan, M. H. (1914). Vitruvius. The ten books on architecture. Cambridge: Harvard University Press.
- Perdicoyianni-Paléologou, H. (2017). The beginning of the Pythian games in Delphi (582 BC). In *Great events in religion. An encyclopedia of pivotal events in religious history* (Vol. 1, pp. 69–70). Santa Barbara, California: ABC-CLIO.

- Ricciardi, M. (1986). Il tempio di Apollo Pizio a Gortina. *Annuario Della Scuola Di Atene e Delle Missioni Italiane in Oriente*, 64–65, 7–130
- Rindel, J. H. & Lisa, M. (2006). The ERATO Project and its contribution to our understanding of the acoustics of ancient Greek and Roman theatres. In *Audio Visual Conservation of the Architectural Spaces in Virtual Environment* (pp. 1–10). Istanbul, Turkey: Yildiz technical University.
- Sanders, I. F. (1982). Roman Crete. An Archaeological Survey and Gazetteer of Late Hellenistic, Roman and Early Byzantine Crete. Oxford: Warminster: Aris & Phillips.
- Scullard, H. H. (1981). Festivals and ceremonies of the Roman republic. London: Thames and Hudson LTD.
- Spagnolo, R. (2014). Manuale di acustica applicata. Torino: CittàStudi.
- Taramelli, A. (1902). Cretan Expedition: XXI Gortyna. American Journal of Archaeology, 6(2), 101–165.

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