POLITECNICO DI TORINO

Honors thesis

COURSE OF

DEGREE IN ARCHITECTURE CONSTRUCTION CITY

Abstract

Design of an acoustic shell for Pier Maria Cantoregi Theater in Carignano (TO)

Tutor

Arianna Astolfi

Giuseppe Ferro

by

Eleonora Arpellino

December 2014

The Pier Maria Cantoregi Theatre is a multifunctional hall of about 4700 m^3, with 340 seats, a big stage of 130 m^2 and a scenic tower of 10 m high over it. This space is now used by the Corale Carignanese, a choir of 30 male voices.

The hall presents a basic incorrect design for the execution and the perception of music and singing: the parietal walls and the ceiling are covered by sound absorbing panels that makes the hall very dull and dry; the result is a brief duration of the Reverberation time, which means that only the language is clear and intelligible; the singing voice is lost in the scenic tower and the upper gallery, very jutting over the audience area in the back, creates a sound shadow zone preventing the reflected sound from the ceiling to reach the listeners: the result is a reduced sound intensity and a shallow perceived reverberation.

The project's aim is to solve the acoustical problems inside the hall adding an acoustic shell on the stage, that is a scenic structure behind singers and musicians during their performances, starting from a specific analysis of the space, with a design of an acoustical characterization studied to ensure the welfare of the musicians on the stage and to maximize and optimize the reflections of the sound produced toward the audience; in particular, it has to increase the first reflections on the stage, which are very important for singers for their intonation and for the maintenance of the rhythm.

To determinate the acoustical characterization of the Theatre an experimental measurement was carried out, following the requirements of *International Standard ISO 3382-1:2009 (E) Acoustics – Measurement of room acoustic parameters*, with the impulse response method. Reverberation Time is the rooms acoustic parameter used for the acoustical characterization and for the calibration of the 3D model of the Theatre using *Odeon ®, version 12*, an acoustical software based on a hybrid calculation. The results show that the values of the Reverberation time are typical for hearing speech sound.

Four hypothetical designs were developed with different materials and shapes. The common characteristic of the four acoustic shells is modularity: the structure is conceived of single modular combined panels; each module is constituted by a vertical panel (0,8x3,50x0,018 m) and a top panel tilted at 20° (0,8x0,8x0,018 m); the first three shells (curved, fun, rectangular) are MDF panels, while the fourth is made up by convex Plexiglas module (0,8x3,50x0,018 m), without the upper panels. For each configuration the reflective properties of sound were analysed (Fig. 1).

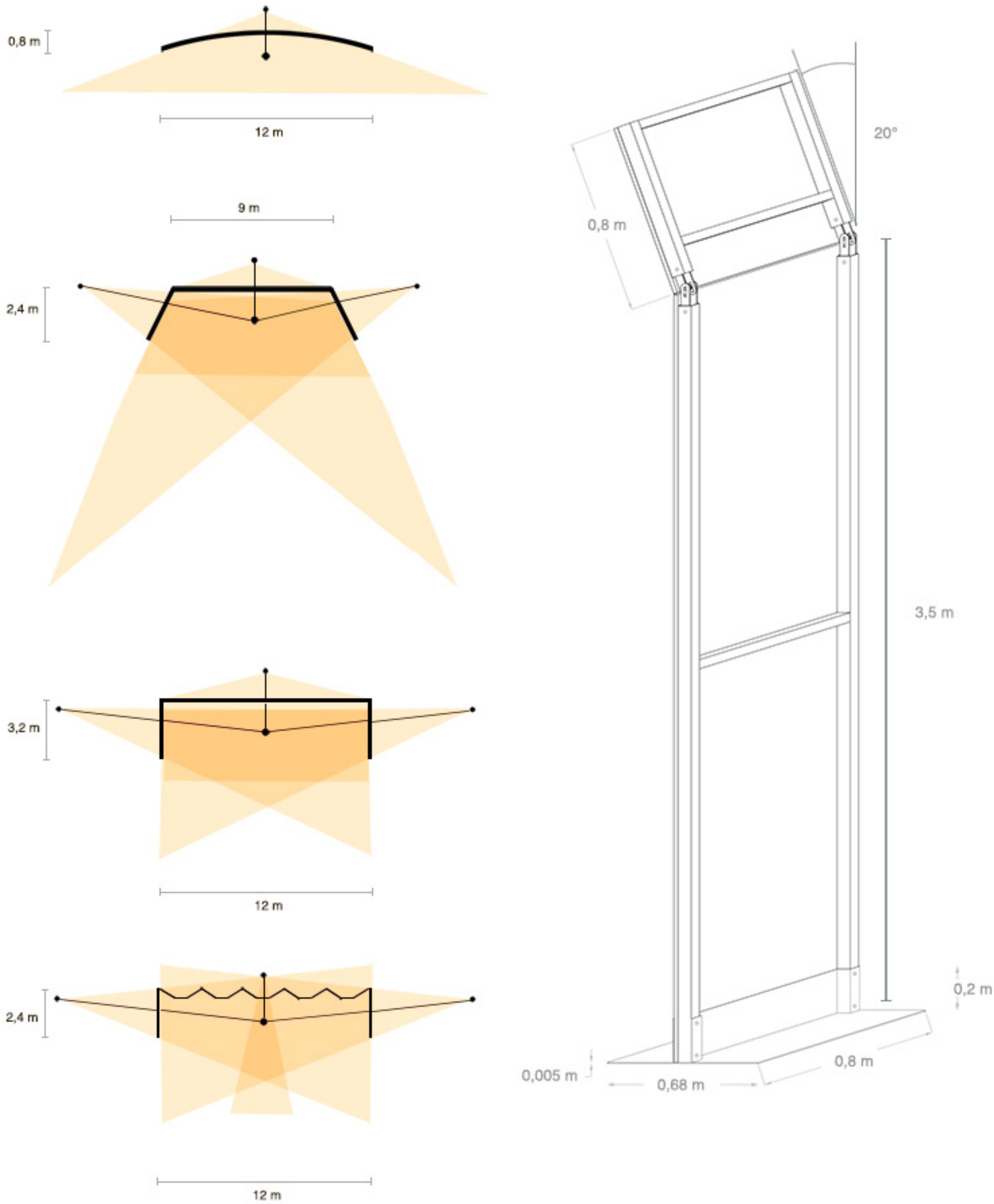

Fig. 1: The four hypothetical shells designs: curved, fun, rectangular, with convex module; on rights, an isometric view of a single module.

To evaluate the best configuration, a 3D design of the four hypothesis was imported in the model previously calibrated and a calculation was made using *Odeon* with reference to the most unfavourable points for the audience, which are the furthest seats from the stage (Fig. 2).

Receiver M10	Condition of things	Curve Acoustic Shell	Fan Acoustic Shell	Plexiglas Acoustic Shell	Rectangular Acoustic Shell	Typical range (*ISO 3382-1*)	JND (*ISO 3382-1*)
$EDT_{500\text{-}1000\,Hz}$ [s]	1,0	0,62	0,63	0,69	0,64	1,2 s; 3,0 s	rel. 5%
$D_{50\;500\text{-}1000\,Hz}$ [-]	0,71	0,8	0,76	0,76	0,75	0,3; 0,7	0,05
$C_{80\;500\text{-}1000\,Hz}$ [dB]	6,3	8,6	7,8	7,6	7,9	- 5 dB; + 5 dB	1 dB
$LF_{80\;125\text{-}1000\,Hz}$ [-]	0,117	0,108	0,132	0,135	0,136	0,05; 0,35	0,05
$G_{500\text{-}1000\,Hz}$ [dB]	-2,9	0,1	-0,2	-1,6	0,0	- 2 dB; + 10 dB	1 dB

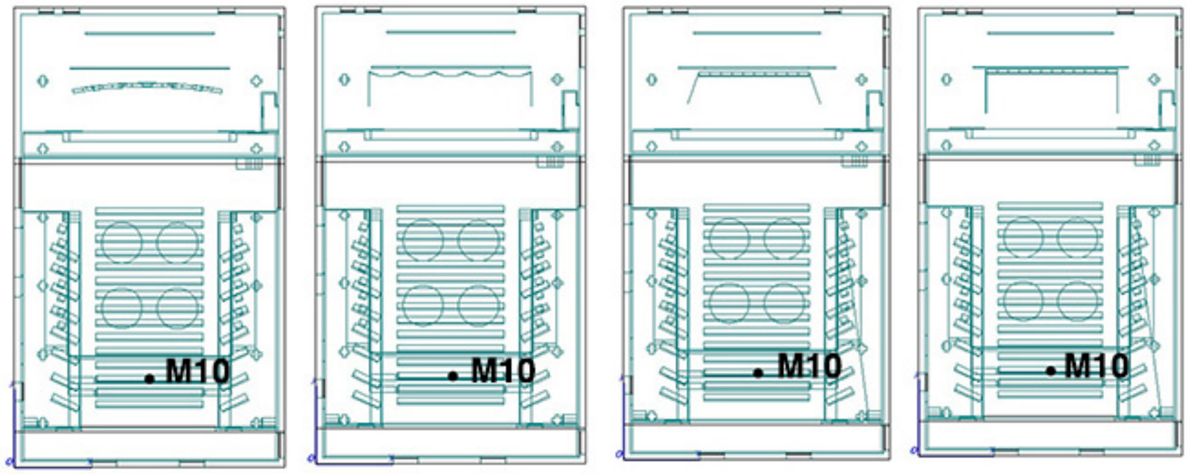

Fig. 2: Results of the simulations of the four shells.

The curved acoustic shell results showed the major improvement, so a further calculation on *Odeon* was carried. With the addition of the acoustic shell, the acoustical parameters change more than the values of *Just Noticeable Difference* indicated in *ISO 3382-1*, therefore the acoustical variations are perceptible (Fig. 3).

Simulated Parameters	Spatial average values	Dev. St. of S1 - S2 mean value	Typical range (*ISO 3382-1*)	JND (*ISO 3382-1*)
$EDT_{(500\text{-}1000\ Hz)}$ [s] condition of things	0,7	0,04	1,0 s; 3,0 s	5 %
$EDT_{(500\text{-}1000\ Hz)}$ [s] with acoustic shell	0,56	0,02		
$D_{50\ (500\text{-}1000\ Hz)}$ [-] condition of things	0,77	0,01	0,3; 0,7	0,05 [-]
$D_{50\ (500\text{-}1000\ Hz)}$ [-] with acoustic shell	0,81	0,001		
$C_{80\ (500\text{-}1000\ Hz)}$ [dB] condition of things	8,2	0,13	-5 dB; +5 dB	1 dB
$C_{80\ (500\text{-}1000\ Hz)}$ [dB] with acoustic shell	9,4	0,22		
$LF_{80\ (125\text{-}1000\ Hz)}$ [-] condition of things	0,146	0,02	0,05; 0,35	0,05 [-]
$LF_{80\ (125\text{-}1000\ Hz)}$ [-] with acoustic shell	0,153	0,01		
$G_{(500\text{-}1000\ Hz)}$ [dB] condition of things	1,2	0,4	-2 dB; +10 dB	1 dB
$G_{(500\text{-}1000\ Hz)}$ [dB] with acoustic shell	4,2	0,3		

Fig. 3: Table shows results of the curved acoustic shell simulation. They are spatial average values of all receivers and sound sources using for simulation, to have a global valuation of the conditions of the hall.

15 individual separable modules compose the acoustic shell, in order to make it completely independent. Two steel hollow tubular frames prevent the deformation of the MDF panels and two hinged bolted screws permit the mounting and the tilting of the shell. The vertical panel is wedged and bolted a ground plate made out of stainless steel, where in the rear part a ballast is placed.

The uniqueness of the project is in the plate, where its sides are bevelled to accelerate and simplify the installation: it is sufficient to combine the individual modules to obtain the radius of curvature previously occurred.

The acoustic shell has not been built up yet, so it is impossible to determinate and to evaluate the new features through an acoustical test. To identify the perceptual differences between the presence and the absence of the structure on the stage a listening test was carried out on the auralized tracks prepared with *Odeon*.

The auralized method consists on the remodelling of the spatial impulse response of an anechoic signal. Three stimuli were chosen for the test: *choir*, *speech* and *string quartet*. The tracks were recorded in anechoic room and then virtually convolved, with a duration of 6 seconds.

For every signal, two points were tested: one was the centre of the hall and one at the back of the hall, where there are perceptual problems.

The three sound sources were located in the middle of the stage.

The A-B Comparison method invokes a two-comparison forced-choice test methodology using a 5-points response scale. The test was conducted with 26 subjects: 13 subjects in Polytechnic of Turin and 13 Professors of *Orchestra Sinfonica Nazionale of Rai* of Turin.
The results were analysed by a statistical evaluation.
The listeners preferences for the presence of the acoustic shell have been confirmed for the two positions and the three signals, except for *speech signal* in the centre of the hall. This result was expected, because in the pre-exinsting condition the acoustic is optimal for speech, in reference to Reverberation time: with the acoustic shell, an annoying echo occurs in the hall that affects speech comprehension.

For further information please contact:
Eleonora Arpellino
eleonoraarpellino@gmail.com