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The Control of Early Decay Time on Auralization Results based on Geometric Acoustic Modelling

Aglaia Foteinou and Damian T. Murphy
Audio Lab, Department of Electronics, University of York, Heslington YP10 5DD, UK, af539@ohm.york.ac.uk

In the modelling and simulation of acoustic spaces, previous work has focused mostly on optimising the values of reverberation times as the primary acoustic design parameter. According to ISO 3382, Early Decay Time (EDT) is an acoustic parameter which is more relative to perceived reverberance and is actually affected by the very early reflections. In this way EDT becomes an additional and useful method for characterising and optimising a room acoustics simulation. The goal of this project is to investigate the physical changes that affect this acoustic parameter most directly. For this purpose, a model of a 3D shoebox-shape room is used in which the user can control a range of physical acoustic properties relating to the simulation. The influence of the distance between the source-receiver, their distance from the boundaries and the orientation of the source are investigated. For the computer simulation, ODEON 10.1 Auditorium was used which is based on the principle of geometric acoustic techniques. The results are verified through listening tests as well by objective comparison in terms of the resulting effect of each variation.

1 Introduction

Acoustic simulation techniques aim to achieve accurate and reliable auralization results through optimisation and matching of acoustic parameters to real-world measurements (where obtainable). Reverberation Time (RT) is the primary measure used to characterise the acoustics of a space although it is well known that it is not sufficient to present a complete profile of its properties, particular in terms of perception of the resulting auralization. Acoustic designers look more specifically at Early Decay Time (EDT) and Clarity values in order to give more information related to impulse response energy in relation to time. The aim of this paper is to study the behaviour of EDT in a virtual space based on geometric acoustic modelling subject to changing source/receiver positions.

According to the ISO 3382 [1], EDT is evaluated from a linear regression of the first 10dB of decay of the backwards-integrated squared impulse response curve. Hence strong early reflections will have a greater influence on this parameter over e.g. T20 or T30, as less of the reverberant tail is used to arrive at the final quantity. EDT is also referred as an acoustic parameter which is more directly related to perceived reverberance than the RT. Hence, it is considered that RT is a global parameter which is relative to the overall physical properties of the space while EDT is a parameter dependent on receiver position [2]. This leads to the conclusion that when considering this parameter, results should not be based on average values of many receiver points in the space.

The goal of this study is to examine variations in EDT by changing the strength of the very early reflections in a standard space and examine the influence of the distance between the source/receiver, their distance from the boundaries and the orientation for the source on the results obtained. For this purpose, an experimental 3D shoebox-shape room is created where a range of physical acoustic properties can be directly controlled by the user. The model has been created by using commercial acoustic simulation software, ODEON 10.1 Auditorium which combines the geometric acoustic techniques of image source and ray tracing.

2 Physical characteristics of the examined virtual model

2.1 Dimensions and absorption coefficients

Based on a previous study [3], the dimensions for the shoebox-shaped test model are based on those of existing large reverberation chambers. Thus, the dimensions of 10m x 8m x 5m are considered suitable for a sufficient number of reflections for reasonable calculations of the acoustic parameters.

In order to keep the basic model relatively simple it was decided to define the same acoustic characteristics for all the boundaries. Taking into account the typical range of the defined Just Noticeable Difference (JND) in ISO 3382 [1], the reverberation time of the space was defined to be between 1 and 3 sec by applying absorption coefficient of 0.1 for all the frequencies bands.

2.2 Calculation method in ODEON and scattering coefficients

For the investigation of the physical factors, such as source/receiver position, that might influence EDT, it was necessary to create a stable model, independent of the calculation method software used. ODEON uses a hybrid method to calculate the acoustic parameters of a room, combining image source and ray tracing methods for the early reflections and ray tracing only for the late reflections. The shift from one calculation method to the other is defined by the Transition Order (T.O.). In previous work [3], it was concluded that with low values of T.O., early reflections were not simulated or they were not strong enough. It was also observed that higher values of T.O. did not result in a significant change in T30. Hence for this study it was considered better to use a T.O. of 5 to give more accurate simulation of early reflections. This means that the image source method is used for the calculation of early reflections up to 5th reflection order and above this a ray tracing method is used. The number of rays was defined to be 1,000 based on the software recommendation and the impulse response length to 2,000 ms, sufficient for calculation of the overall reverberation time.

The most common way to simulate the scattering effect of a reflecting sound in geometric computer modelling is based on the Lambert's Law. Based on this law, the applied scattering coefficient takes a percentage of the energy of the specular reflections and scatters it in random directions [4]. Thus, for the purposes of this experiment, in order to avoid this random behaviour only the specular reflections based on the Snell's Law were used. For this reason, a scattering coefficient of 0.00 was applied across all frequency bands for all of the boundaries.

3 EDT in relation to source/receiver positioning

3.1 Source at the centre of the space

In order to examine the influence of the distance between the source and the receiver position, a grid area of receiver positions is used, at a distance of 1m from each other and at the same height as the source (1.5m). An omnidirectional source was placed in the centre of the space and 80 receiver positions were defined each pointing towards the source (Figure 1).

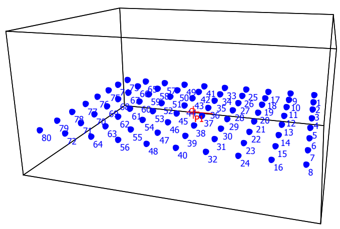

Figure 1: Figure of the grid with the receivers as points

By using colour-mapping across the grid of receiver positions the variations of EDT values are presented, as obtained directly from ODEON. The colour scale on the right side of each plot shows the range of the EDT values in seconds for each frequency band. The colours are mapped across 0.01s variations in EDT for easier comparison of the changes in terms of JND. The parameter was examined across 8 frequency bands from 63Hz to 8000Hz. Although, for this paper only the colour-maps of 500Hz and 1000Hz are presented (Figure 2).

Based on [5], the critical distance was estimated at 0.866m, within which it can be assumed that the acoustic parameters calculated cannot be relied upon. This explains the white areas in a range of 1m from the source position in which EDT is too short.

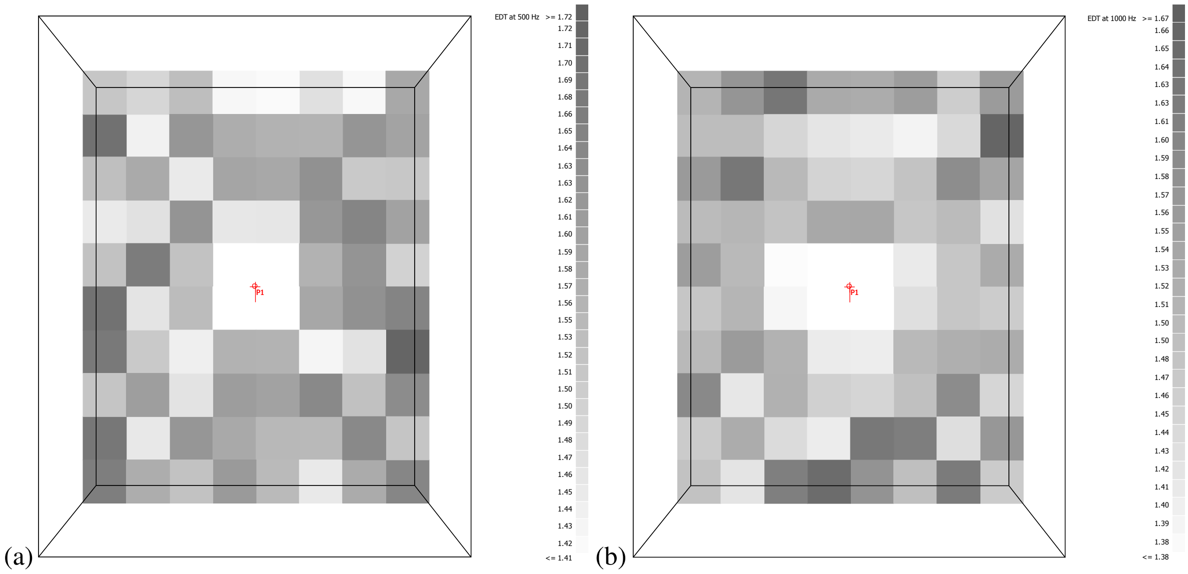

Figure 2: Colour-maps at (a) 500Hz and (b) 1000Hz, measuring EDT across the 80 receiver positions of the grid with the omnidirectional source placed at the centre of the space

3.2 Source closer to one boundary

In the second studied case, the omnidirectional source is placed at a distance of 2m from the upper boundary shown as the Figure 3. The colour-maps of 500Hz and 1000Hz are presented.

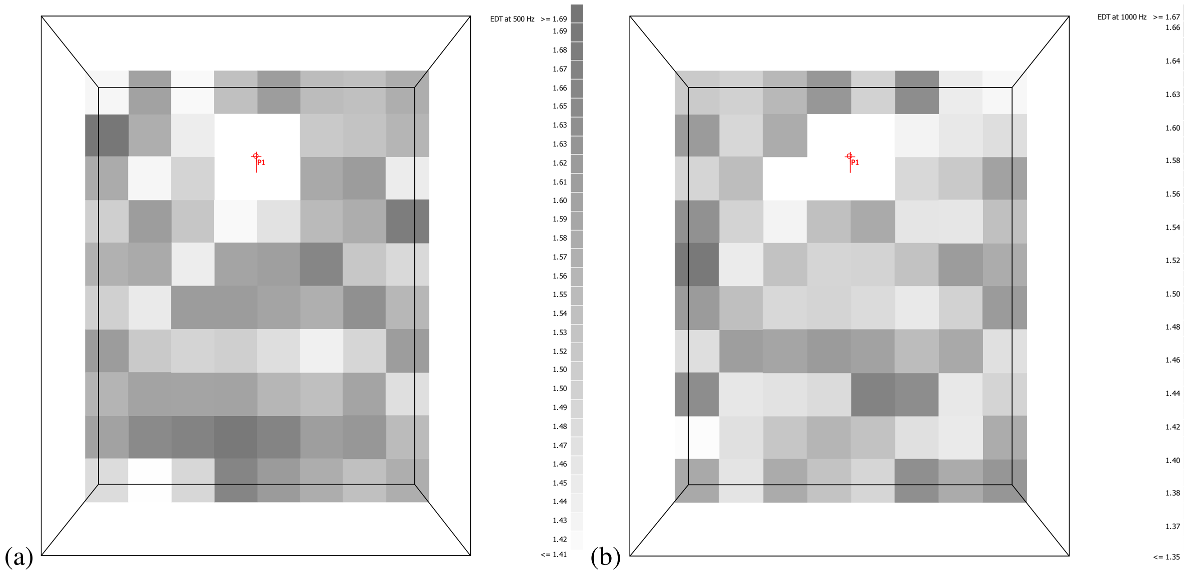

Figure 3: Colour-maps at (a) 500Hz and (b) 1000Hz, measuring EDT across the 80 receiver positions of the grid with the omnidirectional source placed at a distance of 2m from the upper boundary

4 EDT in relation to source orientation

As an omnidirectional source is not going to have any influence on the results if it is rotated on its axis, in order to study the influence of source orientation on EDT, a frequency independent half-omnidirectional (hemispherical) source was placed at the centre of the space. Results were obtained and compared for four cases with the source oriented to 0° (towards the lower boundary in the plots which follow), 30°, 60°, 90° (rotated anticlockwise from 0° position). Figure 4 shows the colour-maps at 1000Hz for the source rotated at 0° and 60° on its axis. The critical distance is estimated now as 1.23m from the source.

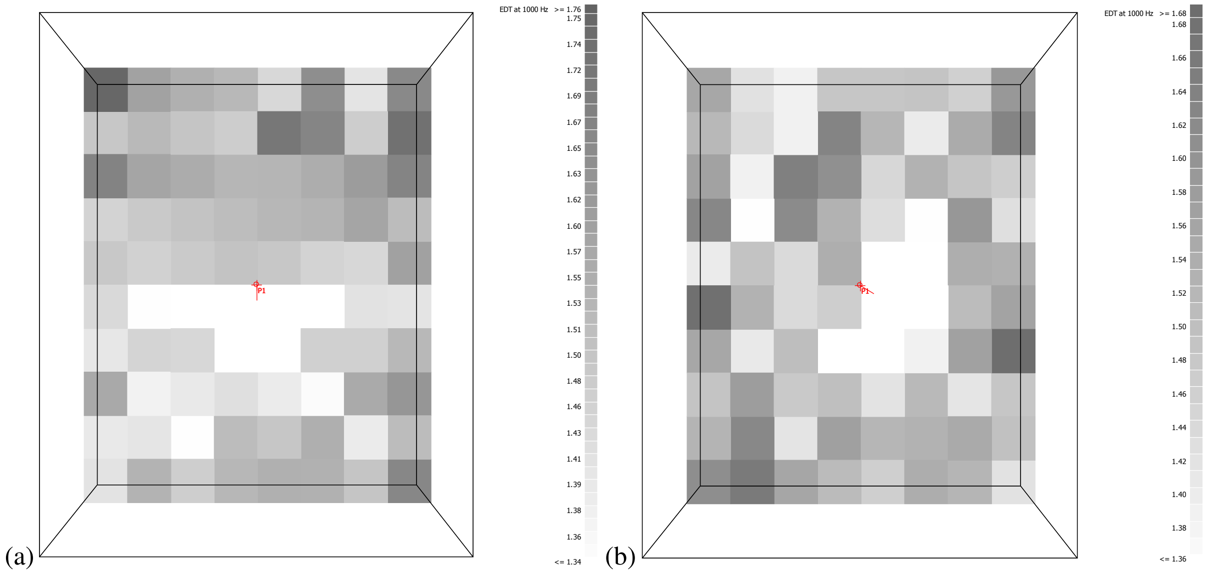

Figure 4: Colour-maps for 1000Hz, measuring EDT across the 80 receiver positions with the half-omnidirectional source rotated on its axis at (a) 0° (towards lower boundary) and (b) 60° (rotated anticlockwise from 0° position)

5 Discussion

By observing the colour-map of EDT values across the 80 receiver positions, no symmetry was observed. Thus, it was difficult to draw conclusions from the test cases described above designed to investigate the influence of relative source/receiver positioning and source orientation on EDT especially for low and mid-frequencies.

However, symmetric behaviour was observed at higher frequency bands (4000Hz and 8000Hz). Shorter values of EDT were observed closer to the source (Figure 5) (and for those receivers that directly face the half-omnidirectional source (Figure 6)), which implies that early reflections have a stronger influence on EDT at these receivers. Moving further away from the source EDT increases with the largest values observed approximately 1m from the corners (and for those receivers facing the rear of the half-omnidirectional source).

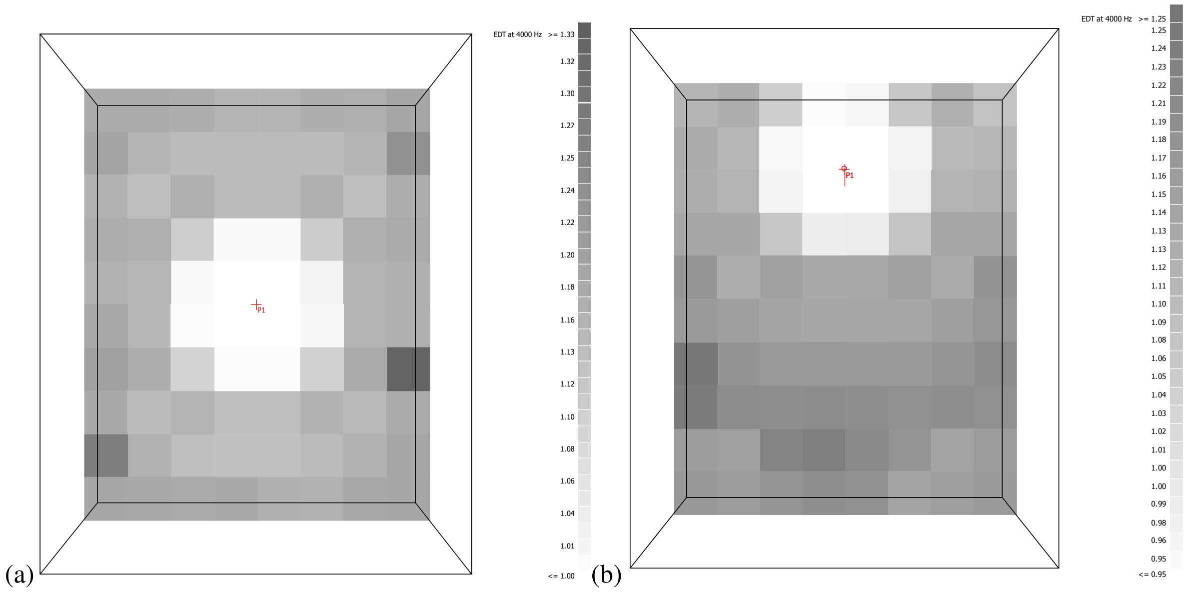

Figure 5: Colour-maps for 4000Hz, measuring EDT across the 80 receiver positions for the omnidirectional source placed (a) at the centre of the space and (b) at a distance of 2m from the upper boundary

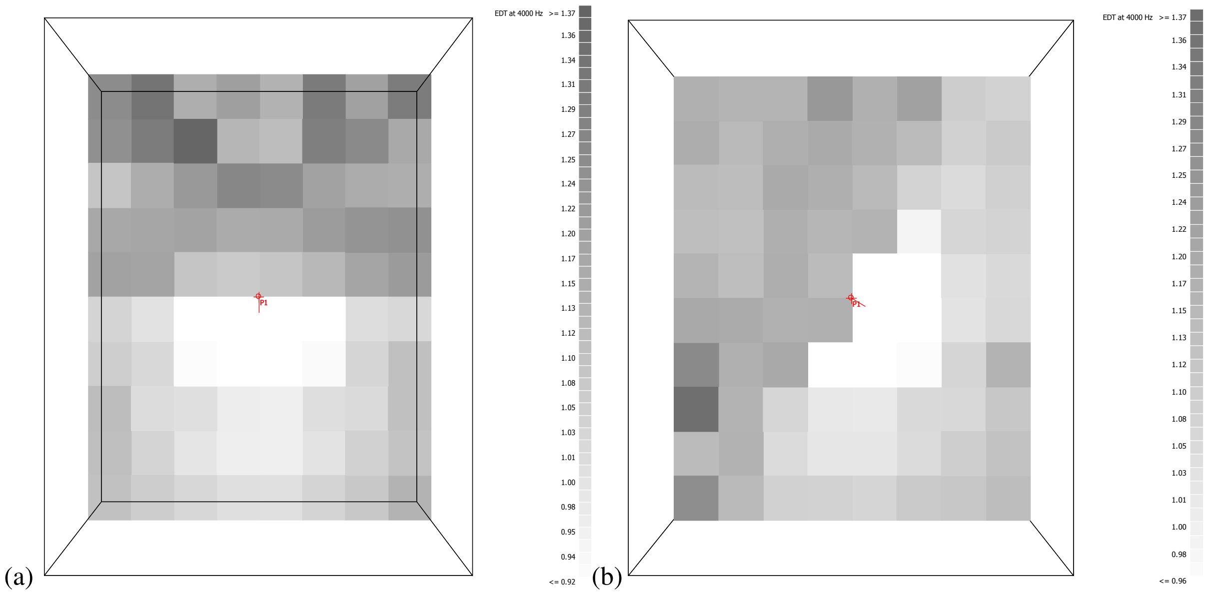

Figure 6: Colour-maps for 4000Hz, measuring EDT across the 80 receiver positions for the half-omnidirectional source rotated on its axis at (a) 0° (towards the lower boundary) and (b) 60° (rotated anticlockwise from 0° position)

6 Auralization results

Based on the results obtained above, auralizations were prepared for a series of related listening tests. As EDT does not relate directly to spatial impression, it was considered that multi-channel reproduction might have an impact on the perception of these results as presented. Hence, anechoic material was convolved with only the W-channel of the B-format impulse responses obtained and the resulting mono files played to subjects through closed headphones. The stimulus used was 40s of female singing, the long-term averaged spectra of which is represented at the Figure 6. Note that the audio examples are normalized relative to the direct sound such that it is perceived to be of equal level in each case. Hence, the participants focused only on the reverberant response of the space negating the possible impact of loudness on their perception.

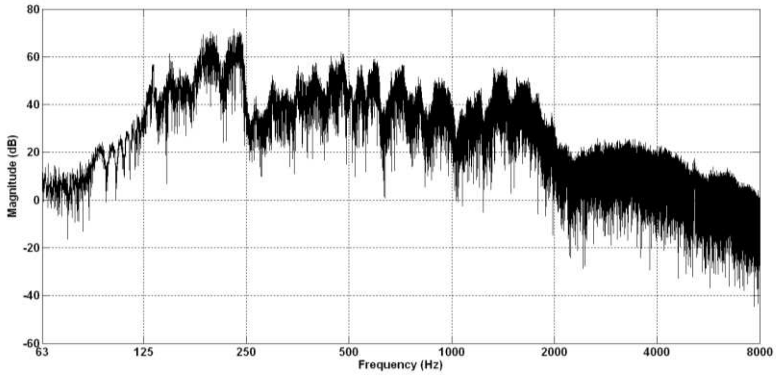

Figure 6: Log-term average frequency domain plot of the anechoic recording used for the auralizations in the range of 63-8000Hz

As discussed above, it was difficult to make conclusions from the EDT values observed when changing source/receiver distances or source orientation. Therefore in order to test a possible relationship between these factors and EDT, the auralized examples used for the listening tests were chosen based on the symmetry of the space.

For the case of the omnidirectional source placed at the centre of the space, three receiver positions were chosen. One near the source (A) (Figure 7(a)) (but still outside the critical distance), one further away from the source (B), and a third closer to two of the boundaries (C). Additionally their symmetric counterparts were selected (A', B', C'). For the case of the omnidirectional source placed closer to the boundaries, receiver positions were chosen respectively (Figure7(b)). For the case of the half-omnidirectional source, two receiver positions were used. The first (A) (Figure7(c)) was in the receiver area of facing the direction of the source and the second (B) was on the opposite side facing the rear of the half-omnidirectional source. The near field was taken into account for all cases of and is marked in Figure 7.

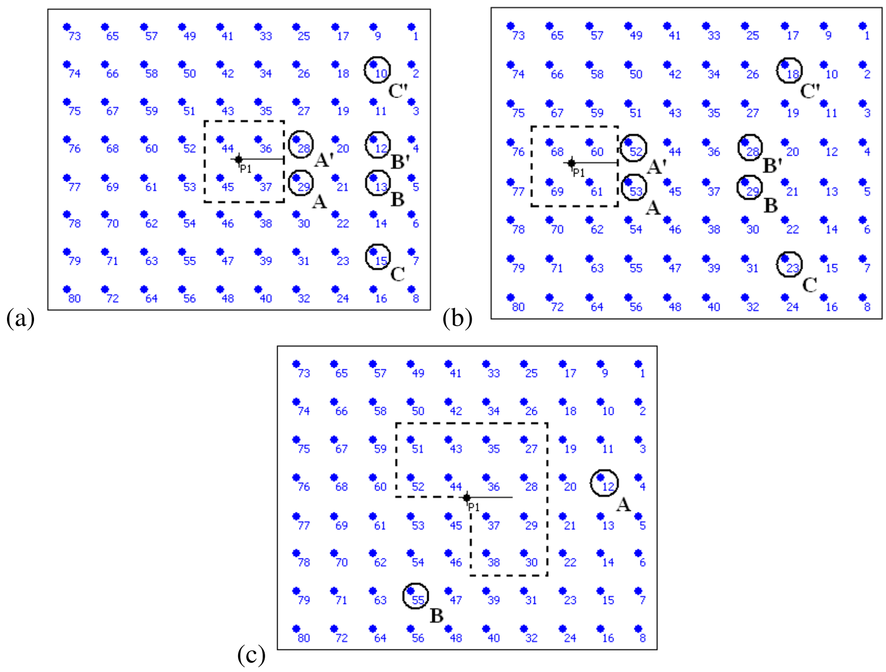

Figure 7: Selected receiver positions for auralization; (a) for the omnidirectional source placed at the centre; (b) for the omnidirectional source at a distance of 2m from the left boundary and (c) for the half-omnidirectional source. The near field areas are marked with dotted lines in all cases and for (c) the summary of the near fields for the four rotated sources at 0°, 30°, 60° and 90° (rotated anticlockwise from 0° position) was taken into account

Figure 8 displays EDT values for all frequency bands for the six auralization receiver positions (A, B, C, A', B', C') for the case shown in Figure 7(b). Note the irregular behaviour of EDT across the frequency bands and the asymmetric behaviour for the corresponding receiver pairs.

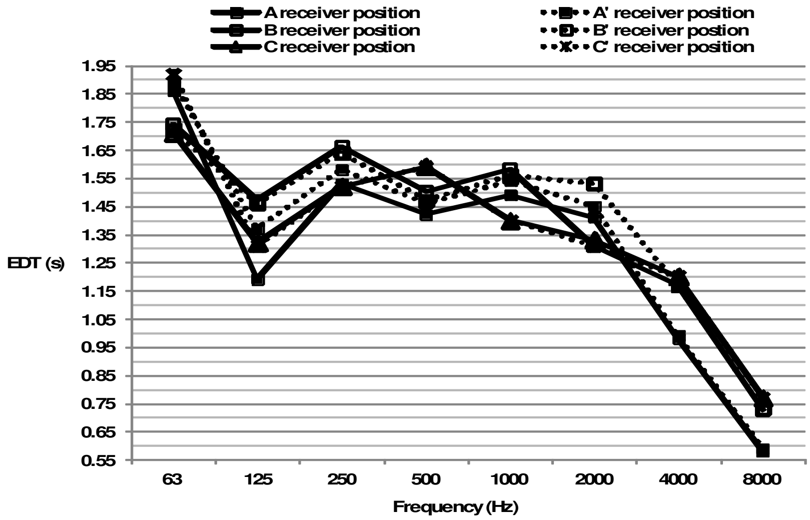

Figure 8: EDT values across all the frequency bands and selected auralization receiver positions for the omnidirectional source placed at a distance of 2m from the upper boundary as shown in Figure 7

Seven participants in the listening test were asked to express their perceived differentiation between pairs of presented sounds. The comparison was made between A-B, A-C, A'-B', A'-C' receiver positions for the first two cases of the omnidirectional source and A(0°)-A(30°), A(0°)-A(60°), A(0°)-A(90°), B(0°)-B(30°), B(0°)-B(60°), and B(0°)-B(90°), for the rotated half-omnidirectional source, which gives 14 examined pairs in total. They were marked using in 5-point scale, with 1 for very similar pairs and 5 for very different ones. Also they were asked to clarify which of each pair they perceived as being most reverberant.

After an explanation of what was required of them the subjects heard two additional pairs as a training session to allow them to be familiar with the testing process as well as the rating scales [6]. These training examples include the most and the least expected differentiation in terms of perception of reverberation time and the subjects were allowed to hear them as many times as they needed it to be confident with their decision. During each examined example the subjects were able to play backwards and forwards within each individual case in order to be able to make comparison between different extracts.

In the analysis of the subjective results, the difference in EDT between each pair was taken into account. If the difference was more that the JND a response was only considered correct if it was marked as greater than 3 on the scale. Additionally, the participants should have correctly identified the most reverberant of the two examples. Both of these conditions must be satisfied in order to consider the answer correct. For example, if someone had marked the perceived difference between a given pair as 4, but had incorrectly identified the most reverberant example of the two, the response was considered as being not reliable.

No firm conclusions could be made when examining results relating to a change in source/receiver positions. There were cases where participants could not hear a difference, despite respective stimuli having EDT values with a difference greater that the JND. It is noted that this could be a disadvantage of the source material used in the test and giving the participants flexibility in selecting different extracts within each example.

In the examples concerning changes in source orientation, participants could discriminate most clearly for the receiver position (A) (Figure 7(c)) and this corresponds to EDT values that differ by more than the JND across all frequency bands. Note that for receiver position (B) EDT values are less than the JND and yet most participants were able to determine a clear difference between the examples presented to them in terms of which was the most reverberant. This needs to be investigated further by considering changes in other related acoustic parameters that could possibly confirm this perceptual impression.

7 Conclusions and further work

This work is a primary step in a series of experiments relating to the variation and influence of EDT when considering auralizations based on geometric acoustic modelling. The idea is to study the physical factors and acoustic properties in a controlled computer model which could have an impact on the results of this specific acoustic parameter. In this paper, a very simple geometric shoebox shape model was used to examine the influence of the source/receiver position and orientation of a directional source. The model was created in ODEON 10.1 Auditorium and the acoustic parameter results were also obtained through the software. A non-symmetric behaviour of the EDT values was observed across the space especially for low and middle frequencies which did not give confidence in the conclusions reached about the behaviour of EDT for these studied cases. This concern was confirmed through listening tests in which the participants were not able to hear the expected differentiation of EDT based on a moving source/receiver position or on a different orientation of the source.

This study will continue by investigated the influence of the number of rays used for this specific model and the scattering/absorption coefficient from one or all of the boundaries. Also, it is significantly important to study if the shape and the size of this specific model is a problematic case for the nature of the used algorithm. Additionally, different software methods will be used to generalize these results. From the outcome of the results of the 2nd Round Robin on Room Acoustical Computer Simulation [7] it was also stated that "the evaluation according to the rules fixed in ISO may leave arbitrariness in its application for the case of EDT – determination of the 'initial 10dB' may also be dependent on the filter applied and its steepness".

Finally, it is considered very important to use different stimuli (music, speech or noise) for the listening tests as this might have an impact on the perceived auralization results.

References

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