# "RENOVATION OF THE THEATER PUCCINI IN MILAN. PREDICTION OF ACOUSTIC QUALITY OF TWO ROOMS"

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# 1 INTRODUCTION

This work deals with the theoretical evaluation of the acoustic quality of two rooms to be realized in the building of the former Cinema-Theater Puccini in Milan. In particularly the renovation consists in the execution of a 500 seat theater room, a 300 seat polyvalent rehearsal room and a 100 seat conference room. In this paper we describe the studies concerning the two main rooms that in the following we will simply call as "500" and "300" in relation with the numbers of seats. The analysis has been carried out through the predictive software *Ramsete 2.5* for "geometrical acoustic" and through theoretical study for "wave acoustic". This approach enables us to verify the relevance, by the point of view of acoustic comfort, of the arrangements regarding the room structure as well as the materials. The following parameters have been used to evaluate acoustic performances: Reverberation Time, Early Decay Time, Initial Time Delay Gap, Clarity, Definition, Centre Time, Strength, and Speech Transmission Index.

# 2 THE ROOMS: GEOMETRY AND MATERIALS

## 2.1 The "500" room

This room is essentially made of two connected sections: the stall and the stage (see Figure 1). The total volume is approximately 9900 m$^3$ (6700 m$^3$ for the stage and 3200 m$^3$ for the stall). The plant of the stall is fan-shaped (but with a very small angle) and the maximum distance from the boccascena and the last seats of the stall is about 20 meters.

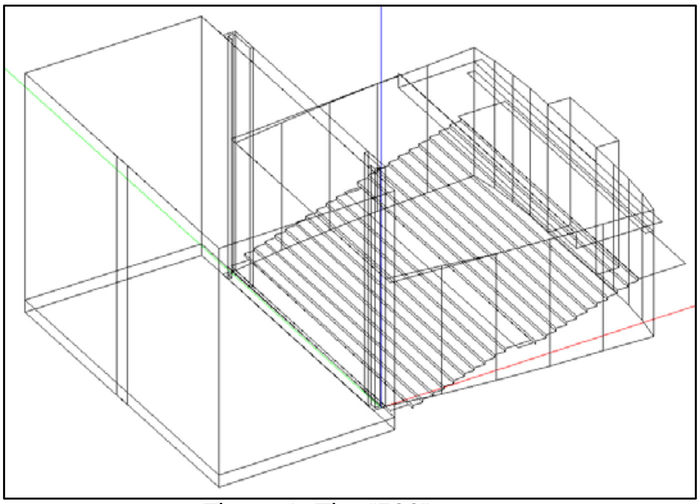

Figure 1. The "500" room

This room must be designed to host mainly drama , but occasionally it could host also simple music performances: therefore the values of the selected parameters will be chosen to allow an optimal perception of the speech without prevent a good audition of music.

| | $T_{60,1000Hz}$ (s) | EDT (s) | ITDG (ms) | $C_{80}$ (dB) | $D_{50}$ (%) | $T_S$ (ms) | STI | G (dB) |
|---|---|---|---|---|---|---|---|---|
| **"500" room** | 1.30 | $<T_{60}$ | < 20 | 3-4 | 50 | <80 | 70 | > 0 |

Table 1. Acoustical parameters: optimal values for the "500" room

The fan-shaped stall permit a general diffusion of sound waves also preventing stationary waves, echoes and flutter. The side walls are covered by special drop-shaped panels in order to increase diffusive phenomena, so keeping high reflection coefficient, and, as a consequence, a reinforcement of sound (see Figure 2).

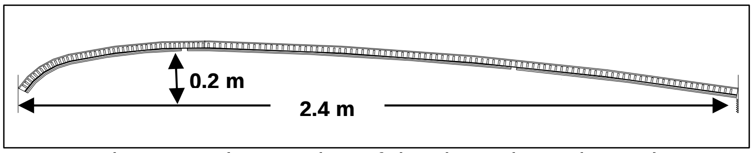


Figure 2. Plan section of the drop-shaped panel

To prevent selected absorption phenomena at low frequencies the panel's thickness is almost 2 cm. The steps of the stall's floor are covered by parquet, the flat ceiling is completely wood made and the back wall consists in special absorbent panel with high absorption coefficient at all frequencies.
The stage, due to its high dimension, has a big influence on the acoustic of the room. For a realistic simulation we have considered a permanent structure consisting in a gypsum made absorbent false ceiling. We have also planned some temporary structures: 6 wood panels on the stage, the wings (total surface: 230 $m^2$); 2 heavy velvet curtains in the upper part of the stage (total surface 190 $m^2$) and 1 heavy velvet curtain on the back wall of the stage (170 $m^2$) (see Figure 3).

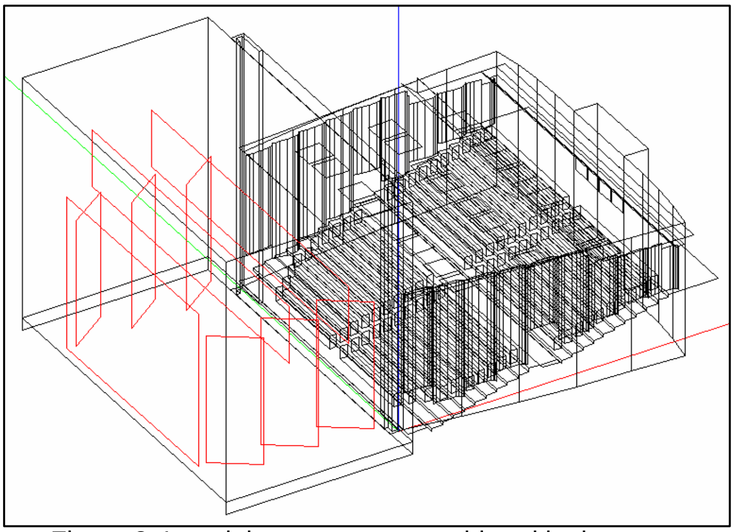

Figure 3. In red the structures considered in the stage

To guarantee a sufficient absorption in the case of partially full room, we propose upholstered seats. For the simulations we always consider an occupation of the room of 66 % (2/3 of audience).

## 2.2 The "300" room

The volume of this room is almost 2500 $m^3$, the plant is rectangular and the ceiling is sloping (from 5.5 m to 9 m of height) (see Figure 4).

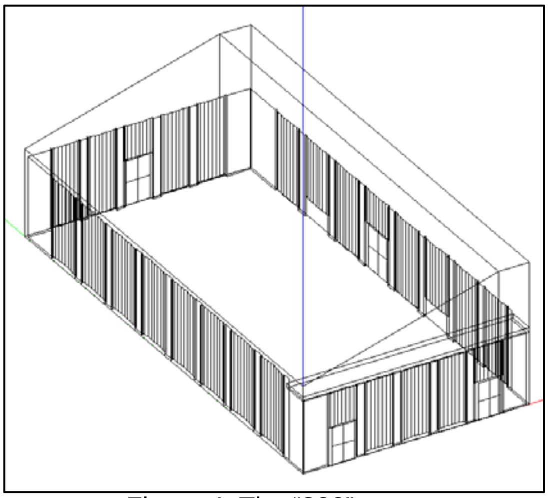

Figure 4. The "300" room

The main purpose of this room is to perform drama, but it will be also used as a rehearsal room. One of its main characteristics is the possibility to change the position of audience and stage (of small dimension). The maximum distance from the stage to the audience is about 15 meters.
The optimal values of the selected parameters for the 300 room are reported in table 2.

| | $T_{60,1000Hz}$ (s) | EDT (s) | ITDG (ms) | $C_{80}$ (dB) | $D_{50}$ (%) | $T_S$ (ms) | STI | G (dB) |
|---|---|---|---|---|---|---|---|---|
| **"300" room** | 1.1 | $<T_{60}$ | < 20 | 4-6 | 60 | <70 | 75 | > 5 |

Table 2. Acoustical parameters: optimal values for the "300" room

The floor of the room is made by parquet. The rectangular shape of the room could generate stationary waves at specific frequencies. To guarantee diffusion and absorption of sound, side walls (from floor to 5.5 m high) are covered by special concave panels with circular section shape. Each panel is made of ten elements of 0.55 m high, 1,9 m large and with 15 cm maximum distance to the wall (see Figure 5). Some of the panels have a milling cutter (slot) in the middle (1 m long and 1 cm width) and, to enlarge the absorbed frequencies range, half of them have the air space between panel and wall reduced by means of the insertion of a slab of wood. The position of panels with the milling cutter was chosen with care, in particular they are displaced alternatively one each the other like in a chessboard.
The walls above the panels and the ceiling are made with reflective material (concrete or plaster); to reduce the reverberation time it was necessary to introduce an absorbent false ceiling made of gypsum covering the 44 % of the ceiling surface (140 $m^2$). To distribute it uniformly on the ceiling of the room, the absorbing gypsum was positioned on 5 separated strips. In addition, to guarantee a sufficient absorption, we propose upholstered seats.
A specific characteristic of this room is the possibility of varying the position of the stage and audience. In the Figure 6 are shown the three different position that we consider in the simulation model to analyze the acoustic response of the room. In the simulation a 66 % (2/3 of audience) occupation of the room was considered.

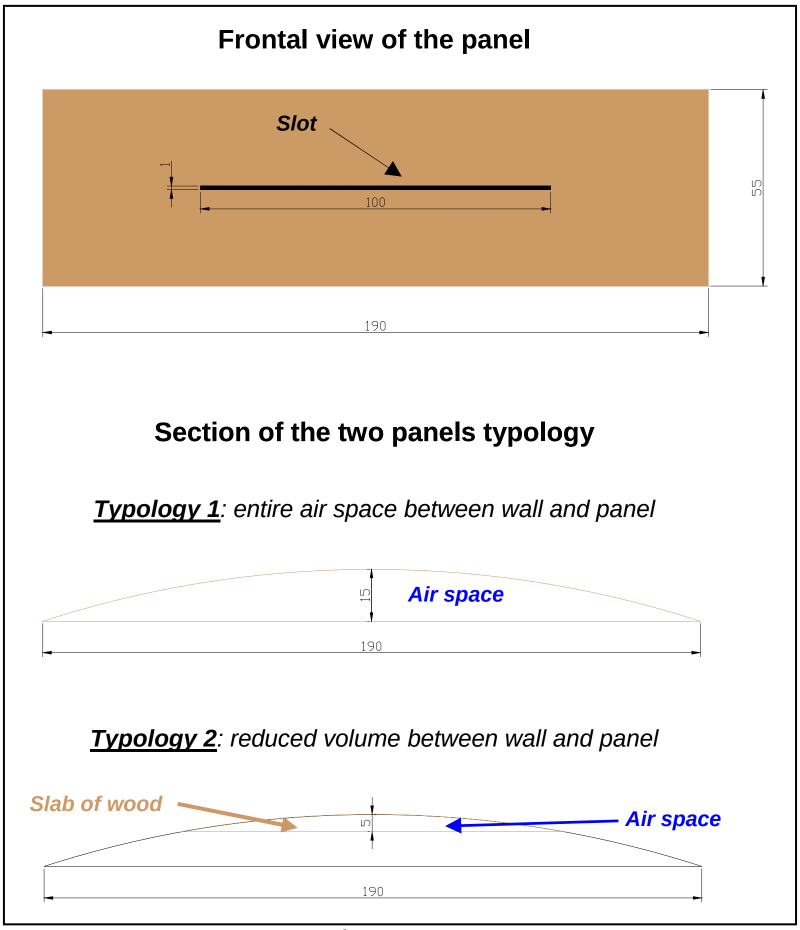


Figure 5

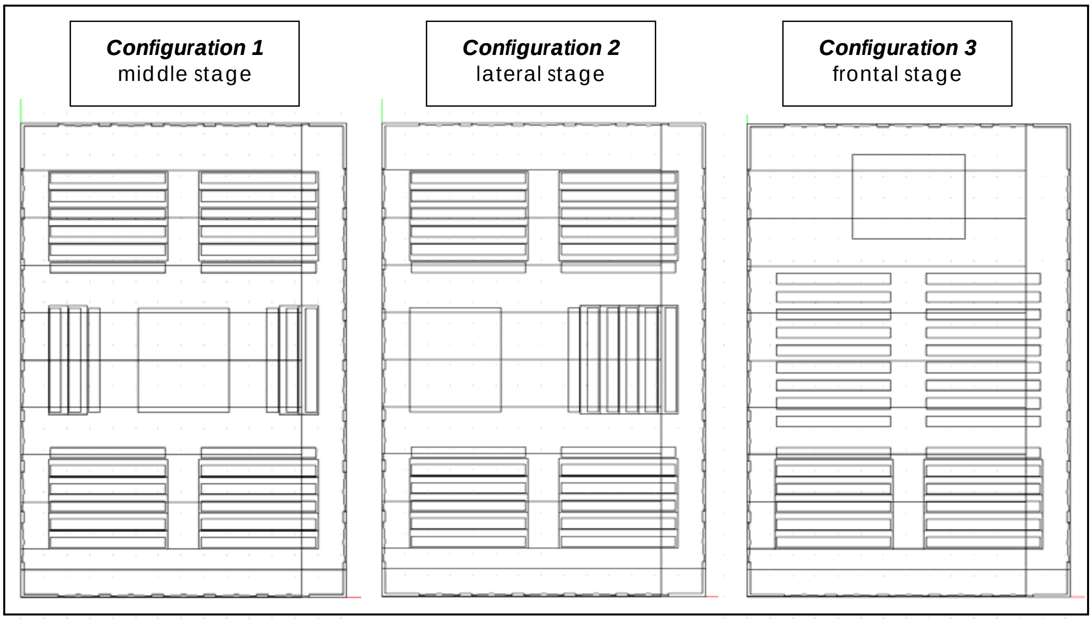


Figure 6. The three different positions of stage and audience

# 3 RESULTS OF SIMULATION

The average values of $T_{60}$, $C_{80}$, $D_{50}$, $T_s$, G and STI, calculated on the whole stall for each room, are reported for a series of frequencies in tables 3 and 4.
We will compare the optimal values indicated before for the two rooms, with the mean value of the $T_{60}$ at 1000 Hz and the global mean value weighing A for the others parameters.
As the absolute value of EDT is not relevant, we just report, in the conclusions, that it is always smaller than the correspondent optimal $T_{60}$ value. ITDG values strongly depends on the auditory position and we have just verified that it is always less than 20 ms.

| Frequency [Hz] | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | Lin | A |
|---|---|---|---|---|---|---|---|---|---|
| $T_{60}$ (s) | 2.54 | 1.53 | 1.27 | 1.29 | 1.53 | 1.65 | 1.39 | 6.49 | 1.52 |
| $C_{80}$ (dB) | 1.20 | 3.88 | 4.51 | 4.39 | 3.44 | 3.01 | 4.05 | 1.04 | 3.71 |
| $D_{50}$ (%) | 43.18 | 55.89 | 59.56 | 59.75 | 55.21 | 53.37 | 58.46 | 44.13 | 56.58 |
| $T_s$ (ms) | 120.3 | 74.0 | 65.3 | 66.0 | 77.4 | 83.4 | 70.5 | 180.2 | 74.7 |
| G (dB) | 6.7 | 5.3 | 4.8 | 4.8 | 5.5 | 5.7 | 4.6 | 6.1 | 8.3 |
| STI | 0.63 | 0.72 | 0.75 | 0.74 | 0.71 | 0.70 | 0.73 | 0.72 | 0.71 |

Table 3. Obtained values for “500” room

Taking into account that the most representative frequencies for drama are 500, 1000 and 2000 Hz, in order to verify the uniform distribution of the acoustical parameters inside the two rooms, we have carried out specific maps, of the whole stall, at the frequency of 1000 Hz for $T_{60}$, $C_{80}$, $D_{50}$, $T_s$, e G.

| | Frequency [Hz] | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | Lin | A |
|---|---|---|---|---|---|---|---|---|---|---|
| $T_{60}$ | *Configuration 1* | 1.81 | 1.26 | 1.06 | 1.12 | 1.18 | 1.26 | 1.03 | 1.87 | 1.18 |
| | *Configuration 2* | 1.88 | 1.35 | 1.16 | 1.17 | 1.24 | 1.31 | 1.04 | 1.98 | 1.23 |
| | *Configuration 3* | 1.97 | 1.39 | 1.20 | 1.24 | 1.31 | 1.40 | 1.09 | 2.00 | 1.31 |
| $C_{80}$ | *Configuration 1* | 2.20 | 4.41 | 5.49 | 5.21 | 4.83 | 4.39 | 5.72 | 3.47 | 5.00 |
| | *Configuration 2* | 1.76 | 3.83 | 4.85 | 4.47 | 4.09 | 3.74 | 5.25 | 2.92 | 4.34 |
| | *Configuration 3* | 1.13 | 3.26 | 4.18 | 3.75 | 3.48 | 3.11 | 4.55 | 2.30 | 3.67 |
| $D_{50}$ | *Configuration 1* | 49.15 | 60.19 | 65.26 | 63.60 | 61.76 | 59.83 | 65.56 | 55.98 | 62.70 |
| | *Configuration 2* | 47.94 | 58.53 | 63.60 | 61.58 | 59.60 | 57.85 | 64.53 | 54.30 | 60.82 |
| | *Configuration 3* | 40.79 | 51.37 | 56.17 | 54.36 | 53.05 | 51.34 | 58.35 | 47.50 | 54.06 |
| $T_s$ | *Configuration 1* | 94.0 | 64.4 | 54.3 | 57.1 | 60.9 | 65.4 | 53.1 | 79.6 | 59.4 |
| | *Configuration 2* | 100.7 | 70.0 | 58.9 | 62.1 | 66.0 | 70.0 | 55.0 | 86.2 | 63.9 |
| | *Configuration 3* | 112.4 | 80.5 | 70.4 | 74.4 | 77.7 | 82.0 | 65.9 | 97.2 | 75.7 |
| G | *Configuration 1* | 13.4 | 11.8 | 11.1 | 11.3 | 11.7 | 12.1 | 11.5 | 12.3 | 14.8 |
| | *Configuration 2* | 13.3 | 11.6 | 10.9 | 11.1 | 11.5 | 11.9 | 11.1 | 12.1 | 14.5 |
| | *Configuration 3* | 13.0 | 11.3 | 10.6 | 10.9 | 11.3 | 11.7 | 10.8 | 11.8 | 14.3 |
| STI | *Configuration 1* | 0.66 | 0.73 | 0.76 | 0.75 | 0.74 | 0.73 | 0.76 | 0.74 | 0.73 |
| | *Configuration 2* | 0.65 | 0.72 | 0.74 | 0.74 | 0.73 | 0.72 | 0.76 | 0.73 | 0.72 |
| | *Configuration 3* | 0.65 | 0.71 | 0.74 | 0.73 | 0.72 | 0.71 | 0.75 | 0.72 | 0.71 |

Table 4. Obtained values for the three different configurations of the “300” room

# 4 CONCLUSIONS

The optimal values of the acoustical parameters, useful for the characterization of "500" room, were chosen to guarantee a good perception of speaking (drama and conference) but at the same time not excluding the possibility to perform musical events. For the choice of structures and materials we consider both the acoustic waves problems and the optimal values of the acoustical parameters. We have selected these parameters among those optimal for speaking but as nearer as possible to the optimal values for music.
The values obtained by the acoustic model and the reference ones (goal values) are reported in table 5.

| Acoustical parameters room "500" | $T_{60,1000Hz}$ (s) | EDT (s) | ITDG (ms) | $C_{80}$ (dB) | $D_{50}$ (%) | $T_S$ (ms) | STI | G (dB) |
|---|---|---|---|---|---|---|---|---|
| **GOAL** | 1.30 | $<T_{60}$ | < 20 | 3-4 | 50 | <80 | 70 | > 0 |
| **simulated** | 1.29 | $<T_{60}$ | < 20 | 3.71 | 56 | 75 | 71 | 8.3 |

Table 5

The values obtained by the model are very similar to the reference ones or lie into the specific intervals.

The acoustic of "300" room was deigned just for drama representations. But the possibility, for this room, to change the position of stage and seats, has significant repercussions on its acoustic. In particular the configuration with the stage in the middle on the stall (1) is excellent for drama representation, the configuration with the stage in frontal position (3) can be used also for simple music representations and the configuration with the stage in lateral position (2) has intermediate characteristics.
In table 6 the simulated values for the three configurations with the optimal values identified for drama (goal values) are reported.

***Configuration 1 (Middle Stage)***

| room "300" | $T_{60,1000Hz}$ (s) | EDT (s) | ITDG (ms) | $C_{80}$ (dB) | $D_{50}$ (%) | $T_S$ (ms) | STI | G (dB) |
|---|---|---|---|---|---|---|---|---|
| **GOAL** | 1.1 | $<T_{60}$ | < 20 | 4-6 | 60 | <70 | 75 | > 5 |
| **simulated** | 1.12 | $<T_{60}$ | < 20 | 5 | 62.7 | 59.4 | 73 | 14.8 |

***Configuration (2) (Lateral Stage)***

| room "300" | $T_{60,1000Hz}$ (s) | EDT (s) | ITDG (ms) | $C_{80}$ (dB) | $D_{50}$ (%) | $T_S$ (ms) | STI | G (dB) |
|---|---|---|---|---|---|---|---|---|
| **GOAL** | 1.1 | $<T_{60}$ | < 20 | 4-6 | 60 | <70 | 75 | > 5 |
| **simulated** | 1.17 | $<T_{60}$ | < 20 | 4.34 | 60.8 | 63.9 | 72 | 14.5 |

***Configuration 3 (Frontal Stage)***

| room "300" | $T_{60,1000Hz}$ (s) | EDT (s) | ITDG (ms) | $C_{80}$ (dB) | $D_{50}$ (%) | $T_S$ (ms) | STI | G (dB) |
|---|---|---|---|---|---|---|---|---|
| **GOAL** | 1.1 | $<T_{60}$ | < 20 | 4-6 | 60 | <70 | 75 | > 5 |
| **simulated** | 1.24 | $<T_{60}$ | < 20 | 3.67 | 54 | 75.7 | 71 | 14.3 |

Table 6

# 5 REFERENCES


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3. R. Spagnolo, Manuale di Acustica, UTET Libreria, Torino (2001).