Acoustics of Roman theatre of Salona.

Marjan Sikora[1]; Jurica Đerek[1]; Matija Pauković[1]; Ante Jurčević[2]

[1] University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Ruđera Boškovića 32, 21000 Split, Croatia, sikora@fesb.hr
[2] Archaeological Museum in Split, Zrinsko-Frankopanska 25, 21000 Split, Croatia

ABSTRACT

Salona was the capital of the Roman province of Dalmatia, and as all similar roman cities, had a theatre. Today, in Salona only scarce remains of an ancient Roman theatre exist, such as its foundations and low walls. To analyse the acoustical properties of Salona's theatre, we made a reconstruction of the theatre, according to data provided by the archaeologists and other similar preserved theatres. We then performed the acoustic simulation of the theatre to explore its acoustical properties. We performed the simulation using the geometrical simulation based on the hybrid ray tracing/image source method. In this paper we present the results of the simulation and discuss them. We analyse the influence of an audience and a stage wall on the acoustic performance of the theatre. The results suggest that the acoustics of this theatre was good for dramatic performance, which was its primary role.

Keywords: Acoustics, Geometrical Simulation, Ancient Theatre

1. INTRODUCTION

Although not as attractive as amphitheatres, Greek and Roman theatres present an important part of the architectural heritage in Western culture. Furthermore, many Greek and Roman theatres are preserved in such measure that they still serve their original purpose. A total of 744 structures of ancient theatres have been identified and documented [1], four of them in Croatia [2]. The theatre in Pula is best preserved, the theatre in Salona is preserved only in its foundations, while in the town of Vis the Franciscan monastery was built on the remains of *cavea* of ancient theatre. The remaining theatre of Zadar was identified only by architectural elements.

In this paper we concentrate on the theatre of Salona and present the reconstruction as well as the acoustical simulation of the reconstructed theatre.

2. THEATRES AND EXISTING MEASUREMENTS AND ANALYSIS

The literature review on ancient theatres must be started with Roman architect Vitruvius [3] who in his fifth book gives the principles of the design of theatres and their acoustics. Canac [4] in 1967. presented detailed study of ancient theatres, in which he used the method of image sources to analyse different geometries of ancient theatres. The evolution of ancient Greek and Roman theatres was researched by Chourmouziadou [5].

The ERATO project aimed at identification, virtual restoration, and revival of the acoustical heritage of ancient theatres and odea [6]. Reconstructed were theatres of Jerash, Aspendos and Syracusa, and virtual reconstruction and simulation was compared to measurement of present structures. Simulations were made with the room acoustic software Odeon [7]. The measurements and simulations were performed with and without audience. The reverberation time T_{30} with audience was 0.3-0.4 s less than without audience. Also, the simulation detected that presence of the colonnade on the top of *cavea* increased reverberation for about 0.6 s. C_{80} and STI were very good in all theatres due to the lack of reflections from the roof.

Alvares-Corbacho in [1] analysed three Roman theatres in Spain: theatre of Regina Turdulorum, theatre of Italica and Segobriga. Regarding the theatre of Regina Turdulorum they measured the impulse response of the existing theatre and simulated it with CATT software. They analysed the differences of acoustic parameters between simulated results and measured ones. T_{30} and T_s did not have significant difference at any frequency, while C_{50}, C_{80}, D_{50} and IACC showed significant differences, except on central frequencies. Similar results were presented for the theatre of Italica. For the theatre of Segobriga, authors analysed the measurements of three sources (2 on *proscenium,* and 1 in *orchestra*), and 19 receivers. Averaged reverberation time T_{30} was 0.45 s. When analysing different source-receiver combinations they discovered that their position influences the results, but in general no significant differences were detected, except in the aspect of spatiality.

Psarras [8] measured and analysed the theatre of Epidaurus, the best-preserved Greek theatre, with a capacity of 14500 seats. He noticed a dip of intensity level in the frequency range between 170-200 Hz, and

10.58874/SAAT.2022.217

the broad amplification region around 1000 Hz. These measurements are in accordance with Lokki [9] who used FDTD simulation along with beam tracing, and concluded that theatre's step size and backscattering generate the interference dip. This dip and amplification around 1000 Hz are responsible for good intelligibility and powerful sound of male actors who were performers in ancient times.

The measurements Psarras did are also in accordance with Declercq and Deskyser [5], who analysed the influence of diffraction on seats using numerical study and found out that it amplifies the frequencies above the 530 Hz. Psarras however did not confirm their findings of low frequency attenuation.

Works of Lokki and Declerq were performed for empty cavea, so it would be interesting to see to which extent such effect would be present in the case of full audience.

3. ROMAN THEATRE OF SALONA

3.1 Roman Colony of Salona

Colonia Martia Iulia Salona was the capital of the roman province of Dalmatia. It was situated at the end of a well-protected bay, beside the estuary of the river Salon [2]. Salona was founded in 3rd century BC by the Greeks and became Roman after their conquest of Dalmatia. In the peak of its expansion, it reached over 60 000 inhabitants.

3.2 Roman Theatre of Salona

F. Carrara started the research of the theatre of Salona in 1849. when a peasant ruined a part of the walls while building its house [10]. E. Dyggve in 1922. performed more detailed excavations revealing the theatre and an adjacent temple. The theatre was built in the middle of the Ist century AD and has been rebuilt several times later.

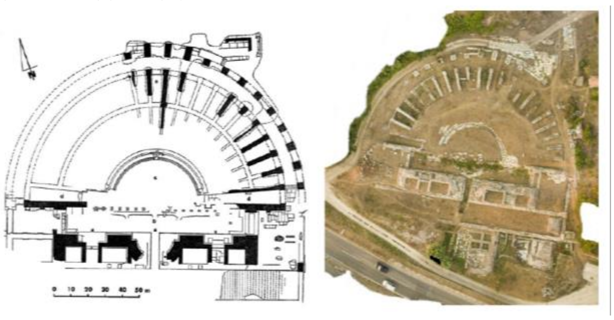

Figure 1 – Plan of theatre according to E. Dyggve, and aerial photo from the present time.

The theatre has 65 m in diameter, and the length, from rim of the *cavea* to the end of the *porticus* is 58 m. The theatre *cavea* is oriented towards south, but theatre's axis has an angular shift of 9° eastwards from pure north. *Imma cavea* is built using the natural slope of the terrain, while the *summa cavea* is supported on substructures comprised of walls and pillars. Besides this the foundations of *proscaenium*, *parascenios* - two buildings that flank the *proscaenium,* and front stage wall or *scenae frons* remain today. The *orchestra* is outlined between the *imma cavea* and *proscaenium,* but without the stone pavement.

4. RECONSTRUCTION AND SIMULATION OF THEATRE

4.1 Reconstruction of Theatre

Unfortunately, until the present time, archaeologists did not make the reconstruction of the theatre of Salona. However, some of them made assumptions about certain aspects of the theatre, like the number of rows in the *cavea*. So, to make the model for acoustic simulation, we had to make the reconstruction of our own.

As a starting point we used theatre plan according to Eynar Diggve (figure 1). Then, we georeferenced the plan to the aerial photo [11] in GIS system and extracted the following theatre dimensions: diameter of *cavea* 66.58m, diameter of *orchestra* 17.17 m, and the dimensions of *proscenium* 37.67m x 7.55m.

Besides this we analysed the list of 198 ancient theatres and odea from [12] and filtered 20 theatres that are similar to the theatre of Salona in its size and age. From this short list we selected the theatre of Dougga [14] and the south theatre of Jerash [15], as the most similar to the theatre of Salona. The criteria for selection were the similarity of footprints of *cavea*, *proscaenium* and *scenae frons*. Using those two theatres we reconstructed the features in the third dimension that is not present in the remains of the theatre of Salona. We have defined following dimensions: the seat height 0,41m, seat length 0.67m, *proscenium* height 1.05m, column height 5m, column width 0.62m, door height (*orchestra*) 2.6m, central door height (*scenae frons*) 4.5m and side door height (*scane frons*) 4.2m.

We also used the theatres of Dougga and Jerash to recreate the look of *scane frons* while respecting its footprint that is still preserved. We did not recreate the fine details of *scane frons* and its elements, but instead adjusted the scattering coefficient in the simulation. We created the 3D model using SketchUp Pro software.

4.2 Simulation of Theatre

The simulation of the theatre of Salona was carried out using Odeon software (v14.05). The 3D model of theatre of Salona was exported from SketchUp to Odeon using the SU2Odeon extension. In Odeon we assigned marble material for Scenae frons, empty cavea, orchestra, and other surfaces made of stone. We assigned the highest scattering coefficient of 0,8 to *scene frons* to simulate the decorations that were not modelled in detail. Other stone surfaces had the scattering coefficient of 0,6. To wooden *proscaenium* we assigned the floating wooden floor material, with 0,4 scattering. For the case when *cavea* was full of spectators, we used the Odeon's audience material with lowest absorption, because the seats were made of stone. To the virtual roof of the theatre and all doors we assigned the 100% absorption.

Air conditions were set according to ISO standard

3382-1:2009. The positions of sources and receivers are presented in figure 2. We placed three sources, at the height of 1,5m above the surface they were positioned on. The source S1 and S2 were positioned on the *proscaenium* one meter from the edge, the first one centred, and the second one moved to 7 m to the right. S3 was placed centred in the orchestra, 3,5 m from its edge. Ten receivers were scattered through the *cavea* in three rows: the first one was on central axis, the second one in the middle of the right quadrant, and the third one near the end of the *cavea*. The height of the receivers was 0,8 m above the seat.

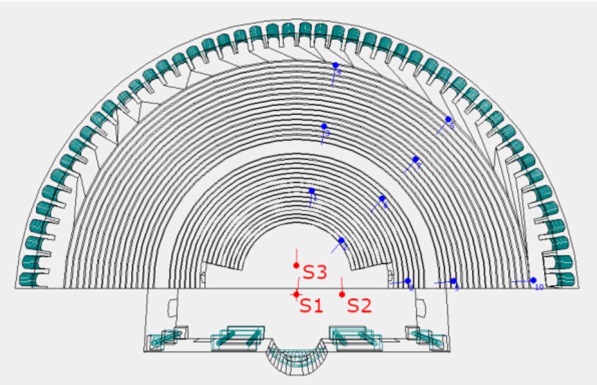

Figure 2 – Position of sources and receivers for the simulation of theatre of Salona.

To perform simulations, we set the "precision" parameters in Odeon simulation, with impulse response length of 1000 ms, approximately 145 984 late rays, max reflection order of 10 000, transition order of early reflection set to 2, 100 early scattered rays per image source, and screen diffraction on.

Simulations of theatre of Salona were carried out on three configurations: C1 *with empty audience,* C2 corresponds to the reconstructed configuration of theatre *with full audience*, and C3 - the reconstructed theatre *without the scene frons and with empty audience*

4.3 Results and Discussion

Figure 3 shows the simulation results for source S1, without the audience. Reverberation time T_{30} for empty audience (C1 – green line) is around 1,4 s, except for highest frequencies. When audience is added to the simulation (C2 – red line), reverberation time drops to 1 s on 1 kHz. This is consistent with results of ERATO project [6] where for south theatre of Jerash simulation produced T_{30} of 1,54 s (empty) and 1,06 s (full) respectively. It is also in accordance with the measurements of theater of Aspendos [13], which has completely preserved *scenae frons* and which has T_{30} of 1,7 s.

Clarity C_{80} in the theatre of Salona was rather low for empty theatre – 1,5 dB on 1 kHz, and good for full audience – 6,1 dB on 1 kHz. Results for definition show similar difference. D_{50} is relatively low without audience - 0,48 on 1 kHz, and good for full audience - 0,71 on 1 kHz.

We noticed that results we obtained are not as good (for dramatic performance) as those shown in [1,7,8] where simulations and measurements were performed for present state of various theatres. These theatres however do not have the *scenae frons* preserved or it is preserved only partially.

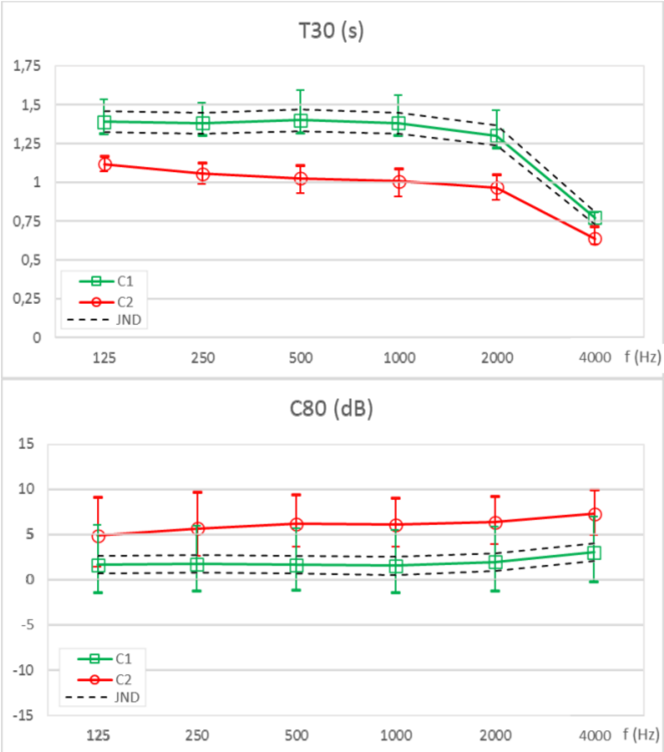

Figure 3 – Results of simulation for source S1: reverberation time T_{30} and clarity C_{80}. Green line shows simulation without audience (C1), and red line with audience (C2). Dashed line show ±1 JND region.

So, we performed simulation for the theatre of Salona without its *scenae frons* to compare it to the above-mentioned cases. Results are presented in Figure 4.

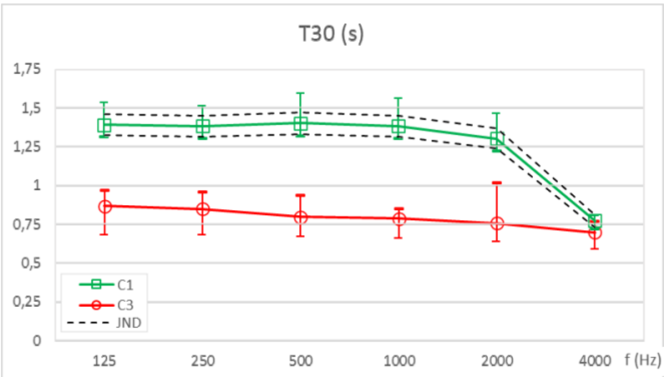

Figure 4 – Comparison of reverberation time T_{30} with (green line – C1) and without *scaene frons* (red line – C3) for source S1. Dashed line show ±1 JND region.

In this configuration, since there are no reflections from *scenae frons*, reverberation time is around 0,8 s. This is almost half than in configuration with *scenae* *frons*. Other parameters follow similar pattern, so on 1 kHz C_{80} is now 9,5 dB and D_{50} is 0,82. These values are now comparable with similar above-mentioned simulations – for example in [7] for 1 kHz T_{30} was 0,65 s, C_{80} was 12 dB and D_{50} was 0,86.

Next, we analysed the influence of different positions of the source on the simulation results, and found that the change in the position of the source does not induce a significant change in the reverberation time, as differences are bigger than 1 JND only for highest frequencies.

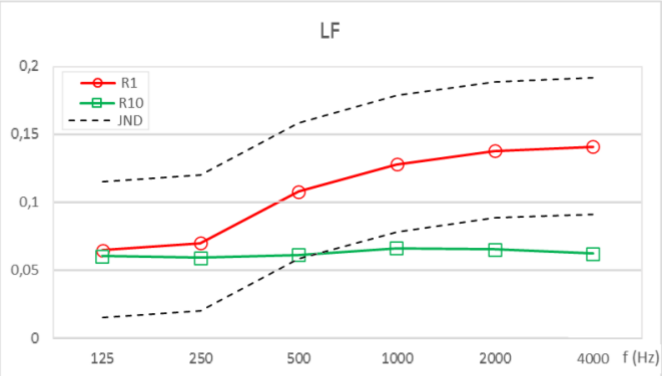

Figure 5 – Lateral fraction of received sound for source S1 and receivers R1 (red line) and R10 (green line) Dashed line show ±1 JND region.

Finally, we analysed the influence of the position of the receiver on the spatial parameters of the received sound. Figure 5 shows the lateral fraction coefficient LF of sound received by the receivers R1 and R10. Receiver R10 is positioned at the edge of the *cavea* and is partially occluded by the *scenae* buildings. LF is for receiver R1 equal to 0,13 (on 1kHz), while for R10 is only 0,07, or 46% less. The reverberation time T_{30} was only 7% lower for the same two sources. These results are consistent with Alayon in [7] and are caused by the screening of one side of receiver with building wall.

5. CONCLUSION

This paper presents the simulation of the theatre of Salona. Since this theatre is not well preserved, nor was it reconstructed, we made a reconstruction based on the remains and similar, existing, preserved theatres of Jerash and Dougga. The simulation results show good acoustical properties of the theatre for dramatic performances, with T_{30} equal to 1 s, C_{50} equal to 6,1 dB, and D_{50} 0,71 on 1 kHz for full audience. We found that different positions of sources produced similar acoustic results, and that position of receiver mainly influences the spatial properties like lateral fraction. We also made the simulation without the *scenae frons* to compare our simulation to simulations of existing theatres, that have well preserved *cavea*, but lack the scene. We got a significantly lower T_{30} and higher C_{50} and D_{50}.

The reconstruction of the theatre of Salona presented here gives valuable insight to the function of this important building of the ancient city of Salona and has confirmed that the theatre's acoustics was good, comparable to other great Greek and Roman theatres.

ACKNOWLEDGEMENTS

We want to thank to archaeologist Jagoda Mardešić from Archaeological Museum in Split, who worked on excavations of theatre of Salona and have helped us with its reconstruction.

6. REFERENCES

[1] A. Álvarez-Corbacho, T. Zamarreño, M. Galindo, S. Girón. Acústica Virtual del teatro romano de Regina Turdulorum. Proceedings of Tecniacustica. Valencia, pp 1515-1522, 2015.
[2] J. Jeličić-Radonić, A. Sedlar, "Topografija antičke Salone (I) Salonitanska Urbs vetus", Tusculum, vol.2, No. 1, 7-32, 2009.
[3] Vitruvius and M. H. Morgan, "1st century BC," in Vitruvius: The ten books on architecture, New York: Dover Publications, 1960.
[4] F. Canac, "L'acoustique des théâtres antiques: SES Enseignements", Paris: Édition du Centre national de la recherche scientifique, 1967.
[5] K. Chourmouziadou and J. Kang, "Acoustic evolution of ancient Greek and Roman theatres," Applied Acoustics, vol. 69, no. 6, pp. 514–529, Jun. 2008
[6] J. H. Rindel, "Roman theatres and revival of their acoustics in the ERATO project," Acta Acustica united with Acustica, vol. 99, no. 1, pp. 21–29, 2013.
[7] J. Alayón, S. Girón, J. A. Romero-Odero, and F. J. Nieves, "Virtual Sound Field of the Roman Theatre of Malaca," Acoustics, vol. 3, no. 1, pp. 78–96, Feb. 2021
[8] S. Psarras, P. Hatziantoniou, M. Kountouras, N.-A. Tatlas, J. N. Mourjopoulos, and D. Skarlatos, "Measurements and Analysis of the Epidaurus Ancient Theatre Acoustics," Acta Acustica united with Acustica, vol. 99, no. 1, pp. 30–39, Jan. 2013
[9] T. Lokki, A. Southern, S. Siltanen, and L. Savioja, "Acoustics of Epidaurus – Studies With Room Acoustics Modelling Methods," Acta Acustica united with Acustica, vol. 99, no. 1, pp. 40–47, Jan. 2013
[10] J. Mardešić. "Teatar i hram u Saloni", Archaeologia Adriatica, vol.2, No. 1, 223-234, 2008
[11] "Geoportal DGU," geoportal.dgu.hr. https://geoportal.dgu.hr (accessed Apr. 12, 2022).
[12] S. Girón, Á. Álvarez-Corbacho, and T. Zamarreño, "Archives of Acoustics." Committee on Acoustics PAS, PAS Institute of Fundamental Technological Research, Polish Acoustical Society, 2020.
[13] A. Farnetani, N. Prodi, R. Pompoli, "On the acoustics of ancient Greek and Roman theaters," J. Acoust. Soc Am., Vol. 124, No. 3, pp. 1557-1567, 2008.
[14] H. F. Pfeiffer, "The ancient roman theatre at Dugga," Memoirs of the American Academy in Rome, vol. 9, p. 145, 1931.
[15] F. Sear, A. Hutson, "Reconstructing the south theatre at Jerash," Ancient Near Eastern Studies, vol. 37, pp. 3–26, 2000