Multi-positional acoustic measurements for auralization of St Margaret's Church, York, UK

Aglaia Foteinou
Department of Music and Music Technology, University of Wolverhampton, Walsall, United Kingdom.

Damian T. Murphy
Department of Electronics, University of York, York, United Kingdom.

Summary
A common approach for studying the acoustic behaviour of a space is to measure the impulse responses across different receiver positions, and report the average values of the acoustic parameters obtained. Since the variations of the reverberation time values across the different measured positions are minimal, this approach is considered suitable for describing the acoustics of the space and for acoustic design purposes. For auralization purposes, however, the average values cannot represent the listeners auditory experience at a specific position in the space as significant differences are observed for EDT and Clarity parameters across the measured positions. For this study, impulse response measurements based on the Exponential-Swept Sine Method have been made in the historic site of St Margaret's Church, York, UK. The church has been acoustically modified to create a multi-functional space acoustically suitable for a variety of events, from conferences to classical and early music recitals. For an appropriate coverage of the space, 26 receiver positions were used and variations in the orientation of the sound source were additionally applied for the in-situ acoustic measurements. The auralization results have been analysed in objective terms by studying the values of the acoustic parameters T30, EDT and C80. This paper highlights the importance of studying the frequency-dependent acoustic behaviour at each individual position in order to obtain reliable auralization results, rather than using spatial averaging. A novel way to represent the data across different measured positions, using acoustic floor maps, is also introduced. This provides information on the variations across both frequency bands and position.

PACS no. 43.55.Nn

1. Introduction

The acoustic behaviour of a space can be studied in objective terms by calculating the room acoustic parameters. Historically, reverberation time was the primary measure used for this purpose. As a global parameter, reverberation time does not change significantly with spatial variation within the space, thus averaging values across different receiver positions was considered a reliable method. With the introduction of additional acoustic parameters, the same procedure was followed with the values of the acoustic parameters obtained across different positions averaged, and an overall conclusion drawn for the acoustic behaviour of the space [1, 2, 3, 4, 5, 6].
This traditional computational method, however, can lead to incorrect conclusions, especially for position-dependent parameters. The fact that significant differences between individual results can be masked by only taking into consideration the average emerged from the series of Round Robin surveys that were conducted into room acoustics measurement and simulation [7, 8]. These results considered combinations of individual source and receiver positions, from both computer based, and measured impulse responses. It was highlighted that significant difference between the individual results was masked by the averaging over all results. Hence position-dependent results need to be considered when individual impulse responses are used for auralization purposes.
For this study, multi-positional measurements were taken in a heritage site. Variations in the orientation of the sound source were additionally applied in order to investigate any related changes in acoustical parameters T30, EDT and C80. The site under study is the medieval St Margarets Church, located in York, UK. The church, currently known as The National Centre for Early Music, has been redeveloped and is used as both a concert and conference venue.

Figure 1. Acoustic panels mounted on the north wall are closed and folded in half (on the right).

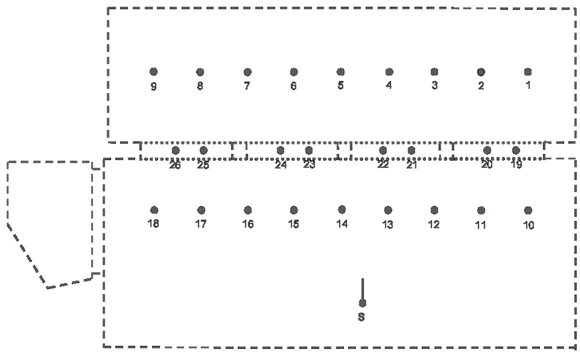

Figure 2. Source (S) and 26 measured positions marked on the floor plan of the church.

As part of the redevelopment acoustic treatment has been added - reversible acoustic panels and drapes arranged throughout the space can easily change the acoustic characteristics of the venue. For this current case study the acoustic configuration defined as appropriate for musical/operatic performance was used. For this configuration, the drapes were set on the ceiling and 75% of the panels were in use (open). The remaining closed panels were those mounted on the north wall, as demonstrated in Figure 1.

2. Impulse response measurements

A logarithmic sine sweep based on the Exponential-Swept Sine (ESS) method, with a frequency range of 22Hz to 22kHz, was used as the excitation signal [9]. The sweep lasted 15 seconds and was generated using the Aurora Plug-in for Adobe Audition.

2.1. Sound source and microphone

The sound source (S) was placed half-way along the length of the south wall, facing towards the north wall, as this is the typical position of a performer during his/her performance, as shown in Figure 2. A Genelec S30D was used as the source transducer, in contrast with ISO3382 [10] recommendations for an omnidirectional source, due to its flat frequency response and relative uniform directional characteristic. The measured impulse responses will ultimately be used for auralization purposes, and convolved with typically directional anechoic sources, such as voice or musical instrument. Thus, any bias from effects caused by omnidirectional excitation should be avoided. For the microphone positions, 26 receiver positions in a grid were measured. A Soundfield SPS422B was used as the receiver microphone. This was orientated towards the south wall of the church for each measured position.

2.2. Sound source orientation

As a non-omnidirectional source was used for this study, changes in the orientation of the sound source were applied to test for the effects of source directionality as investigated in a previous study based on an acoustic simulation of a shoebox room [11, 12] was carried out in an acoustic simulation shoebox shape model. A 3D version of the Genelec S30D directionality characteristic was created based on a 2D polar plot [13] (as shown in Figure 3). This virtual source was rotated from 0° to 10°, 40° and 70°, and changes in T30 and C80 were measured and noted, as shown in Figure 4. T30 values changed slightly across the six octave bands, while more significant changes were observed in C80 in middle and high octave bands. Based on these results, during the acoustic measurements made as part of this study, impulse responses were captured by rotating the Genelec on its axis to 40° and 70° right with respect to its original orientation.

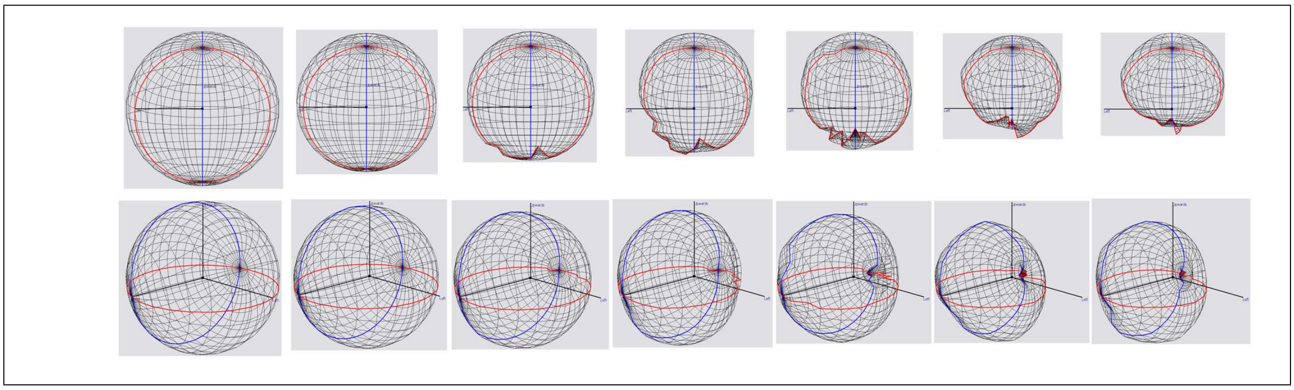

Figure 3. 3D directivity plots of the virtual Genelec S30D (azimuth top and elevation bottom), across the octave bands 125Hz, 250Hz, 500Hz, 1kHz, 2kHz, 4kHz and 8kHz.

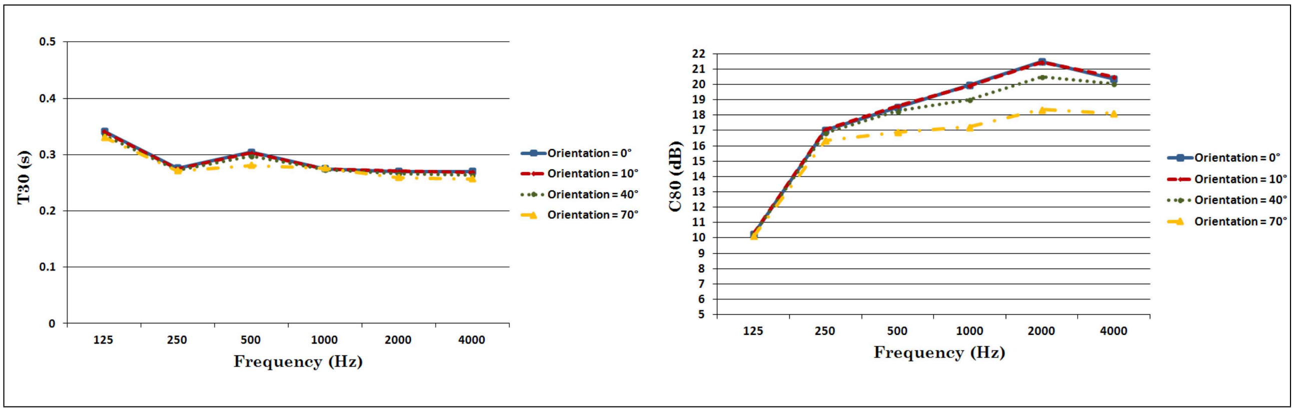

Figure 4. Comparing T30 and C80 values observed from a single receiver point in a virtual shoebox model by varying the orientation of the virtual Genelec S30D sound source (0° to 10°, 40° and 70°).

3. Results

3.1. Acoustic Floor Maps

In order to investigate further the main hypothesis of this paper, that is, considering the importance of observing variations in acoustic behaviour for each individual measured position across frequency, a method of presenting this data across spatially distinct positions is required. In previous work colour-maps are often used to discriminate between values and/or positions e.g.[CATT-Acoustic or ODEON]. Stenner [14] introduced a method to represent multivariate data across many measured positions in a space by using 3D images with different shapes and colours.

However, the frequency dependence of each acoustic parameter was not taken into account by Stenners methods. Therefore, in order to counteract the perceived shortcoming of these data visualisation methods, we introduce 'acoustic floor maps', which enables the combination of position and frequency dependence for each acoustic parameter with only a single representation. These acoustic floor maps consist of a combination of radar charts, as shown in Figure 5, centred at each individual measured position, across the three rows of the 26 receiver positions, while the values of the acoustic parameters are presented clockwise across the 6 octave bands, 125Hz, 250Hz, 500Hz, 1kHz, 2kHz and 4kHz.

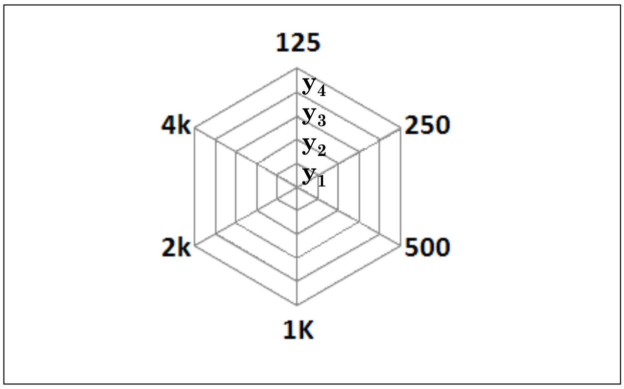

Figure 5. Radar charts represent the values of the acoustic parameters at each individual measured position clockwise across the 6 octave bands.

3.2. Acoustic Parameters

Three acoustic parameters were studied in this present work, T30, EDT and C80. The results of each acoustic parameter are demonstrated on the corresponding acoustic floor map, representing the values

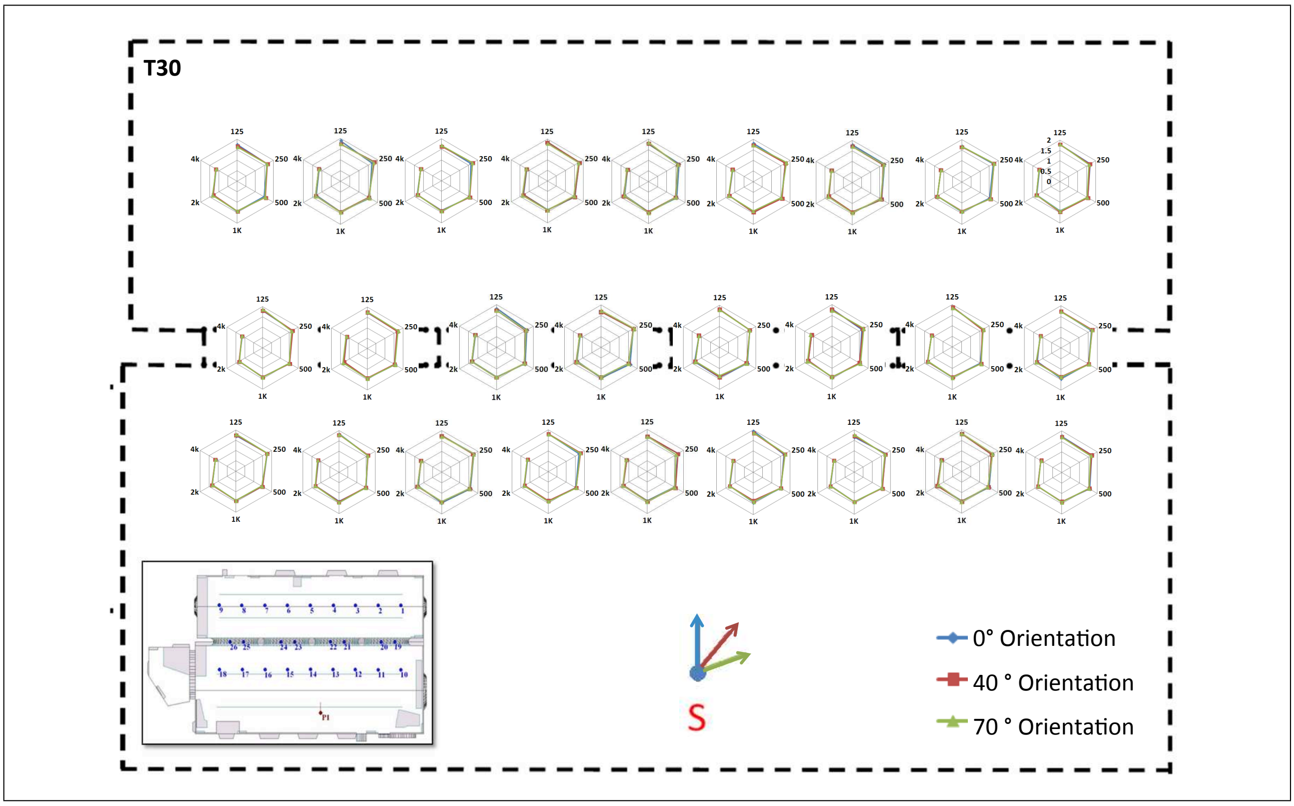

Figure 6. Acoustic floor map of T30 values obtained across the grid of 26 receiver positions, varying with source orientation 0°, 40° and 70°.

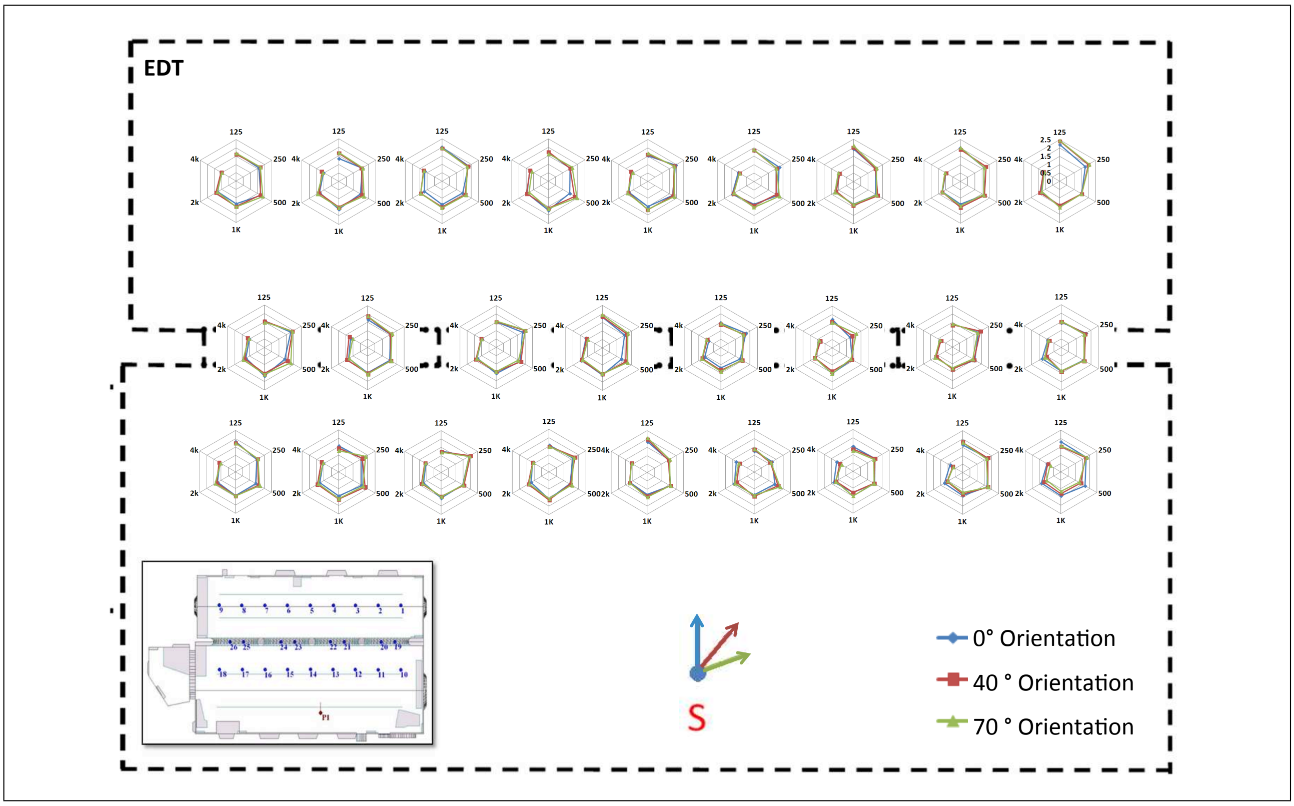

Figure 7. Acoustic floor map of EDT values obtained across the grid of 26 receiver positions, varying with source orientation 0°, 40° and 70°.

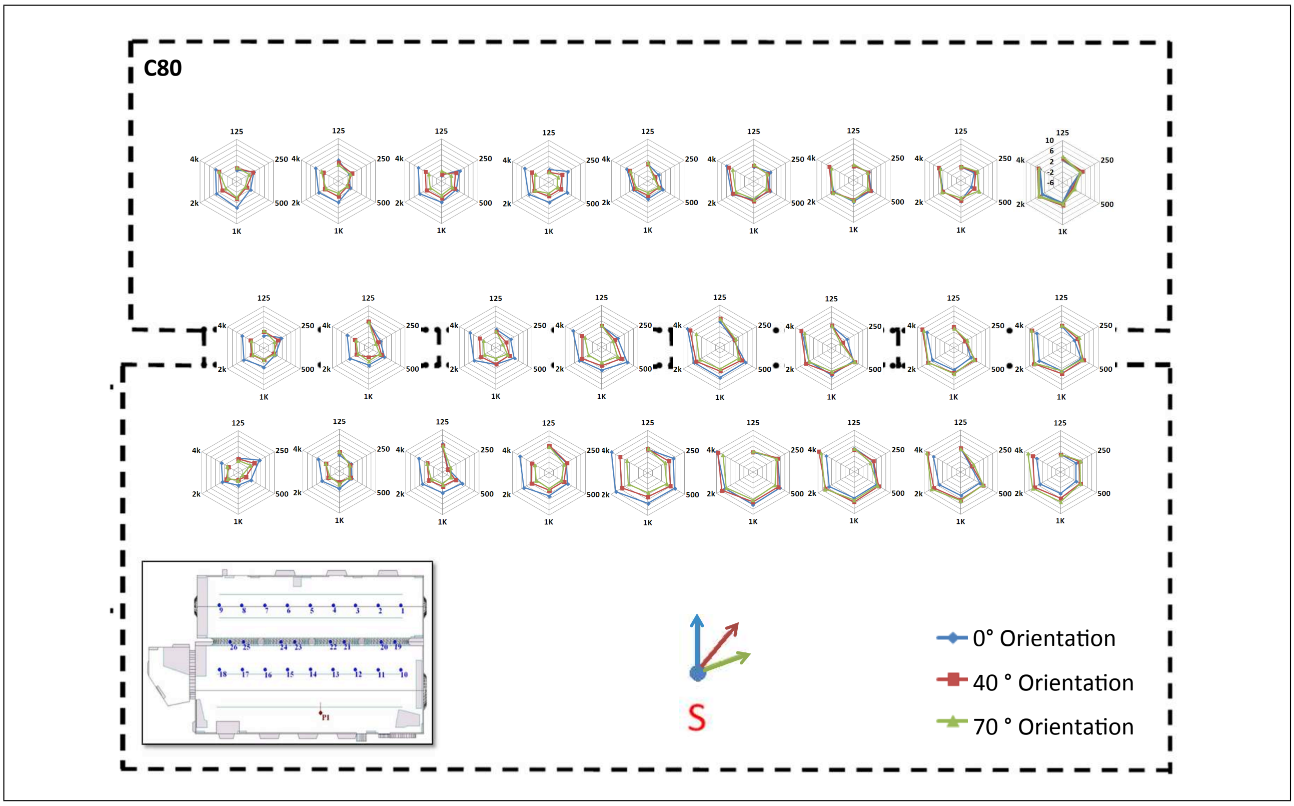

Figure 8. Acoustic floor map of C80 values obtained across the grid of 26 receiver positions, varying with source orientation 0°, 40° and 70°.

across the six octave bands for each individual measured position (Figures 6, 7, 8).
It can be observed that T30 values are not affected by the orientation of the sound source. EDT values have minimal changes, especially at those positions where physical characteristics of the space (such as walls or columns) combined with the effects of the source orientation influence the energy of the early reflections. It can be concluded that the orientation (or generally speaking the directivity) of the sound source does not affect significantly the reverberation parameters [12]. Due to the non-symmetric directionality of the Genelec, early reflections appear much stronger than the direct sound when the source is oriented from 0°, to 40° and 70°, resulting in wider variations in the clarity parameter C80.
Changes have been observed across the measured positions as well as across frequency bands; however, a specific pattern for these changes could not be found. A difference greater than 1 JND for C80 parameters in a single frequency band has been measured, and this can result to audible differences in the auralization results. This highlights the lack of accuracy of the current ISO3382 recommendations for defining the JND values as an average of the acoustic parameters at 500Hz and 1kHz.
It is also important to note that two of the measured positions (R2 and R5) were not visible from the sound source due to the presence of the columns in the centre of the venue. This implies that there was a lack of direct sound reaching these positions.

4. Conclusions and further work

In this paper, the importance of studying the frequency dependent acoustic behaviour at each individual position has been highlighted. Objective results of C80 have shown wide variations across frequency bands and measured positions, which should be taken into consideration when aiming at reliable auralization results of an enclosed space.
For the representation of this data, 'acoustic floor maps' combining position and frequency dependent characteristics have been also introduced.
Further work will involve rigorous listening tests in order to gain further insight into the level of the audible differences for these frequency variations. These results will be used to inform future work in order to achieve reliability and repeatability of the auralization methods.

Acknowledgement

The authors would like to thank the National Centre for Early Music, York, for access to their site and development plans.

References

[1] M. Facondini, D. Ponteggia: Acoustics of the Restored Petruzzelli Theater. in Proc. of the 128th AES Convention, London, UK , 2010.

[2] R. Dragonetti, C. Ianniello, F. Mercoglaino, R. Romano: The Acoustics of two Ancient Roman Theatres in Pompeii. in 9th International Congress on Acoustics, Madrid, 2007.

[3] B. Boren, M. Longair: A Method for Acoustic Modelling of Past Soundscapes. in The acoustics of Ancient Theatres Conference, Patras, Greece, 2011.

[4] A. Farina, L. Tronchin, V. Tarabusi: Comparison between Opera houses: Italian and Japanese cases. in Awaji Yumebutai International Conference Center, Hyogo, Japan, 2004.

[5] J. Merimaa, T. Peltonen, T. Lokki: Concert Hall Impulse Responses - Pori, Finland: Reference, in a free documented room response database available at http://www.acoustics.hut.fi/projects/poririrs/, 2005.

[6] T. Lokki, J. Pätynen, A. Kuusinen, S. Tervo: Disentangling preference ratings of concert hall acousics using subjective sensory profiles. Journal of Acoustical Society of America, **132(5)** (2012) 3148-3161.

[7] I. Bork, Report on the 3rd Round Robin on Room Acoustical Computer Simulation Part I: Measurements. Acta Acustica United with Acustica, **91** (2005) 740-752.

[8] M. Vorländer: International Round Robin on Room Acoustical Computer Simulations. in 15th International Congress on Acoustics, Trondheim, Norway, 1995.

[9] A. Farina: Simultaneous Measurements of Impulse Response and Distortion with a Swept-Sine technique, 108th AES Convention, London, UK, 2000.

[10] ISO3382, I.S.-. Acoustics - Measurement of room acoustic parameters, Part 1: Performance spaces, ed. B. Standards, 2009.

[11] A. Foteinou, D. T. Murphy: Evaluation of the Psychoacoustic Perception of Geometric Acoustic Modelling Based Auralization, Proc. of the 130th AES Convention, London, UK, 2011.

[12] A. Foteinou: Perception of Objective Parameter Variations in Virtual Acoustic Spaces. PhD thesis, University of York, 2013.

[13] A. Farina: Presentation at 24th AES International Conference (slide 16). 2003 [cited 7th August 2009]; Available from: http://pcfarina.eng.unipr.it/Public/Presentations /AES24-Presentation_files/frame.htm.

[14] A. Stettner, D. P. Greenberg: Computer Graphics Visualization For Acoustic Simulation. in Computer Graphics. New York: Proc. Siggraph, 1989.