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Comparison of noise measurements and simulation on Siracusa Greek Theatre

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ABSTRACT

The paper describes the results of some noise measurements recently performed inside Siracusa Ancient Theatre, and the comparison with computerized model. More in details, the considered parameters are speech transmission index and clarity index C_{50}, measured in the field by means of MLS technique, and simulated on computer with numerical model.

Keywords: Model, STI, C_{50}

1. INTRODUCTION

The extraordinary Greek theater of Syracuse, presents itself, today, as a result of the expansion and of the reconstruction of the third century a.C. wanted by the tyrant Hieron II. What has come down to us, unfortunately, is reduces almost exclusively to part of the cavea cut into the limestone rock of the southern flank of the Temenite2 hill, a little elevated relief above sea level, which faces the Grand Port and the which you can see in the distance the opposite points of Ortigia and Plemmirio. Altogether disappeared are the highest part of the cavea and the scenic building, because the limestone blocks of both - steps for the one, wall structures for the second - between 1520 and 1530 were removed and transferred to Ortigia to be reused in the construction of the fortifications ordered by the sovereign Spanish Carlo V.

Today the Theatre is an important well known archaeological site, and it is used also for concerts and classical representations.

Figure 1 shows a picture of the Theatre captured form a drone.

In the period between summer 2021 and spring 2022, two measurement campaigns were carried out inside the Theatre. The first campaign was conducted when the theatre was covered with wooden benches and cushions, whereas the second campaign took place when benches were removed. The main idea of the research was to compare the results of measurements with the computer simulation of the theatre.

2. MEASUREMENT CAMPAIGNS

The measurements were performed by exciting the area of interest with MLS technique by means of a loudspeaker placed between proscenium and orchestra, and by detecting the response in 26 positions distributed inside the theatre, each of them placed 1 meter high from the seat.

Thanks to the acquired signals it was possible to calculate the impulse response for each pair of source-receiver point, and then compute all the classic acoustic parameters.

Figure 2 shows loudspeaker position (red colour) and receiving points position (green colour).

Figure 1 – Siracusa Theatre from a drone

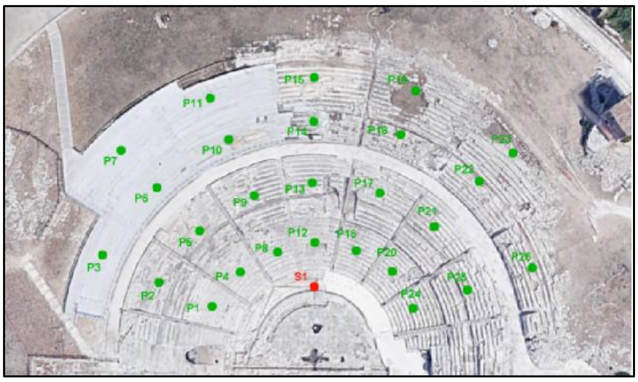

Figure 2 – Measurements points, © 2022 GoogleEatrh

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The MLS technique was implemented with a sequence length of 262144 points and a sampling rate of 48 kHz. The impulse responses were calculated by acquiring the signal coming from a microphone placed one meter from the loudspeaker and, sequentially, the signals coming from all the receiving points.

For the sake of brevity, in this paper only few results relating to the measurement campaign with wooden benches and cushions are reported.

3. MEASUREMENT RESULTS

The following chapters shows some results from the measurements. Results are presented as interpolated maps with 'multiquadric' interpolation algorithm.

3.1 Speech Transmission Index

As described above, starting from Impulse Response function it was possible to compute the Speech Transmission Index. A STI above 0.6 is considered good whereas a STI above 0.75 means that the intelligibility is excellent.

Figure 3 shows the Speech Transmission Index for the octave band of 125 Hz. The picture emphasizes a worse STI to the right-up part of the image where stones seats are still in place, unlike what happens to the left-up part where there are no stones anymore, and so STI is a little bit better.

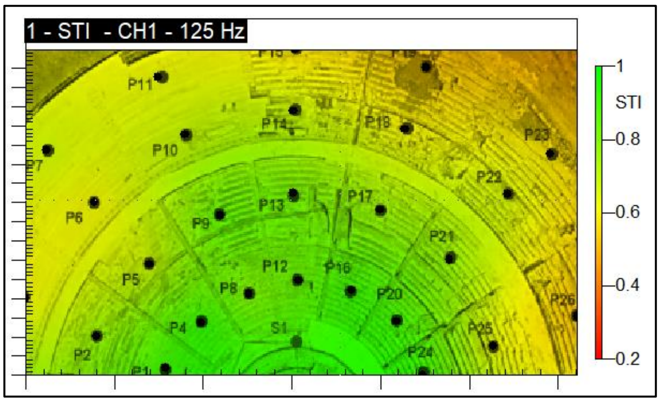

Figure 3 – Speech Transmission Index 125 Hz

In the same way, Figure 4 shows STI for the octave band of 250 Hz. For this frequency band it can be seen a more homogeneous behaviour.

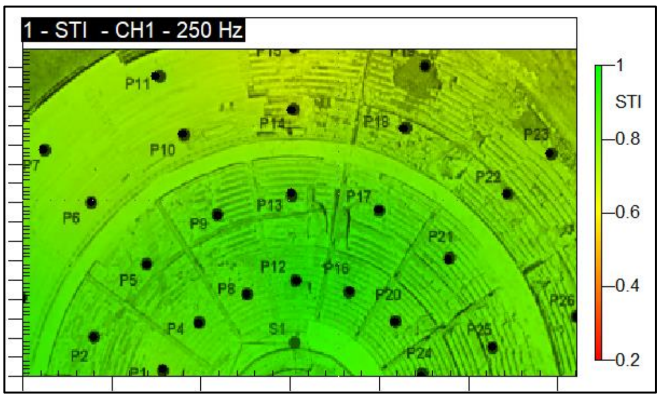

Figure 4 – Speech Transmission Index 250 Hz

Ones more, Figure 5 shows Speech Transmission Index for the octave band of 500 Hz. Even in this situation the map shows quite homogeneous values.

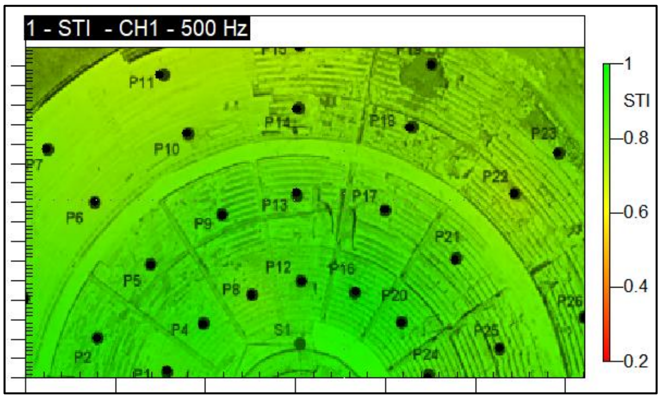

Figure 4 – Speech Transmission Index 500 Hz

In addition to the above, Figure 5 shows the spectrum representing the averaged Speech Transmission Index on all measuring points.

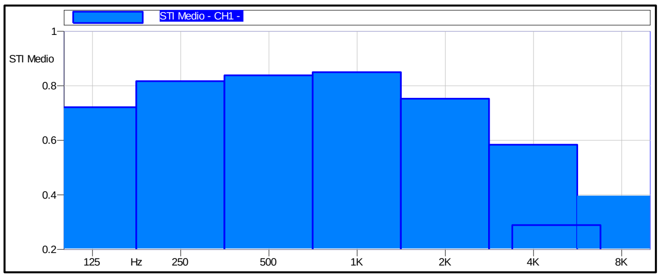

Figure 5 – Averaged Speech Transmission

Table 1 shows the standard deviation related of the STI averaged value. Smallest deviations are between 250 Hz and 1 kHz.

Table 1 – Standard deviation STI

Octave band	Standard deviation
125	0.13
250	0.08
500	0.08
1000	0.07
2000	0.12
4000	0.14
8000	0.12

3.2 Clarity indexes

Using Impulse Response function, also the Clarity Index C_{50} was computed. Generaaly an index above 3 is considered good for voice communication.

Figure 6 shows C50 for the octave band of 125 Hz. The image clearly shows some problems for all position that are far from the orchestra, especially on right-up part of the picture.

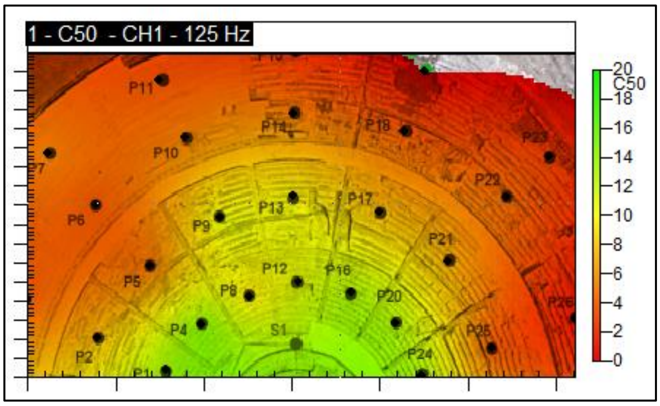

Figure 6 – C_{50} 125 Hz

Figure 7 shows C_{50} for the octave band of 250 Hz whereas Figure 8 is related to octave band of 500 Hz.

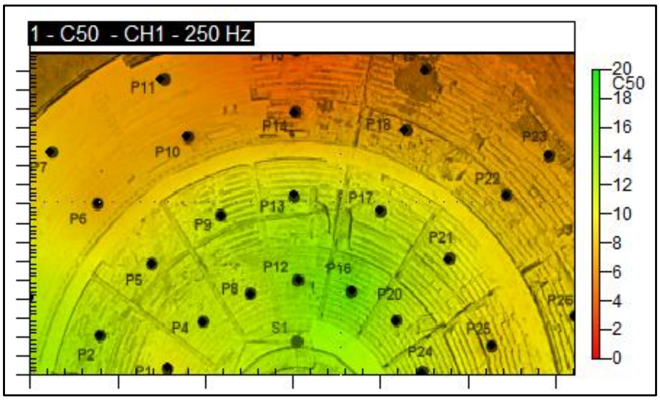

Figure 7 – C_{50} 250 Hz

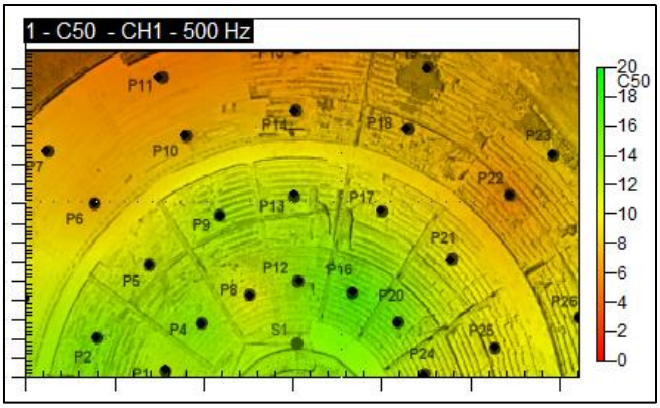

Figure 8 – C_{50} 500 Hz

Figure 9 shows the spectrum representing the averaged C_{50} on all the measuring points.

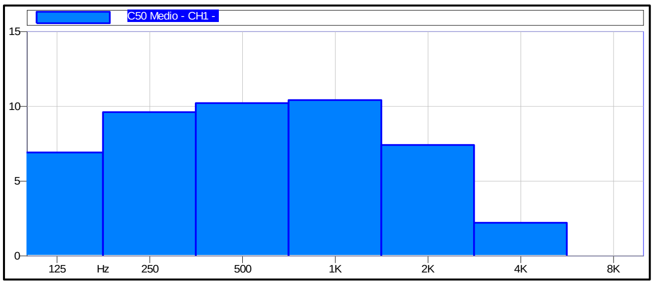

Figure 9 – Averaged C_{50}

Table 2 shows the standard deviation related to the average value (all positions). Smallest σ are between 250 Hz and 1 kHz, and for 8kHz band, where almost all the values are below zero, indicating a worse voice communication.

Table 2 – Standard deviation C_{50}

Octave band	Standard deviation
125	4.3
250	3.0
500	3.1
1000	2.5
2000	3.8
4000	4.2
8000	3.1

4. NUMERICAL MODEL

After the measurements, a simplified numerical model of theatre has been outsourced. Figure 10 shows the 3D model of the theatre which includes loudspeaker and receivers in the original positions for result comparison, plus others receivers in order to obtain more smooth maps.

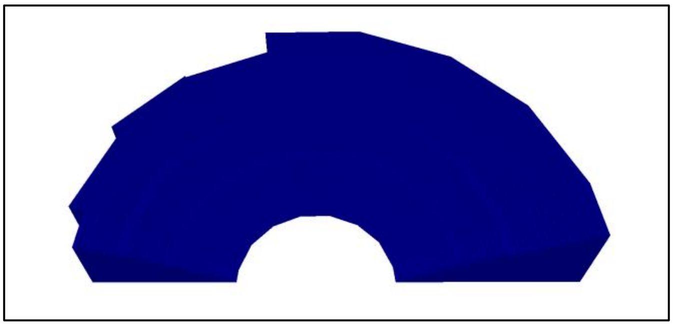

Figure 10 – Simplified numerical model

Thanks to the model it was possible to compute the impulse response function for each couple of loudspeaker-receiver positions, as well as all the other standard parameters, also collected in the field; then, after calculation, some comparison between measured and computed data were possible. Figure 11 shows an example of the computed Impulse Response function, in the example related to the octave band of 125 Hz. Using IRF is possible to compute parameters as reverberation time, EDT for each frequency band, and others, as well as is possible to make convolution with audio file and then auralization.

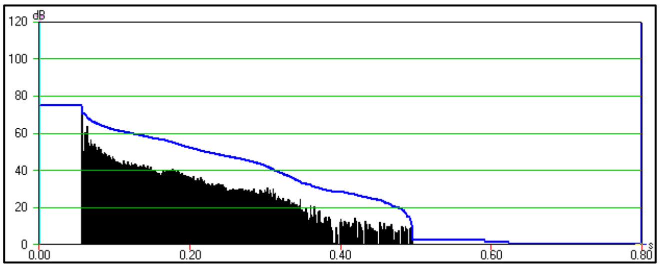

Figure 11 – Computed Impulse Response funcion

4.1 Sound mapping

Figure 12 shows the simulated A-weighted noise map due to an omnidirectional 110dB Lw loudspeaker, placed between proscenium and orchestra.

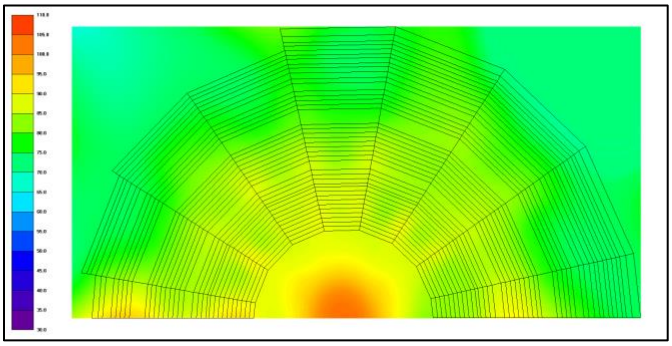

Figure 12 – A-weighted noise map

4.2 STI comparison

Figure 13 shows the computed STI map for the octave band of 125 Hz. Please note that the order of the colours in the picture is reversed respect to Figure 3, so the behaviour of the simulated STI for this band is practically similar to the experimental one. More in details there are low values in the upper right corner, and partially on the upper left corner.

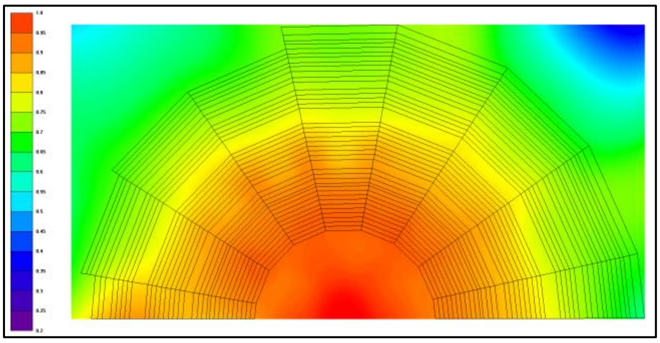

Figure 13 – 125Hz STI map

Figure 14shows the computed STI map for the octave band of 250 Hz. Also in this case the order of the colours in the picture is reversed respect to Figure 4, so the behaviour of the simulated STI for this band is again similar to the experimental one, that is more homogenous values.

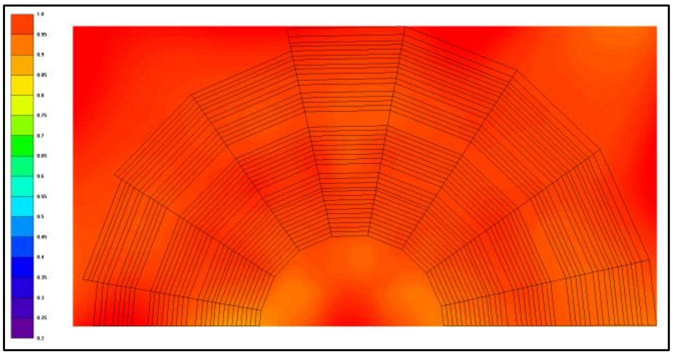

Figure 14 – 250Hz STI map

Similar behaviour is obtained for the 500 Hz octave band.

4.3 C_{50} comparison

C_{50} comparison showed an over estimation of the simulated parameter. Table 3 reports averaged measured and simulated values and, in the last column, the difference between values.

Table 3 – C_{50} comparison

Octave band	Meas.	Simul.	Diff
125	6.9	12.9	6.0
250	9.6	13.0	3.4
500	10.2	14.0	3.8
1000	10.4	16.0	5.6
2000	7.4	17.9	10.5
4000	2.2	19.3	17.1
8000	0	20.7	20.7

Data shows that differences are much higher at high frequencies. The reason for this mismatching is under investigation.

5. CONCLUSIONS

Measurement pointed some peculiarity of Siracusa Greek Theatre, which in any case demonstrate to have as very good acoustics. The comparison between experimental data and computer model, showed a good match of results for STI, whereas an overestimation of simulated C_{50} values, especially at high frequencies, emerged.

6. REFERENCES

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