MEASUREMENTS OF ACOUSTICAL PARAMETERS IN THE ROMAN THEATRE OF VERONA

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Résumé

L'attention des érudits concernant l'acoustique des anciens théâtres en plein air s'est considérablement accrue au cours des siècles et parmi les bâtiments historiques qui ont survécu jusqu'à nos jours, l'acoustique du théâtre romain de Vérone n'a pas encore été approfondie. Dans cet article, les résultats de l'étude acoustique ont été comparés aux valeurs mesurées par des chercheurs dans les théâtres romains de Bénévent et de Séville. Cependant, les données de post-traitement obtenues à l'intérieur du théâtre de Vérone ont été analysées de deux manières différentes : par une méthodologie classique représentant les graphiques des paramètres acoustiques, et par la création d'une vidéo montrant une réponse impulsionnelle (IR) en temps réel et les réflexions relatives survenues aux limites de la construction. La technique la plus récente a été réalisée en utilisant un réseau de microphones sphériques multicanaux, qui rappelle l'approche MIMO, capable d'avoir un contrôle spatial complet de la propagation du son dans l'espace. Les auteurs de cet article illustrent une brève histoire du théâtre, y compris la description des éléments de construction, ainsi que deux procédures distinctes en montrant les résultats qui renforcent la nécessité d'utiliser l'approche MIMO à côté des graphiques traditionnels capables de détecter la directivité des réflexions sonores et d'estimer l'intensité de la diffusion.

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Mots clefs: Théâtre antique en plein air; paramètres acoustiques; échantillonnage PCM spatial, réseau de microphones sphériques, mesures MIMO.

Abstract

The attention of the scholars to the acoustics of ancient open-air theatres has increased considerably through the centuries. Among the historical buildings survived to nowadays the acoustics of the Roman theatre of Verona has not been deeply investigated, yet. In this paper, the outcomes of the acoustic survey have been compared with the values measured by researchers in the Roman theatres of Benevento and Seville. However, the post-processing data obtained inside the theatre of Verona have been analysed in two different ways: by a standard methodology representing the graphs of the acoustic parameters, and by the creation of a video showing a real-time impulse response (IR) and relative reflections occurred at the boundaries of the construction. The latest technique has been realised by using a multichannel spherical microphone array, which calls back the MIMO approach that is capable to have complete spatial control of the sound propagation through space. The authors of this paper illustrate a brief history of the theatre, including the description of the construction elements, and also two distinct procedures in showing the results that strengthen the necessity of using the MIMO approach beside the traditional graphs capable to detect the directionality of sound reflections and to estimate the intensity of scattering.

Keywords: Open-air ancient theatre; acoustical parameters; spatial PCM sampling, spherical microphone array, MIMO measurements.

1 Introduction

Recently, the European Union has financed several research projects in order to increment the knowledge related to the architectural and acoustical characteristics of ancient open-air theatres [1-4]. The necessity of further investigations is driven by the intention to adopt the acoustics of classical open-air theatres, historically used for comedies and tragedies, to contemporary uses, including musical entertainments and summer festivals [5-7]. In fact, the introduction of modern sound systems electronically amplified could cause a risk of damaging these cultural heritages, corrupting their preservation to the new generations. This paper focuses on the acoustic study of the Roman theatre of Verona, a city located in northern Italy, in comparison with the acoustics existing in the Roman theatre of Benevento and Seville.

Today the Roman theatre of Verona is back to be one of the city points flourishing of cultural activities during the summer seasons.

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2 The Roman Theatre of Verona

2.1 Historical Background

When Romans planned the first expansion behind the river Adige, Verona was a small village developed along two main roads, called *Via Postumia* and *Via Claudia Augusta*. Under the influence of Julius Caesar, Verona was proclaimed a *municipium* in 49 BC, to be governed by local magistrates. As such, a great transformation began: the main doors of the city walls became monumental and the civic spaces saw the construction of different public buildings.

The idea of building a theatre out of the core of the village was primarily due to taking advantage of the natural slope of Saint Peter's hill in order to save as much construction materials as possible to support the steps of the *cavea* [8]. The theatre was surrounded by a temple honoured to god *Jupiter*, built on top of the hill and connected to it through a few terraces (Figure 1).

The roman age was for Verona the first flourishing period, with a singular richness of architectural monuments and bridges. During the 3^{rd} century AC, the theatre of Verona started to fall in disuse. The great cause was the development of Christianism, which considered immoral all kinds of shows [9]. Another reason was a fire occurred in the second half of the 3^{rd} century, which destroyed the core of the theatre, causing the fusion of the lead pipelines that were used for collecting rainwater. After that, the theatre was transformed into a necropolis, while the temple was converted to a Christian church [10].

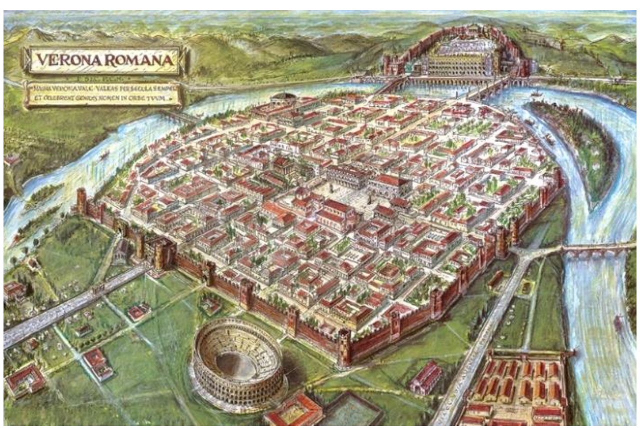

Figure 1: Ideal reconstruction of Verona during the 1^{st} century AC, by G. Ainardi.

During the Middle Ages, an entire district was built on the same site, with private residences standing directly above the Roman theatre, covering completely the historical building. During the 19^{th} century, the invasion of the Austrian soldiers transformed the site into a military base. Different campaigns of archaeological excavations were promoted by Andrea Monga, a well-off merchant. His effort brought to the purchase of the whole area where the theatre was located just underneath the various constructions built wildly on the hill [11].

A French architect, named Edmond-Jean-Baptiste Guillame (1826-1894), described the conditions of the theatre and produced lots of drawings, showing to be deeply keen in studying all the details noted on his booklet (i.e. Memoire).

The sketch represented in Figure 2 gives an idea of how the theatre should be erected, based on the hypothesis of Guillame. The wooden sticks, supported by shelves at the level of the third order, should be a trace of the presence of a *velarium* that coronated the ambulatory [12].

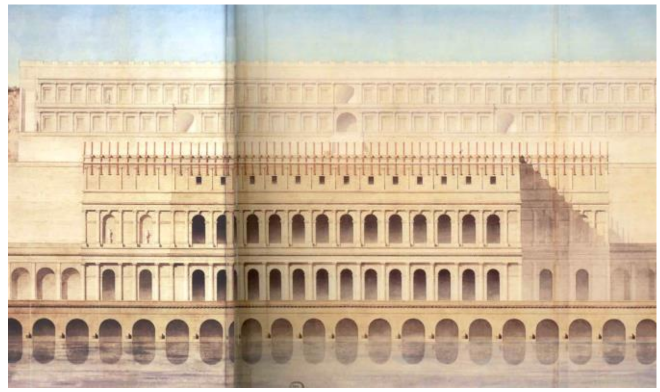

Figure 2: Elevation of the Roman theatre. Reconstruction designed by E. Guillame, 1860 [12].

2.2 Constructive characteristics

The structural elements of the Roman theatre of Verona were realized by using a light grey tuff, which corresponds to the stone composing S. Peter's hill [8]. Despite its good resistance, the tuff deteriorates quickly if subject to meteorological conditions when installed outdoors. Another type of stone (i.e. limestone from Valpolicella), in white and pink colours, was used for architectural decorations, frames and arch keys.

The architectural orders of the columns were tuscan for the lowest level, ionic for the second and corinthium for the upper level [8].

Because the theatre was built on the slope of the hill, the heavy rains during adverse conditions could provoke landslides. In order to comply with this problem, a cut of 18×2 cm (L×W) was created into the stone blocks between the steps of the audience area, where the rainwater falling from the hill could be collected and convolved to the river through a canalization system below the *cavea* [10].

What is visibly disrupting the continuity of the hemicircular seats is the construction of a medieval church dedicated to S. Siro and Libera (Figure 3).

The original capacity of the theatre of Verona could be approximately 3000 seats, although today it is reduced to 2000. The main parts are the following:

- The orchestra is placed at the centre of the theatre in a semi-circular space. The diameter of the orchestra is 29.60 meters;
- The *proscaenium* is in front of the scenic building and it is 1.4 meters above the level of the orchestra;
- The entries (called *vomitoria*) are usually at the sides of the *parascaenia* and facilitate the public access to the seats;

Figure 3: View of the Roman Theatre in Verona and of a post-construction on the left representing the church of S. Siro and Libera.

- The scenic building is composed of tuff blocks and covered by marble sheets. It was 27 meters high, 72 meters long and 6 meters wide;
- The *cavea* is the space dedicated to the audience. Horizontal corridor (*praecinctio*) subdivided the *cavea* into two main sectors, called *ima* (lower) and *summa* (upper) *cavea*;
- The *ambulacrum* (ambulatory) is an arched gallery crowning the upper *cavea*, having dimensions of 2.3 meters height and 2.95 meters width.

2.3 Brief *excursus* of other Roman theatres

Theatres of similar characteristics were built also in other parts of the Roman territory. In particular, to cite a few of them, the theatre of Benevento, located nearby Naples, and Seville, in Spain, represent the evidence of the flourishing construction activity undertaken by Romans other than their love for the shows. The theatre of Benevento and Seville are herein chosen in order to show a few samples of how the Romans were able to construct different volume sizes of such types of buildings.

The theatre of Benevento was built during the 2nd century AC and was made of up to 25 arcades divided into three levels. The diameter of the *cavea* is approximately 80m while the diameter of the orchestra is 20m [13]. The *cavea* is composed of 19 and 8 steps, respectively related to the *ima* and *summa cavea*, against the 25 and 12 steps found in Verona. The large dimensions of the theatre allowed it to have a capacity of over 10000 seats [14]. The scenic building was 44.2m long and 3.5m wide, but nowadays only disconnecting parts of the *scenae fronts* are erected, the rest has been lost throughout the centuries, as shown in Figure 4.

Another important Roman theatre is that one located in Seville, Spain, so called the Italic theatre because it was built in one of the Roman provinces. In particular, the diameter of the *cavea* is about 71m, similar to what is found in Verona (i.e. 76m), having a capacity of 3000 seats. The diameter of the orchestra is 15m while the dimensions of the scenic building are 42m in length and 5.6m in width [15]. From Figure 5 it is possible to see that the *ima cavea* and the scenic building have been preserved almost intact.

The presence of the scenic building is very important under acoustic point of view, because it promotes to build-up of the reflections, acting as a reflector that directs the sound towards the audience area.

Figure 4: Aerial view of the Roman theatre of Benevento

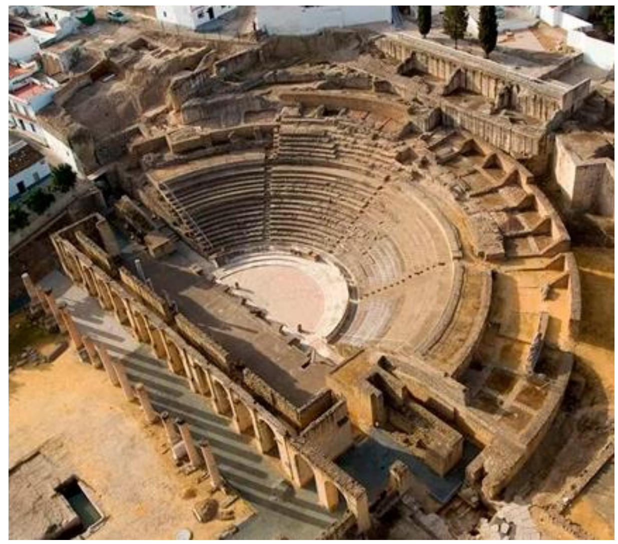

Figure 5: Italic theatre of Santiponce, Seville.

Table 1 summarises the architectural features of the three theatres, as discussed.

Table 1: Architectural characteristics of the theatres of Benevento, Verona and Seville.

Description	Benevento	Verona	Seville
Orchestra diameter (m)	20	29.6	15
Cavea diameter (m)	80	76	71
Actual Capacity (seats)	8000	2000	3000
Scenic Blg [L×W] (m)	44.2×3.5	72×6	42×5.6

3 Acoustical measurements in Verona

In order to analyse the acoustic characteristics of the theatre of Verona, an acoustic survey was carried out with the following equipment:

- Equalised omnidirectional loudspeaker (Look Line);
- Microphones:
  - Binaural dummy head (Neumann KU-100);
  - B-Format (Sennheiser Ambeo);
  - Omnidirectional microphone (Bruel&Kjaer)

- 32-channel (MhAcoustics em32 Eigenmike®);
- 360° Camera;
- Personal Computer connected to the loudspeaker and all the receivers.

The measurements were executed by using a dodecahedral sound source emitting an excitation signal (a 20s long Exponential Sine Sweep (ESS)) having a uniform sound pressure level for the range between 40 Hz and 20 kHz, while the microphones were employed to record signals necessary to obtain the impulse responses (IRs).

The sound source was placed at 1.5m from the finished floor, precisely in the proscenium area where the actors were used to stand on, and the microphones were positioned on the radial axes of the *cavea*, with the probes at the height of 1.1m above their reference floor. All the microphones were moved for 11 positions across the *cavea* to represent as much as possible the audience area (Figure 6). The 360° camera was installed in the same positions as the em32 microphone locations. The acoustics measurements were carried out without any audience and any scenery installed.

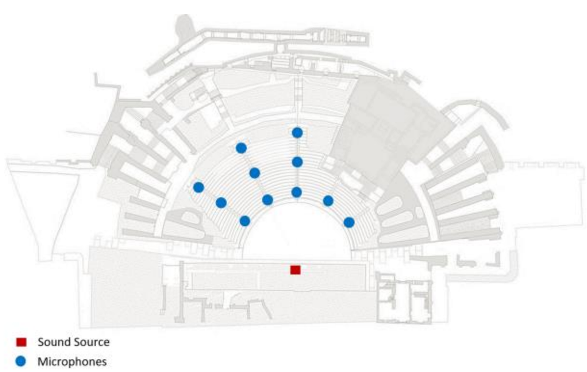

Figure 6: Measurement setup: red point indicates the sound source position and the blue points indicate the receiver positions.

The reason why different microphones were used is to highlight the difference of result representation between the traditional setup and the innovative system. The multichannel em32 Eigenmike® microphone (manufactured by MhAcoustics), equipped with 32 capsules mounted on a spherical surface, has the capability to extract any arbitrary directivity of virtual microphones from real microphones arrays by using a Spatial PCM Sampling (SPS) beamformer, which has a better resolution for high directivity patterns when used as an 8th order cardioid, by representing 122 directions uniformly covering the whole solid angle [16].

4 Results

4.1 Traditional acoustic parameters

Figure 7 shows the IR measured with the dodecahedral sound source. The recorded ESS signals have been processed by using the plugin Aurora suitable for Audition.

Several acoustic parameters defined in the international standards ISO 3382-1 [17], such as the early decay time (EDT), reverberation time (T_{30}), clarity (C_{80}) and definition (D_{50}) have been analysed [18]. Figures 8 to 11 show the comparison between the values found in Verona and measured by the authors and those related to the other two open-air theatres, as provided by the literature [14, 15].

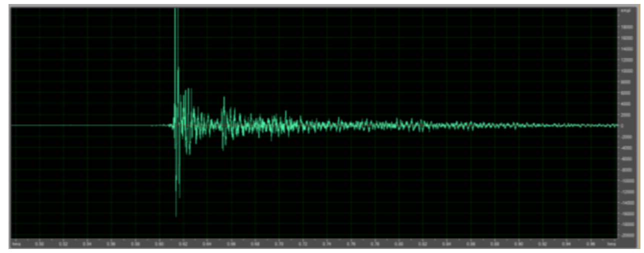

Figure 7: Measured IR in the Roman theatre of Verona having the sound source placed in the *proscaenium* and the receiver (omnidirectional microphone) placed in the central sector of the *summa cavea*.

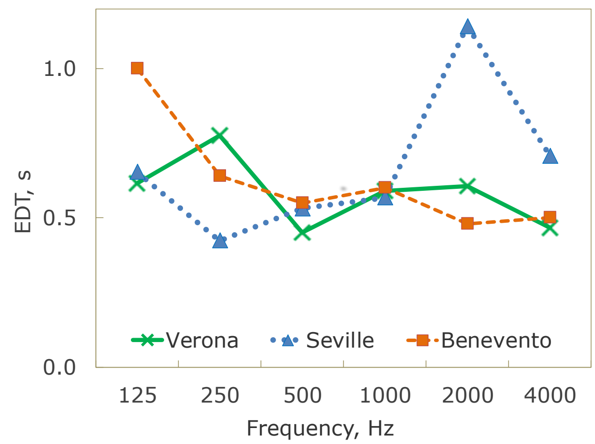

Figure 8: Measured results of Early Decay Time (EDT).

The values of the acoustic parameters are shown in the octave bands between 125 Hz and 4 kHz, considered as the average results of all the measurement positions.

Figure 8 shows that the EDT is approximately 0.6s in Verona, having the values over the frequency range similar to Benevento. What is most in evidence from the graph above is the peak at 2 kHz related to Seville, probably due to the presence of the entire stage walls, reflecting strongly the high frequencies sound rays. However, the overall value of EDT is good for both speech and music in all the theatres.

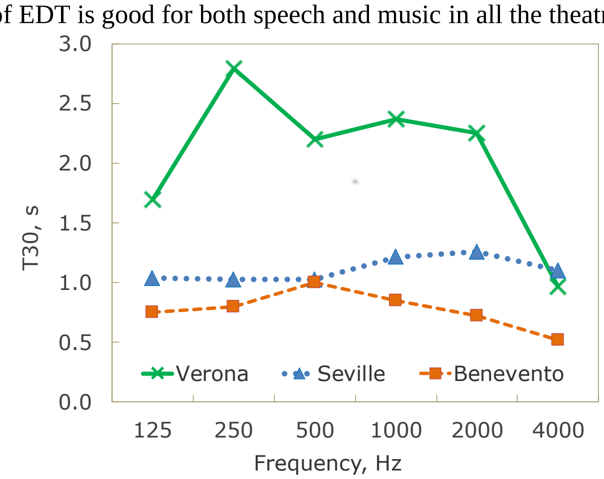

Figure 9: Measured results of Reverberation Time (T_{30}).

Figure 9 shows that T_{30} is higher in Verona than the other two theatres. This effect is due mainly to the reflections on the buildings surrounding the *cavea*, like the presence of the archaeological museum on one of the extremities of the scenic building, the church of S. Siro and Libera, the convent of S. Jerome parallel to the scenic building and behind the *summa cavea* and other residential properties crowning other sides and built on the slope of S. Peter's hill. The buildings' facades reflect the sound and therefore this geometrical circumstance is favourable to cause a longer reverberant tail.

In Benevento and Seville, despite the partial presence of the scenic building, no significant reflections are given by other contributions because of the absence of surrounding buildings and, thus, the values of T_{30} are contained around 1s. Probably the difference between Benevento and Seville regarding the integrity of the scenic building's wall justifies that slight variance in values, which is null at 500 Hz.

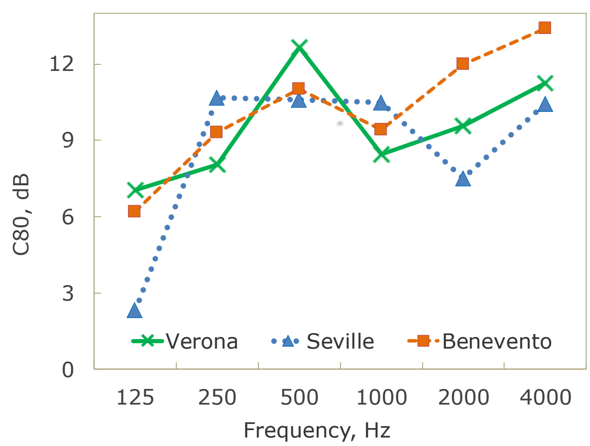

Figure 10: Measured results of Clarity Index (C80).

Figure 10 shows the averaged values of C_{80} of all the receivers as a function of frequency. The results indicate that clarity is similar among the three theatres. If the average value is approximated to 11dB across all the frequency bands, it can be considered good for music perception. High peaks were found at 500 Hz in Verona and at 4 kHz in Benevento, which could be due to the materials (i.e. stone in Verona and bricks in Benevento) currently installed on the seats of the *cavea* as a result of recent restoration works [14]. These hard surface materials reflect the sound at different frequency bands and help to achieve a good listening. In Seville probably the roughness of the original stone of the seats attenuated this effect, resulting in more uniform on the mid frequencies, with very good clarity at 125 Hz.

For all the three cases, although the field is not completely diffuse as the open-air theatres are, the definition (D_{50}) is 85% across all frequencies, as shown in Figure 11, which is considered a good value for good listening and speech comprehension based on the parameters of Greek and Roman theatres. The values over all the frequency bands are more than 0.5, except for 125 Hz of Seville, which is slightly low compared to the other ones but still considered an acceptable value.

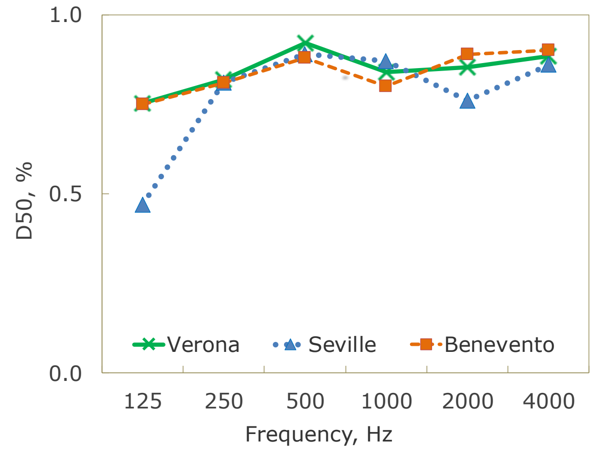

Figure 11: Measured results of Definition (D_{50}).

The analysis then considered the sound strength (G), which is a more suitable parameter to characterize the acoustic of an open-air space than the reverberation time [19]. It is analysed in relation to the Roman theatre of Verona, only.

In Figure 12, all the values of the strength are positive, with significant robustness which can be considered a good result for sound amplification in open air theatre. It is due to the buildings surrounding the *cavea*.

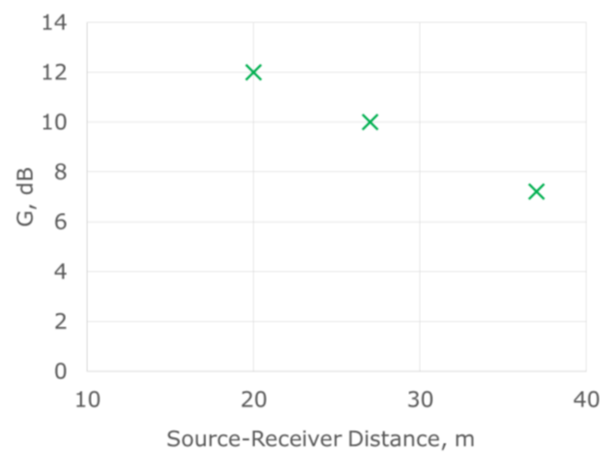

Figure 12: Measured results of StrenGth (G) at 1k Hz.

4.2 Analysis of the distribution of sound reflections

By taking advantage of the em32 Eigenmike® microphone's capabilities, panoramic sound maps were obtained for each source-receiver combination. Such maps are useful to understand the specific role of architectural elements interacting with sound, showing the direction of arrival of the sound reflections and their relative intensity.

The new elaboration technique involves the analysis of data obtained by a combination of an omnidirectional sound source, a multichannel microphone (i.e. em32 Eigenmike®) and a panoramic view (i.e. a 360° image represented in an equirectangular view), where the 32 microphone signals, recorded from each of the 32 capsules, have been processed by extracting 122 high directivity virtual microphones (with

8th order cardioid setup) spreading the directions uniformly distributed in the space (i.e. Spatial PCM Sampling (SPS) encoding) [16]. The beamformed multichannel IR has been divided into short frames, analysed singularly. For each frame, the amount of energy associated with each virtual microphone has been computed and then represented as a colour map overlay. The overall result is a video showing the sound waves arriving at the receiver from all the possible spherical directions.

The video has been realized by processing 2048 samples at 48 kHz sampling rate. Each virtual microphone required to sum the results obtained from the convolution of the 32 input channels with the 32 FIR filters. In order to elaborate a matrix given by the 32 virtual microphone outputs, combined with the FIR filters and having 2048 samples, a VST plugin (i.e. X-volver) was employed to facilitate the massive operation. A 32×32 filter matrix has been used for converting the signal coming from the 32 transducers of the microphone into the 32 SPS signals [20].

In order to have a right read of the following image, some guidance is briefly given. The sound pressure level having different ray energy is faithfully represented by the contour levels. The colour scale indicates that the sound waves having more energy are represented with red and warm colours, while the blue-violet and cold colours indicate a poor energy sound wave.

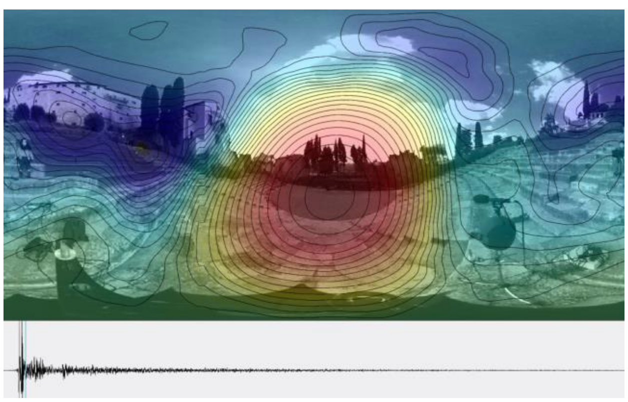

Figure 13: Acoustical map showing the arrival of a direct sound.

An example of the usefulness of such maps is given in Figure 13, which shows the sound coming from the source placed in the *proscaenium* and arriving at the receiver placed in the *cavea*.

The stone of the steps composing the *cavea*, being a reflecting material, contributes to rising upward the reflections of the soundwaves, as the contour levels show laterally in Figure 14.

Other than the early reflections, Figure 14 shows also the late reflections coming from the floor of the orchestra, being as well in hard material (i.e. marble).

The acoustical maps, as shown above, demonstrate to be useful not only for understanding the direction of arrival of the sound rays but also to see how the sound wave is scattered based on the width of the coloured circles shown in the maps. As such, the wider is the circle, the more scattered is the sound wave. The sharper circles (e.g. related to the floor reflections) indicate a more directive sound wave.

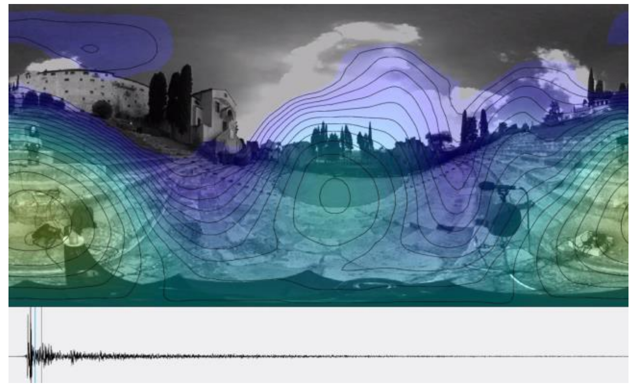

Figure 14: Acoustical map showing the reflections scattered onto the steps.

5 Conclusion

This work presents two types of analysis results about the acoustic survey undertaken in the ancient open-air Roman theatre of Verona. Measurements based on ISO 3382-1 were conducted in situ in unoccupied conditions using omnidirectional sound source and four types of microphones.

The first methodology indicates the results based on the standard configuration, which is composed of the graphs' representation. In particular, the theatre of Verona has been compared with the other two Roman theatres, that are in Benevento and Seville.

Following this approach, results obtained from the measurement campaign showed that the buildings surrounding the theatre of Verona exert their influence on the reverberant tail of the energy decay by undergoing many scattered reflections, which is more attenuated in Benevento and Seville. The energy parameters show an excess of clarity for music and high definition of the word, similar to what has been found in Benevento and Seville.

Regarding the strength of the theatre of Verona, historical studies [21] assume that the circular corridor (*praecinctio*) dividing *ima* and *summa cavea* interrupts the trend of a straight-line tangent to the edges of the steps, in order to follow the natural inclination of the hill. This footfall in terms of sound propagation means a shortened sound-receiver distance for the last row of seats and hence more energy at these receiver positions [22].

This study has been extended to analyse the specific path of sound reflections and relative directionality. By taking advantage of the abilities of the new microphone (i.e. em32 Eigenmike®), 3D sound maps are obtained for each source-receiver combination. Such maps indicate the direction of arrival of the sound reflections and their relative intensity, contributing to understanding the specific role of architectural elements interacting with the soundwave other than the magnitude of scattering based on the size of the contour levels.

Unfortunately, the role of the occupancy inside the theatre of Verona remains unexplored, because not measured. However, by literature [13] if it is assumed that the hypothetical roof of an open-air theatre could be considered as a surface area having a unitary absorption, the additional sound absorption of the audience is not crucial in determining significant variations on the acoustic parameters, since the scattering effect is not substantial as in enclosed volumes.

In addition, further conjectures could be made upon the virtual reconstruction of the theatre of Verona at its initial shape, but this discussion shall be considered in future articles.

Acknowledgments

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References

[1] J.H. Rindel, ERATO; Final Report; Technical University of Denmark: Copenaghen, Denmark, 2006.

[2] J.H. Rindel, Roman theatres and revival of their acoustics in the ERATO project. *Acta Acust. United Acust*. 99, 21–29, 2013.

[3] C. Hak, N. Hoekstra, B. Nicolai, W. Wenmaekers, Project ancient acoustics part 1 of 4: A method for accurate impulse response measurements in large open-air theatres. In *Proceedings of the 23rd International Congress of Sound Vibrations (ICSV23),* Athens, Greece, 2016.

[4] R.H. Wenmaerkers, B. Nicolai, N. Hoekstra, C.C. Hak, Project ancient acoustics part 4 of 4: Stage acoustics measured in the Odeon of Herodes Atticus and in the theatre of Argos. In *Proceedings of the 23rd International Congress on Sound Vibrations (ICSV23)*, Athens, Greece, 10–14 July 2016.

[5] E. Bo, A. Astolfi, A. Pellegrino, D. Pelegrin-Garcia, G.E. Puglisi, L. Shtrepi, M. Ryctarikova, The modern use of ancient theatres related to acoustic and lighting requirements: Stage design guidelines for the Greek theatre of Syracuse. *Energy Build*. 95, 106–115, 2014.

[6] E. Bo, M. Bergoglio, A. Astolfi, A. Pellegrino, Between the archaeological site and the contemporary stage: An example of acoustic and lighting retrofit with multifunctional purpose in the ancient theatre of Syracuse. *Energy Procedia* 78, 913–918, 2015.

[7] U. Berardi, G. Iannace, The acoustic of Roman theatres in Southern Italy and some reflections for their modern uses. *Appl. Acoust.* 170, 107530, 2020.

[8] L. Franzoni, G. Lampronti, The Roman Theater: history and shows (*Il Teatro Romano: la storia e gli spettacoli)* Verona, Editore Comune di Verona, 1988.

[9] F. Dal Forno, The Roman theatre of Verona (*Il teatro romano di Verona*) Vita veronese, 1961.

[10] M. Bolla, The Roman theatre of Verona and its sculptures (*Il teatro romano di Verona e le sue sculture*) Ed. Grafiche Aurora, Verona, 2010.

[11] P. Brugnoli, In beautiful Verona (*Nella bella Verona*) Ed. Cappelli, 81-104, 1972.

[12] M. Bolla, The Roman theatre of Verona, in Italy antiqua. Envois by French architects (1811-1950) (*Il teatro romano di Verona, in Italia antiqua. Envois degli architetti francesi (1811-1950)*). Italy and Mediterranean area, exhibition catalog (Paris-Rome, 2002), 26-40, 2002.

[13] G. Iannace, U. Berardi, L. Maffei, Virtual reconstruction of the historical acoustics of the theatrum tectum of Pompeii *Journal of Cultural Heritage,* 19, 6, 555-566, 2016.

[14] G. Iannace, A. Trematerra, The discovery of Benevento Roman Theatre Acoustics, *Journal of Cultural Heritage,* 15, 698-703, 2014.

[15] S. Giron Borrero, A. Alvarez Corbacho, Patrimonio sonoro de los treatros romanos, *IV Foro Internacional de teatros romanos*, 2018.

[16] A. Farina, A. Amendola, L. Chiesi, A. Capra, S. Campanini, "Spatial PCM Sampling: A new method for sound recording and playback". *AES 52nd International Conference*, Guildford, UK, 2013.

[17] ISO 3382-1 Acoustics-Measurement of Room Acoustic Parameters - Part 1: Performance Spaces, ISO: Geneva, Switzerland, 2009.

[18] P. Ciancio Rossetto, G.P. Sartorio, Teatri Greci e Romani: alle origini del linguaggio rappresentato censimento analitico, Turin, 1994.

[19] Mo, J. Wang, The conventional RT is not applicable for testing the acoustical quality of unroofed theatres, *Build. Acoust*, 20, 1, 81–86, 2013.

[20] A. Farina, L. Tronchin, 3D sound characterisation in theatres employing microphone arrays *Acta acustica united with Acustica,* 99, 1, 118-125, 2013.

[21] Vita Veronese, monthly journal, year XVI, May - June. Ed. Ghidini & Fiorini, 178-187, 1963.

[22] A. Farneatani, N. Prodi, R. Pompoli, On the acoustics of ancient Greek and Roman theatres, *Journal of Acoustics Society of America*, 124 (3), 2008.


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