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Preliminary results of scattering surface modeling and perceptual aspects in wave-based acoustic simulations

Louena SHTREPI[1]; Brian HAMILTON[2]; Arianna ASTOLFI[1]; Marco MASOERO[1]

[1] Politecnico di Torino, Italy

[2] University of Edinburgh, UK

ABSTRACT

The level of detail of a simulated model as well as the assignment of the materials acoustic properties have been largely debated and optimal guidelines have been determined based on the approximations of the scattering algorithm of the simulation tools. These aspects are of great importance when investigating the differences between geometrical-acoustic (GA) based and wave-based methods. To this aim the present study refers to objective and subjective evaluations of wave-based simulations (finite difference time domain method) in a shoebox concert hall, which has been previously studied through GA-based methods. Three models, that consider 1) reflective, 2) low scattering, and 3) high scattering conditions of one of the long lateral walls, have been simulated in order to determine the conventional acoustic parameters such as early decay time (EDT), reverberation time (T30), clarity (C80), definition (D50). GA-based and wave-based simulation results have been compared to measured data. Furthermore, a preliminary subjective investigation has been performed in order to determine the sensitivity of listeners to the surface diffusivity variations in different listening positions.

Keywords: Sound, Simulation, Wave-based, Scattering, Level of modeling detail.

1. INTRODUCTION

The level of modeling detail (LOD) has been object of continuous research since the geometrical acoustic (GA) models have been introduced as a predictive tool (1–3). More in depth has been investigated objectively and subjectively also the diffusive surface modeling detail (4,5). The basis of this interest is mainly related to the fact that the LOD is considered a systematic uncertainty factor in GA models. Conversely, it should be considered that a high level of detail leads to an increase of the GA modeling efforts, which can be time consuming. The LOD related to diffusive surface modeling is also of interest for finite-difference time-domain (FDTD) simulations (6,7) approximating the wave equation in the context of room acoustics. However, more insight is needed regarding the LOD issues in FDTD simulations (8).

Besides the objective parameters that might be affected at some extent by the LOD, also the auralizations plausibility must be considered. It is very important to simulate in an appropriate way the temporal, spectral, and spatial aspects of an impulse response, which are strongly affected by the presence of diffusive surfaces (9).

In this study, the FDTD method (10) has been used to simulate the model of a variable-acoustics concert hall. The work consists of the simulation of two conditions of one lateral wall, which are put in a reflective and diffusive configuration. The aim of the simulations is to examine the effect of surface structures on the reflected sound through comparisons with measurements and GA-based simulations based on ISO 3382 acoustic objective parameters: early decay time (EDT), reverberation time (T30), clarity (C80), and definition (D50).

[1] louena.shtrepi@polito.it
[2] brian.hamilton@ed.ac.uk

2. METHODS

2.1 Room model

The model of a shoebox concert hall, the Espace de Projection at IRCAM in Paris (Figure 1), has been considered in these simulations. This room has been extensively studied both through measurements (11) and simulations (4) based on GA software (Odeon 13.00); thereby in this work have been introduced only the conditions of its simulation with an FDTD method.

The room has a rectangular geometry (24 m × 15.5 m × 10 m) and a variable acoustics. The geometry and the acoustical properties of the hall can be varied by controlling 172 independently rotating prismatic module panels (2.3 × 2.3 m). The variable acoustics is obtained by varying the properties of these three-dimensional structures; the prisms show different acoustic properties for each face when rotated. The particularity of the room relies also on the properties of the absorptive material which is of two typologies: absorptive at low frequencies (type A), while the other one absorbs at high frequencies (type B).

Two conditions were considered in the framework of this study. The two hall configurations, which have been considered also in (4) and (11) were chosen. The models are generated by varying the properties of only one lateral wall and maintain the same conditions of the rest of the room. The lateral wall was set at two different acoustic conditions: reflective and diffusive. The ceiling and the other walls have been fixed to an absorptive condition with absorption coefficients based on type A and type B panels' properties. The floor has been considered as a hard-reflective surface. Two separate CAD models have been created (Figure 1, a and b): the reflective condition (RF), which is modeled with flat surfaces, and the diffusive condition, which has diffusive surfaces modeled as 3D triangular structure (DM). Material properties are expressed in terms of acoustic admittances assigned as boundary conditions to surfaces (10).

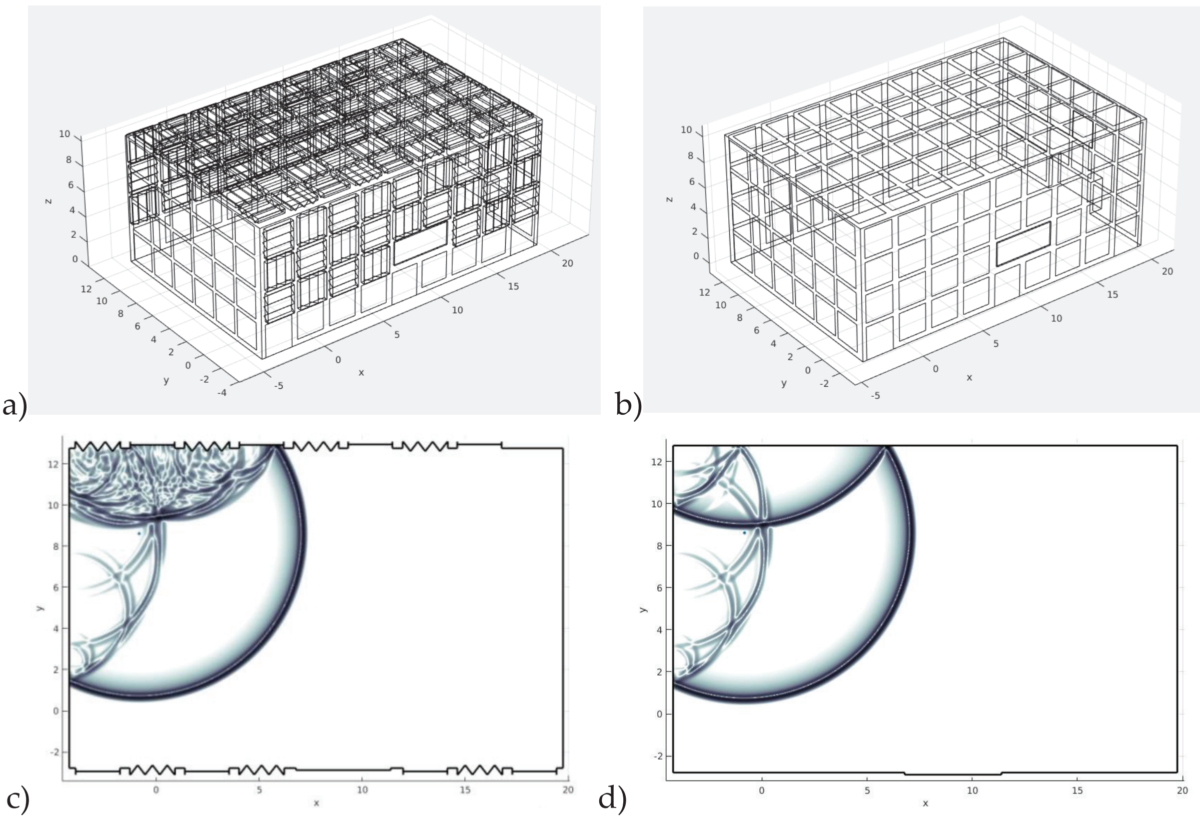

Figure 1 – Snapshots of wave propagation in FDTD model confined to *x-y* plane at with point source at 3.7m height, in calibration model (DM, left) and reflective model (RF, right). Diffraction due to variations in material at left wall is clearly visible (c and d). Scattering due to diffusive geometry can also be observed.

2.2 Numerical method

The numerical method used for the wave-based simulations is the FDTD method described in (10). The numerical grid spacing for these FDTD simulations were chosen such that approximation errors in the form of numerical phase velocity were below 2% up to 8kHz. As the FDTD method solves the wave equation directly, diffraction and scattering are inherently simulated by waves interacting with the model geometry (see, e.g., Figure 1).

2.3 Calibration

Despite a high level of fidelity to the physical acoustics afforded by the FDTD method, some calibration of the model can be expected due to input data uncertainties. Additionally, boundary conditions for the employed FDTD method are generally specified in terms of complex impedances (modelling frequency-dependent absorption), but complex impedance data were not readily available. As such, diffuse-field absorption coefficients were used as a starting point to find a complex impedance with a target absorption profile (see, e.g., (10)). The absorption coefficients calibrated from the GA simulations in (4) were used as a starting point for calibrating the FDTD method. Focusing primarily on the diffusive surfaces, absorption coefficients were calibrated according to measured T30s following general guidelines established for the calibration of GA models (4, 12). T30s obtained from simulated data were found to be within approximately one JND with respect to measurements (Figure 2). It can be observed that also the other parameters show a good match with the measured date, except for the frequency 125 Hz. In this instance, this agreement was achieved by varying absorption coefficients within +/- 0.04 Sabins/m^2 of values provided in (4).

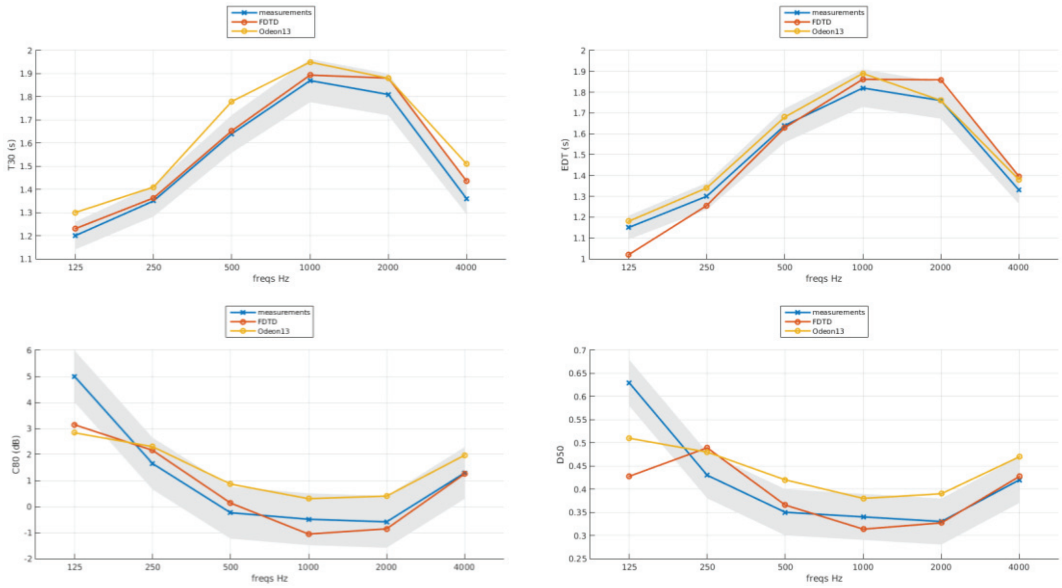

Figure 2 –Objective acoustical parameters for calibration model (DM1) obtained after initial calibration.

2.4 Simulation set-up

The simulation set-up consisted of 24 receivers and one source position. The receivers covered one half of the room and have been located at a height of around 3.70 m from the floor level. The sound source also was maintained unvaried and positioned midway between the axis of symmetry of the room and the lateral wall. The post-processing of the simulated data has been carried out using ITA-Toolbox, an open source toolbox for Matlab (13).

2.5 Room acoustic parameters

The same parameters used in GA simulations and measurements analyses based on of ISO 3382-1 (14) have been used also for the FDTD simulations. The values of four parameters, that is, reverberation time (T30), early decay time (EDT), clarity (C80), definition (D50), have been presented in octave bands as mean values over all the receiver positions in order to assess the accuracy of the calibration process. ITA-Toolbox, which comply with the ISO 3382-1:2009, has been used to analyze the impulse responses. The Just-Noticeable Differences (JNDs) has been used as criteria to judge the significance of the variations due to the change of the surface properties.

3. PRELIMINARY RESULTS AND DISCUSSIONS

The FDTD method has been used in this study to investigate the differences between the reflective (RF) and diffusive (DM) condition of a lateral wall in a shoebox concert hall. First a calibration process has been shown and the objective acoustic parameters based on ISO3382 have been estimated and compared to measured and GA-based simulations results. Acoustic properties assigned within the FDTD method were adjusted with respect to the GA simulations in order to calibrate to measurements. The objective evaluation of T30, EDT, C80, and D50 in each model (RF and DM) showed a good match with the measured data. The calibrated simulation results will serve as the basis of listening tests to evaluate perceptual accuracy. A perceptual evaluation will be carried out through listening tests in order to determine the difference between the reflective and diffusive condition. All the objective and subjective results will be compared to the in-field measurement and Odeon (v13.00) simulation results, that have been introduced in (4, 11).

The findings of this study aim at giving more insight on the fidelity of FDTD simulations of concert halls and large spaces, and at establishing guidelines for calibration processes in the presence of uncertain input data.

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