FROM GREEK FOOTPRINTS TO THE ROMAN AGE: THE ACOUSTICS RESPONSE OF THE ROMAN THEATRE OF TYNDARIS AND VOLTERRA

A Bevilacqua Department of Industrial Engineering, University of Parma, 43100 Parma, Italy
W Fuchs School of Architecture and Community Development, University of Detroit Mercy, USA

1 ABSTRACT

Roman theatres have always been the subject of research studies, under architectural perspective and archaeology other than acoustics. Many ancient theatres, like that one in Tyndaris, are well preserved, but others open-air theatres, like that one in Volterra, are partially preserved since the damages caused by natural events and human intervention heavily affected the original constructions. This paper deals with the acoustic analysis of the Roman theatre of Tyndaris, built in Sicily on the footprint of the original Greek construction, and the ancient theatre of Volterra, located in northern Italy and built during the 1st century BC. Nowadays, the theatre of Tyndaris, more preserved, is used for live artistical performance, while the theatre of Volterra is just open for museal visits. Two campaigns of acoustic measurements have been carried out in order to compare the results of a Roman theatre built on the footprints of the Greek construction with those related to an open-air theatre conservatively built by following the Vitruvian construction rules. The results have been assessed by taking into consideration that light music (classic quartets, not amplified) and prose are the main room functions, as it was in the past. The measured results indicate that the values related to the main acoustic parameters are typical of open-air ancient theatres, where the lack of architectural constructions like scenic building or *summa cavea* contribute to make the theatres drier for music performance, far from the original conditions.

2 INTRODUCTION

Among a wide number of Roman theatres and amphitheaters sparse over the empire territory, the conditions of what is survived to our days can be lacking several parts [1, 2]. In many cases the design is more difficult to be analysed due to destructions as well as a limitation in conducting the archaeological excavations. The theatres subject to be compared under an acoustic perspective are two ancient structures in Italy: one realised in Tyndaris, Sicily, on the original Greek footprint, and the other one realised in Volterra, Tuscany, built with the characteristics of the Roman theatres as dictated by Vitruvius. The acoustic analysis of these open-air theatres is valuable research for the local authorities that have in plan to restore and qualify these precious ruins in order to make them suitable for live artistic performances.

In the case of Tyndaris, part of the *cavea* has been reused for the allocation of modern wooden benches where the spectators can sit and attend to venues [3]. This is the area where the acoustic measurements have been carried out, with access limitations where the original stones of the steps were not restored. In Volterra, the archaeological site is open only for visits, without the possibility of having any performance inside. In this second case, acoustic measurements have been taken over the *cavea* but primarily on the steps dominated by lower risks of fall/slip. These acoustic measurements will be used for future case studies focusing on the architectural design of acoustic shells, capable of improving the existing conditions and making them more suitable for live performances.

3 ENVIRONMENTAL BACKGROUND OF THE ANCIENT THEATRES

3.1 The Greek-Roman theatre of Tyndaris

The theatre of Tyndaris was built by Greeks during the 4th century BCE, with a total capacity of 3000 seats [4]. The construction of the Hellenistic period was composed of a *cavea* having a diameter of 76 m, and the orchestra of 23 m width [5]. The Hellenistic scene remained untouched during the Roman period but has been destroyed during the Middle Age. During the 1st century BCE, the Romans modified the theatre into an arena by lowering the level of the orchestra by 0.9 m and by destroying the first four steps of the *cavea* to build a podium of 2.5 m height [6]. This represents the main change with respect to the Hellenistic construction, as shown in Figure 1. Nowadays, the damage of further architectural elements compromises the faithful integrity of the original construction, including the partial erection of the scenic building, as shown in Figure 1(a), which would be useful to support the sound reflections towards the *cavea*.

3.2 The Roman theatre of Volterra

The Roman theatre of Volterra was built during the 1st century BC and 13 AC, with a total capacity of almost 3000 spectators [6]. The external diameter of the *cavea*, excluding the ambulatory, was 49 m. The theatre was abandoned at the end of the 3rd century when a thermal building was created surrounded by a porch created near the scenic building [7]. During the 13th century, the construction of the theatre was divided into two parts by the realization of the medieval city wall, with the foundations just above the *summa cavea*, including the access to the theatre nowadays no longer existing [7]. The first archaeological excavation occurred between 1950-1953. What is currently left of the theatre of Volterra is the *ima cavea* lacking the upper side, and a portion of the scenic building, as shown in Figure 1(**b**).

(**a**) (**b**)

Figure 1. Existing conditions of the two Roman theatres: Tyndaris (**a**) and Volterra (**b**).

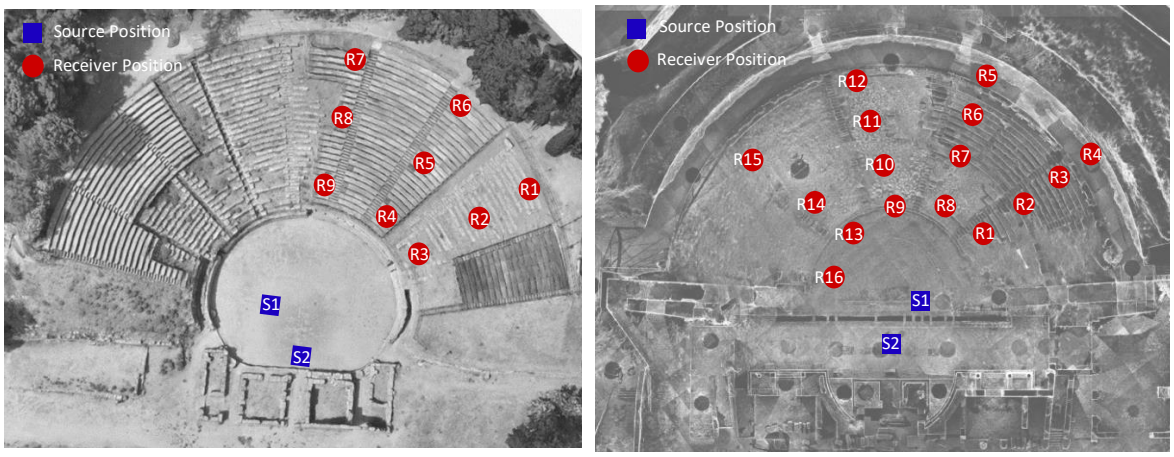
4 ACOUSTIC MEASUREMENTS

Two acoustic campaigns of measurements have been carried out inside the selected theatres. The instrumentation used for gathering the impulse response is the following:

- Tyndaris
  - “DodecMIMO” modified version of dodecahedral sound source “Model Kit103” (12-channels) (by Look Line & E. Armelloni);
  - 32-channel spherical microphone array (em32 Eigenmike®) with EMIB and MADI interface;

    - 32-channel Class-D audio amplifier with Dante interface (by N. Rocchi – UNIPR);
- Volterra
    - Firecrackers as sound source;
    - Omnidirectional microphone (B&K 4189), pre-polarised free-field ½-inch.

The acoustic measurements have been carried out in unoccupied conditions, with the control of thermo-hygrometric conditions. In both theatres, the sound source was placed in two positions, while the microphone was moved across the *cavea* in 9 (Tyndaris) and 16 (Volterra) positions, as indicated in Figures 2. The sound source was placed at 1.8 m from the finish floor while the microphone was installed at 1.2 m from the steps of the *cavea*, corresponding approximately to the ears' height of a sitting person.



(**a**) (**b**)

Figure 2. Scheme of the equipment positions assumed during the acoustic measurements: in Tyndaris (**a**) and Volterra (**b**).

5 ANALYSIS OF RESULTS

The analysis of the results considers the optimal range of the main acoustic parameters in function of prose and classic music as these are the main venues that are studied to be in. The main acoustic parameters are defined based on the standard ISO 3382-1 [8], namely the early decay time (EDT), reverberation time (T_{20}), clarity indexes (C_{50}, C_{80}), definition (D_{50}), and strength (G). The analysis has been assessed in the bandwidth comprised between 125 Hz and 4 kHz, as required by the reference standard, and in relation to the scenarios described in the previous section. The results shall be intended to be averaged for all the sources and receivers' positions assumed during the measurements.

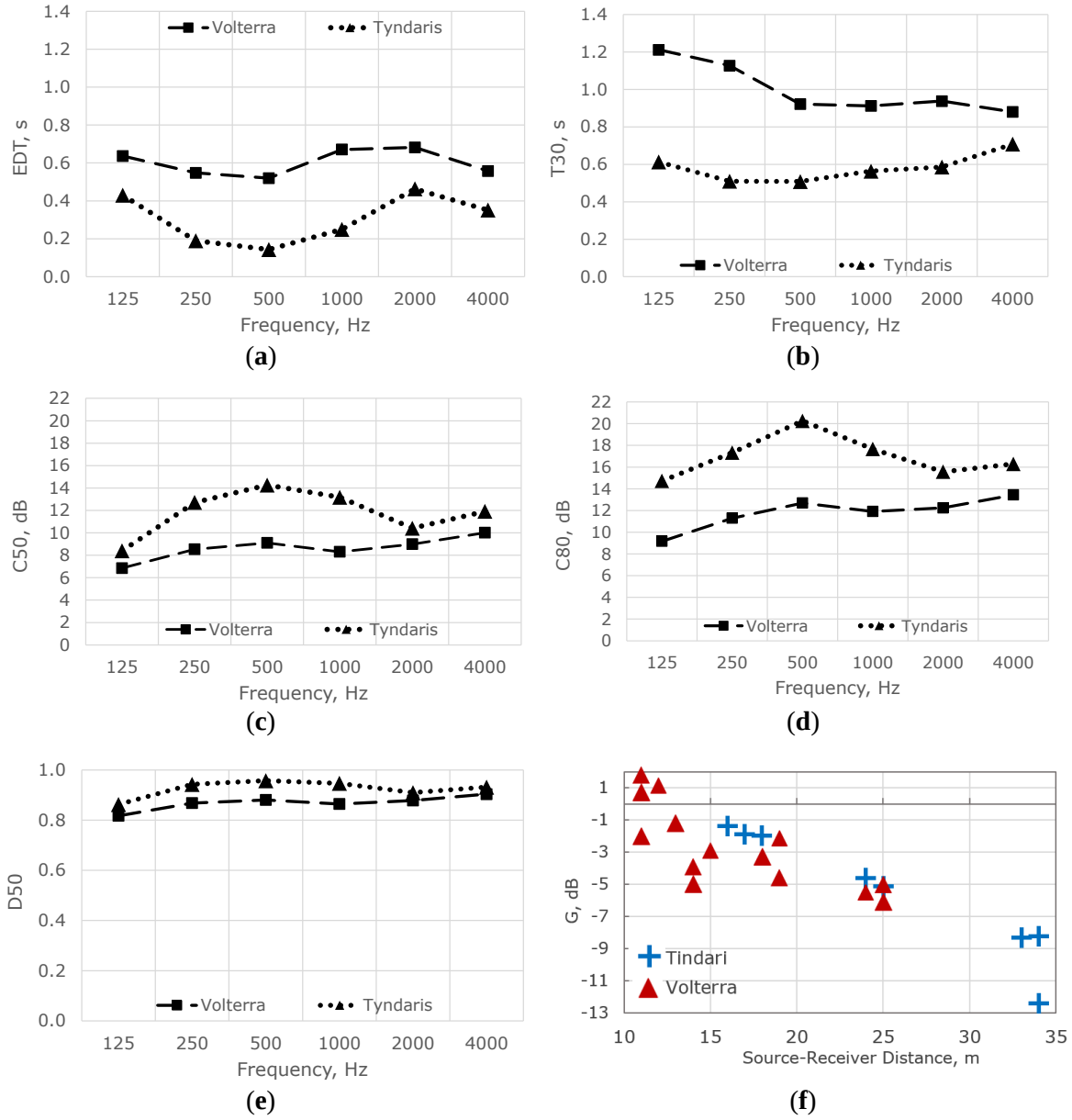


Figure 3. Comparison of acoustic parameters measured inside the ancient theatre of Tyndaris and Volterra in relation to the: early decay time (**a**), reverberation time (**b**), speech clarity (**c**), music clarity (**d**), definition (**e**), and strength (**f**).

Figure 3(**a**) shows that the measured results of Tyndaris fluctuate around 0.3 s, while those of Volterra are around 0.6 s. This difference between the two trendlines can be attributed to the presence of existing constructions around the *cavea* of Volterra, while the archaeological site of Tyndaris is free from any structure around. Also, Volterra has part of the scenic building, which represents a useful vertical surface to support the early reflection, situation that is lacking in Tyndaris [9].
Figure 3(**b**) shows the measured results of reverberation time, to be 0.6 s in Tyndaris and 1.0 s in Volterra, with an increase at low frequencies up to 1.2 s. In Volterra the reverberation time is very similar to the conditions of an enclosed space, to be good for both speech and music performance. In Tyndaris, the reverberation time should be improved with a sort of reflecting panel installed on the back of the orchestra in order to improve the reflections and address the sound energy towards the audience [10].

In terms of speech clarity (C_{50}), the values found in both theatres are over the optimal range (-2 dB, +2 dB), with the trendline of Tyndaris to be up to 6 dB above Volterra at mid octaves, as indicated in Figure 3(**c**). This result is similar to other ancient theatres, where the lack of other architectural elements like the scenic building or the ambulatory determine a sound dispersion in non-useful directions [11].
The music clarity (C_{80}) has a similar trend of the curves related to C_{50}, with an upward shift of around 6 dB for Tyndaris and 2 dB for Volterra, as indicated in Figure 3(**d**), meaning that the music is perceived clearer than what should be in an enclosed space.
The parameter of definition (D_{50}) has been introduced for the relationship between energy level and delay of late reflections with respect to the direct sound. The optimal values of speech definition can be considered between 50% and 100%, while for music the values should be between 0% and 50%. The measured results shown in Figures 3(**e**) indicate a negligible difference between the two theatres. The values fluctuate around 0.9 (90%) across all the bandwidth, meaning that the acoustic response is more suitable for speech [12].
One of the acoustic parameters chosen to assess the open-air theatres is the strength (G) related to the interaction between sound energy and architecture at certain distance in the space. For open-air space, G can range between 0 dB and 6-7 dB, very different from enclosed spaces, where G values can reach even 13-16 dB, depending on the volume of the space.
Figures 3(**f**) shows that the G values on the first step of the cavea are positive in Volterra, around 1 dB. As far as the distance increases, the G value starts to drop significantly as commonly found in open-air theatres. The lack of energy at the last rows of seats is due to the absence of roof and lateral walls that could help to increase the values, as well as the material of the orchestra, nowadays grass/soil instead of original marble, that does not contribute to address the reflections towards the cavea, whether the sound source is on the podium or in the orchestra.

6 CONCLUSIONS

This paper shows the acoustic response of two Roman theatres located in Italy, specifically the ancient theatre of Tyndaris and Volterra. The acoustic measurements have been carried out in unoccupied conditions and mirroring the existing state of degrade of this valuable architectural patrimony. The measured results indicate that the theatre of Volterra at present conditions is more suitable for music, given the adequate reverberation time around 1.0 s at mid frequencies due to the presence of posthumous constructions erected over the *summa cavea,* while the acoustic response of Tyndaris has been found to be drier, due to the Greek configuration of missing completely the porticus in *summa cavea* as well as any constructions that typically invade the sitting area. The energy strength has been found to be typical of any other open-air theatres since the absence of hard surface as finish material and of the full erection of the scenic building contribute to the acoustic response far from what should offer the original architecture. On-going research studies are focused on the digital reconstruction of these two ancient theatres and the acoustic simulations by using the original architectural shape in order to highlight the difference between the two scenarios.

7 FUNDING

Funding has been provided by the European Union's Joint Programming Initiative on Cultural Heritage project PHE (The Past Has Ears, phe.pasthasears.eu).

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