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Extended abstract

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Crossover frequency between geometric acoustics and wave-based simulations: perceptual study

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ABSTRACT

Acoustic simulation and auralization are important tools for predicting the acoustic environment before construction. Today we use two main approaches for simulating room acoustics, namely geometrical acoustics (GA) and wave-based methods (WBM). The often-favored GA methods show inaccuracy in small spaces at low frequencies where the wave-phenomena play a larger role. Solving the wave-equations using numerical WBM can provide more accurate results, but due to expensive computations it is often deselected. In an attempt to combine GA and WBM, we investigated the perceptual crossover frequency that has little to no audible difference between the two auralizations. We used ODEON for a GA method, and discontinuous Galerkin finite element method for WBM. A listening test was performed on 9 subjects whose task was to evaluate octave-band filtered speech and music stimuli in two rooms via a 3-alternative forced choice test: a small rectangular room and an L-shaped room. The results reveal that the monaural auralizations from the two simulation schemes are perceived differently although the reverberation time and clarity indices are within the just noticeable differences.

Keywords: dG-FEM, Wave-based method, ODEON, Geometrical Acoustics, 3AFC, Listening test

1. INTRODUCTION

Room acoustic modeling has proven valuable in architectural acoustics for building design, perception evaluations and virtual acoustics. Acoustic modelling provides information about the acoustic conditions and can enable the possibility to listen to the acoustics under design, which is called auralization.

Currently, geometrical acoustics, GA, has been accepted as primary method for auralization [1] and is popular for providing fast calculation and reasonable accuracy above the Schroeder frequency as well as plausible sound [2], meaning that it can create soundscapes with attributes close to an actual representation of the acoustics in the space. Wave-based solvers are known as being more accurate in including the underlying physics [1] and today's advances in computational power and element-based simulations of room acoustics enables the auralization of sound fields up to a sufficient frequency range.

In this paper, we compare the auralized sound fields using two methods, one being ODEON [3] representing GA and the other dG-FEM (discontinuous Galerkin finite element method) [4] representing the wave-based solvers, WBS. The comparison is performed through subjective perception of each 1/1 octave band to propose the lowest frequency limit that perceptually provides no audible difference between both methods. The aim is to create reliable results and auralizations when combining the two methods in a hybrid where dG-FEM is calculating the low frequencies providing accurate results and keeping the computational time low, and then ODEON is taking over the frequencies where an acceptable accuracy is achieved and auralizations become similar for the two simulations. Note that comparing

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other variants of GA and WBS may produce different results and the following should not be generalized for the simulation method category.

1.1 Room parameters

Auralizations can be impacted to becoming perceptually different due to various factors, two of which are room volume and diffraction which will be the focus in this study. Therefore, a rectangular room and an L-shaped room with homogeneous absorption at the boundary without any scattering objects have been modelled. A third room was initially simulated but is not included in the following paragraphs.

The rectangular room has dimensions 3m x 4m x 2,7m, V = 32 m^3, and is expected to be challenging for the GA simulation due to strong room modes below the Schroeder frequency, 173 Hz.

The L-shaped room investigates diffraction due to the corner, which is known to be problematic for GA simulation methods [2]. The receiver is placed in the shadow zone compared to the source.

The source and receiver positions as well as Schroeder frequency for each room can be found in the table below.

Table 1 – Source and receiver positions and Schroeder frequencies

Room	Volume	Source (x, y, z)	Receiver (x, y, z)	Schroeder freq.
Rectangular	32 m^3	(3.0 m, 2.0 m, 1.5 m)	(1.0 m, 1.0 m, 1.7 m)	173 Hz
L-shape	105 m^3	(1.0 m, 1.5 m, 1.5 m)	(6.5 m, 7.0 m, 1.7 m)	107 Hz

1.2 Audio samples

For the test two samples have been chosen. One is a music signal to challenge ODEON in the low frequencies below the Schroeder frequency, and the other is a female speech signal with meaningless speech both played at 60 dB.

Spectra of the Music and Speech before convolution is shown in Figure 1 below.

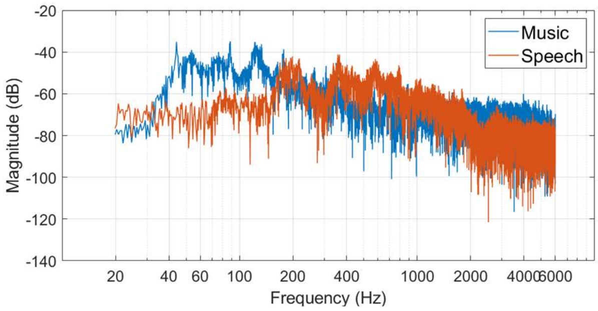

Figure 1 – Frequency response for music (blue) and speech (red) sample.

1.3 Listening experiment

Nine participants (3 females and 6 males) spanning from age 22 to 55 years performed the listening test. Eight of them were native Danish speaking and one had English as their mother tongue. All subjects were self-evaluated as normal hearing. The participants were presented with a sequence of 3 stimuli and were asked to choose the one they found perceptually different compared to the two others. The test follows the 3 alternative forced choice (3AFC) paradygm, in which two stimuli were dG-FEM and one was Odeon. The entire experiment consists of 6 runs; each of the two samples played in two room conditions respectively, in a random order. For each run the test participant was presented to 60 trials: 10 repetitions per 1/1 octave band with center frequencies at 63, 125, 250, 500, 1000 and 2000 Hz. The 10 repetitions are considered tolerable for the test subjects to maintain concentration, while the data is still sufficient to provide statistically valid material.

The test was conducted in a soundproof booth with Sennheiser HD 650 headphones that provides a flat frequency response.

Through the binomial theorem the test subject will need at least 7 out of the 10 repetitions correct to conclude a detection of perceptual difference with a confidence level of at least 95 %.

2. RESULTS AND DISCUSSION

Figure 2 below shows the reverberation time as one of the objective parameters. The T20 curves indicate inaccuracy in the low frequencies using ODEON; first and second octave band for the rectangular room and first octave band for the L-shaped as shown in figure 2 below. This aligns with the L-shaped room having a lower Schroeder frequency and therefore GA is performing well in lower frequencies compared to the rectangular room. This is also visible in the frequency responses in figure 1 (b) where the curves start overlapping more in the frequency spectrum above 150 Hz.

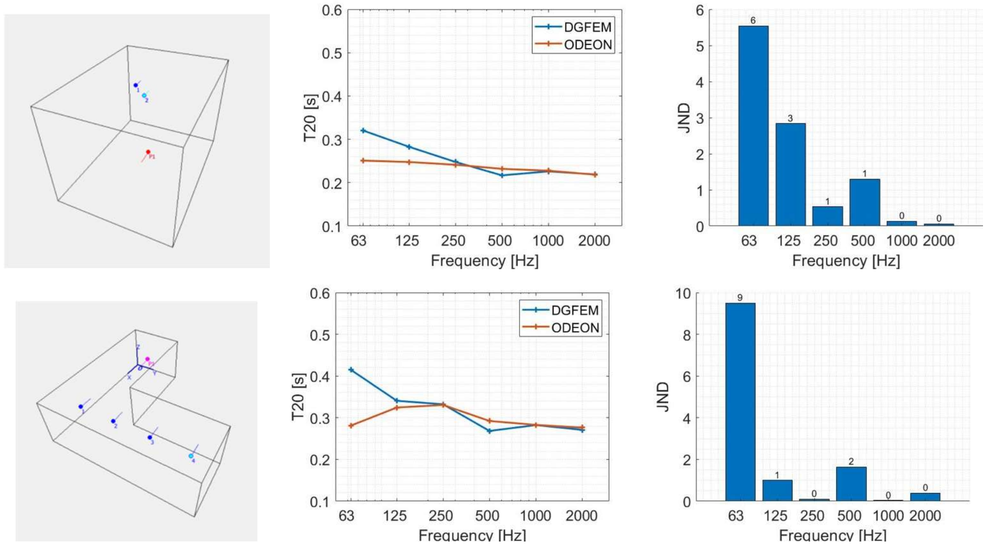

Figure 2 – Reverberation times using dG-FEM (blue) and ODEON (red) and the JND of the methods.

The subjective results from the listening experiment are shown in the boxplot diagrams below. Looking at the orange results in figure 3 representing the speech the listening experiment aligns with the expectations that the two auralization methods are perceived similar at high frequencies. Only at 63 Hz and 125 Hz the differences are considered detectable. ODEON is performing worse in the auralizations from the L-shaped room in low frequencies, which is assumed to be due to difficulties of including diffraction of the corner. Some subjects hear a difference even at high frequencies, particularly at 2 kHz even with a very similar T20 value.

Figure 3 below implies that the discrimination is affected highly by the sample and energy level in the low frequencies. For the music signal the results do not imply little to no audible difference in any frequency bands in either room condition.

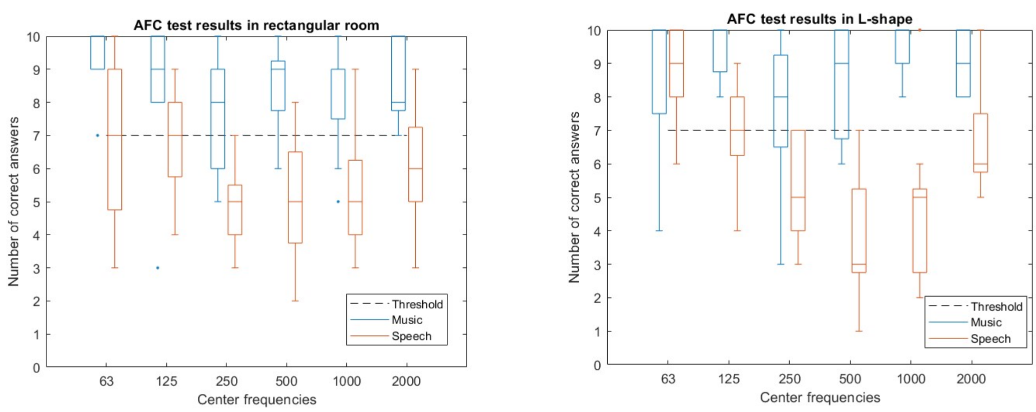

Figure 3 – Results from the AFC test. The results from the music sample are shown in blue, the speech results are shown in orange and the black dashed line shows the threshold of perceptual discrimination.

Combining the objective parameters with the subjective data from the test a cross-over frequency in both rooms for the speech signal could be suggested between octave band 125 Hz and 250 Hz, where it “could” be closer to 125 Hz for the L-shaped room and around 250 Hz for the rectangular room. The cross-over difference is amongst other due to the objective parameters T20 and Schroeder frequency, which is lower in the L-shaped room.

The subjective results are not showing a clear trend when using the music sample. The data showed mixed results which makes it hard to conclude or suggest the cross-over frequency.

3. CONCLUSION

The study shows that auralizations made with the different methods produce perceptual differences in all frequency bands, especially for music. For speech the detection of perceptual difference gets difficult above 250 Hz. A hybrid can therefore be functional for acoustic analysis purposes but should be considered carefully for auralization purposes.

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