

Numerical simulations of Italian opera houses using geometrical and wave-based acoustics methods

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Abstract

The acoustics of opera houses represents an interesting topic in scientific literature due to their architectural and morphological characteristic traits (shape, materials, coupled volumes). A way to exploit the outstanding value of Italian theatres acoustics is to perform different typologies of music while adding or removing acoustically significant elements on the stage. Numerical simulations may be used as useful tools for designing distinct layouts and for optimising such performances. The present study investigates strengths and weaknesses of two different room acoustics modelling approaches: geometrical acoustics (GA) and wave-based methods. The commercial GA software ODEON and a hybrid ray-tracing and finite-difference time-domain (FDTD) approach are applied in this work. Measurements carried out in a sample of Italian Opera houses provide reference data for 3D virtual models calibration. Preliminary comparisons between room acoustical simulation methods are shown and discussed.

Keywords: opera house; acoustic simulation; ray-tracing; wave-based method; finite-difference time-domain.

1 INTRODUCTION

The particular features of theatres designed for classical opera cause recurrent and precise acoustic effects that have always raised a great interest in the scientific community [1, 2]. The present study describes a comparison between two distinct simulation methods used on a sample of four historical Italian opera houses to investigate advantages and disadvantages of each approach when applied to this kind of performance spaces [3]. Acoustic data obtained with a series of physical measurements campaigns were considered as reference point during the assessment of the different performances.

2 METHOD

The opera houses taken under study represent an heterogeneous sample since they vary in the main hall shape, the construction materials, the volumes and the reverberation conditions (see Fig. 1 and Tab. 1). Between 2014 and 2016 these theatres were surveyed through a massive acoustic measurement campaign carried out according ISO 3382-1 [4, 5]. Objective room criteria were extracted from the impulse responses acquired using the exponential sine sweep technique, with two sound source points on the stage and a mesh of receivers spread throughout stalls, boxes and galleries. A simplified numerical model was created for each opera house under study and was maintained for both the simulation methods adopted, on one hand a geometrical acoustics algorithm and on the other hand a hybrid wave-based and ray-tracing method.

2.1 Geometrical acoustics

The ray-based software select in this work uses a hybrid algorithm that mixes the deterministic image source method approach for the early reflections and the statistical ray-tracing for the reverberant tail. A frequency

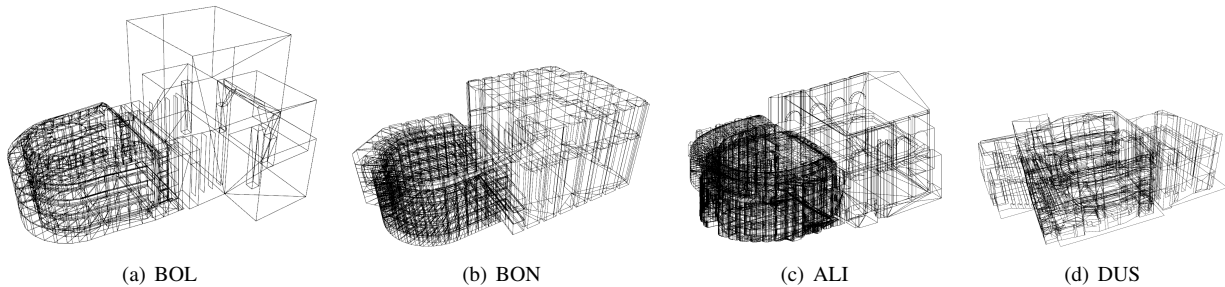


Figure 1. View of numerical 3D models employed in both the calibration processes.

Table 1. Main features of the sample of the opera houses surveyed.

	Shape	V_{hall} (m^3)	V_{flytower} (m^3)	N -	Tiers of boxes/galleries -	Prosc. Arch W x H	Year -	$T_{30,M}$ (s)
BOL	Bell	5500	19900	1000	4 boxes + 1	15 x 12	1763	1.46
BON	Horse shoe	3130	8900	798	4 boxes + 1	12 x 7.8	1846	1.70
ALI	Horse shoe	3360	5280	835	4 boxes + 1	12.5 x 11.7	1852	1.21
DUS	Modern	7400	2820	999	2 galleries + balcones	10.3 x 11.2	1940	1.32

dependent series of absorption coefficient was assigned to the layers of numerical models as well as scattering values allowed to compensate the lack of modeled details and to consider wave phenomena as diffraction effects [6, 7].

2.2 Wave-based method

The hybrid wave-based method uses a finite-difference time-domain procedure for low and medium frequencies and ray-tracing for higher frequencies. In theatres like those surveyed in this work the threshold frequency was approximately 4 kHz, depending mainly on the volume and the available compute resources. Material properties are expressed in terms of acoustic admittances assigned as boundary conditions to surfaces [8].

3 PRELIMINARY RESULTS AND DISCUSSIONS

In order to compare the results between the simulations methods two different calibration processes were carried out employing the same common geometries and achieving the match with measured room criteria (reverberation time, early decay time, sound clarity and centre time). Firstly the calibration of numerical models was developed using the geometrical acoustic software with absorption and scattering coefficients taken from previous scientific literature and then adjusted through an iterative procedure. The absorption values obtained at the end of the process were successively used as starting point for the choice of boundary conditions in the wave-based method. The final absorptive properties resulting from the two calibration approaches show the highest difference in scattering elements as the seats in the stalls and the furniture within boxes and galleries.

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