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PERCEPTUAL VALIDATION IN THE ACOUSTIC MODELLING AND AURALIZATION OF HERITAGE SITES: THE ACOUSTIC MEASUREMENT AND MODELLING OF ST MARGARET'S CHURCH, YORK, UK

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Abstract
Through the use of 3D computer simulations and auralization, it is now possible to reconstruct historical monuments in a virtual environment and reveal further visual and acoustical information about the past. In previous studies, models are usually based on available evidence, often in combination with data obtained from sites and in-situ measurements in their current state. Results and validations are then based on objective acoustical parameters, and although encouraging, there is still limited data available in terms of the correlation of these results with subjective evaluation of the final auralization. This project aims to evaluate perceptual results obtained from the auralization of a heritage site and the correlation with objective acoustical parameters. This will be done by making changes in the acoustical characteristics of the space being studied, which is in this case the medieval St. Margaret's Church in York, UK, which after renovations, is now used for music performances and conferences. The particular advantage being that the church's physical acoustical characteristics can be easily changed through variable acoustical panels and drapes arranged throughout the space, depending on the acoustic requirements of the activity within venue. Based on in-situ multi-source/receiver RIR measurements, a geometric acoustic computer model has been initially optimised according to the acoustical configurations used. Through comparative listening tests the audibility of these changes for both in-situ and model based measurements has been evaluated, with participants also asked to express the resulting degree of perceived differentiation in each case across both actual and virtual space. This paper reports on the measurement and modelling work, together with initial subjective testing leading to recommendations for the modelling and perceptual validation of virtual reconstructions of heritage sites, particularly in cases when physical validation is no longer possible.

Keywords
Auralization, acoustic modelling, measurement, reconstruction, heritage.

1. Introduction

This work focuses on the reliable acoustic reconstruction of heritage sites with the aim of developing particular insights as to how they might have sounded in their historic past. Auralization techniques for this purpose are now commonplace and objective acoustic measurements, such as reverberation time, can be used in the optimisation of both the 3-D model reconstruction and simulation method. However, these results need additional psychoacoustic validation in order to achieve satisfactory results that correlate in subjective terms. In this paper, the auralization of impulse responses obtained from both actual in-situ measurements and a computer simulation of a given space will be presented. The correlation of objective acoustic measures with subjective evaluations will be investigated through the use of different acoustic configurations of the same space.

The studied space is St. Margaret's Church in York, UK. It was founded in the 11th century and then substantially rebuilt in the Middle Ages, 17th century, and late 19th century before falling into disuse in the 1960s. The space has since been redeveloped and is now used for concerts and conferences, and for this reason its acoustics have been extensively redesigned by ARUP Acoustics. Panel absorbers (reflective on the one side, absorbing on the other) as well as drapes in the roof can be adjusted by hand for different configurations according to venue use. For this study, three configurations have been investigated. The first case, for musical/opera performances, includes drapes and 75% of panels in use (open) (medium reverberant space). For the second case, the drapes and 100% of the panels are in use, suitable for lectures/speech (less reverberant space). For the third case, suitable for music recitals, only the drapes are in use (all panel absorbers closed) (most reverberant space).

2. Objective evaluation of auralization

2.1 Impulse Response Measurements

Impulse response measurements in the church were made based on the Exponential-Swept Sine (ESS) Method [1]. The frequency range of the sweep is from 22Hz to 22kHz, using a Genelec S30D as the source and a Soundfield SPS422B for sound capture. Receiver positions were chosen in order to create a virtual grid of 26 points equidistant from each other in the audience area. The source was placed as a performer would be in the space. The impulse responses obtained can be downloaded from [2].

2.2 Computer modelling

The computer simulation of the studied space was created using both ODEON 10 and CATT-Acoustic v8, both based on geometric acoustic methods. Church dimensions were obtained from the redevelopment plans and checked and measured in situ, with the most acoustically important architectural features incorporated in the virtual space including arches, furniture and wall memorials. The total number of surfaces used is 997 and 50,000 rays were used in simulation for both software applications. The source and receiver positions used in the computer model were the same as for the measurements and in both applications a 3-D directivity plot for the Genelec loudspeaker was created for the models.

The surface properties were estimated based on the available material libraries of ODEON and CATT-Acoustic. In order to optimise as much as possible the acoustical parameters of the model with those of the measured space, the absorption and scattering coefficients of the surfaces were readjusted using the case of the medium reverberant space as a reference model and by looking only at one measured position. Additionally, the energy of early reflections in waveforms and reflectograms from both measurements and computer models were studied in order to confirm the reliability of these values.

2.3 Objective Acoustic Parameters

Acoustic parameters based on ISO3382 [3] were obtained independently of the two software simulation methods from the synthesized impulse responses, as well as from the actual measurements made within the space.
For the objective results, previous work has used average values taken from across measured positions. However, the acoustic behaviour changes significantly from one receiver point to another in many of these cases [4]. In this studied space, it is observed (Fig. 1 and 2) that even if the values of T30 are similar, the wide deviation of C80 with receiver position confirms that average values do not give reliable results for each of them. Thus, here the presented results are obtained at one measured position.

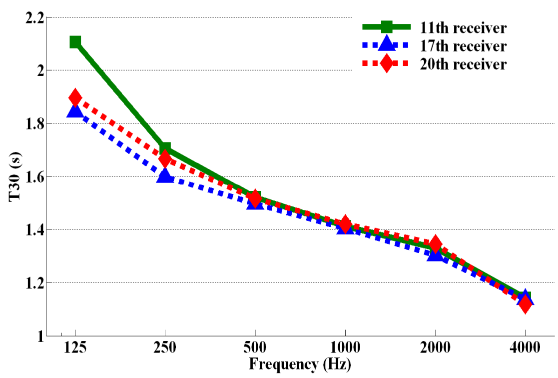

Figure 1 - T30 for 3 measured receiver positions in the actual space (medium reverberant space)

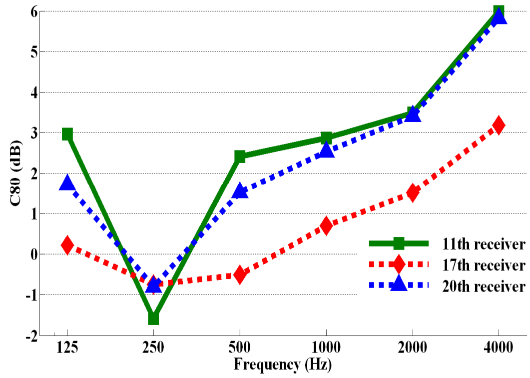

Figure 2 - C80 for 3 measured receiver positions in the actual space (medium reverberant space)

The Schroeder frequency for this space varies from 39Hz to 44Hz, depending on the chosen configuration of the acoustic panels. Thus, the acoustical parameters at the examined frequencies can be assumed to give accurate results.
The ODEON model is based on a hybrid method for impulse response calculation combining image-source and ray tracing methods. Scattering coefficients are defined by default based on a mid-frequency approximation in order to take into account actual variation with frequency. The model was checked with different values of absorption coefficients, higher values for scattering, and the number of rays used was increased from 50,000 to 100,000 to 500,000 correspondingly. There are no major changes in the final calculation results [5] although there is still significant difference compared with the results obtained from the measurements.

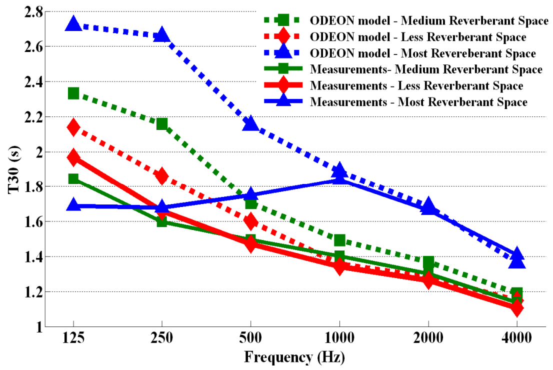

Figure 3 - T30 for the three configurations for the ODEON model and measurements

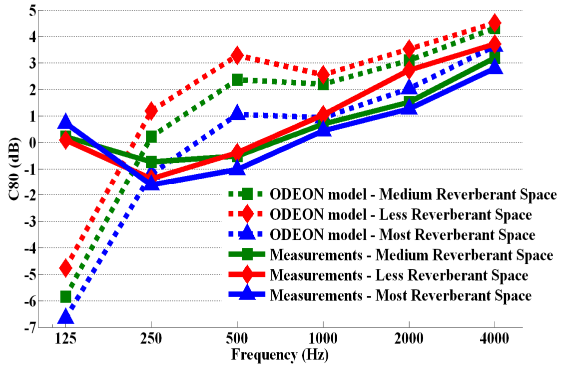

Figure 4 - C80 for the three configurations for the ODEON model and measurements

CATT-Acoustic combines cone-tracing and ray tracing methods for the calculations. Edge diffusion can be applied additionally to diffusion from the surfaces themselves. For this reason different versions were studied in order to investigate the accuracy of this method using the case of the less reverberant space. Thus, it is observed that T30 and EDT values are closer to the measurement results when edge diffuse reflection is used with the same value of scattering coefficient across frequency bands ("First case" in Fig. 5 and 6) for selected surfaces. In the second studied case, a function for estimating the scattering based on the roughness of the surfaces was used. In the third case, no edge diffuse reflection was applied and the same value for the scattering coefficient was used across all frequency bands. Interestingly, in this third case the curves for C80 are closer to those observed for the same acoustic configuration in ODEON and are closer to the results obtained from the measurements.

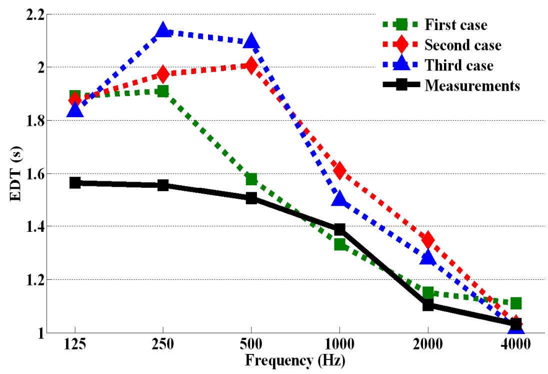

Figure 5 - EDT for three cases of diffusion/scattering modelling in the CATT model (less reverberant space)

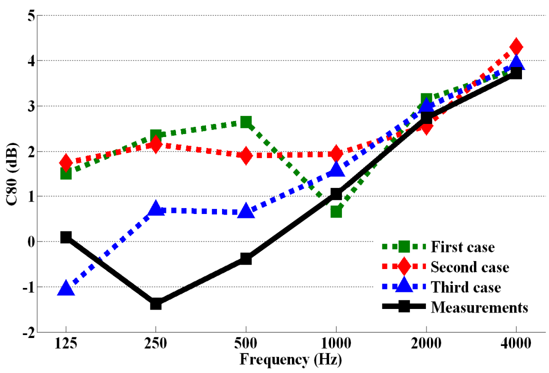

Figure 6 - C80 for three cases of diffusion/scattering modelling in the CATT model (less reverberant space)

Therefore, using the best results for T30 and EDT ("First case" in Fig. 5) to optimise the CATT model, the results of the three acoustic configurations for the church are presented in Fig. 8 and 9 (compare with Fig. 3 and 4).

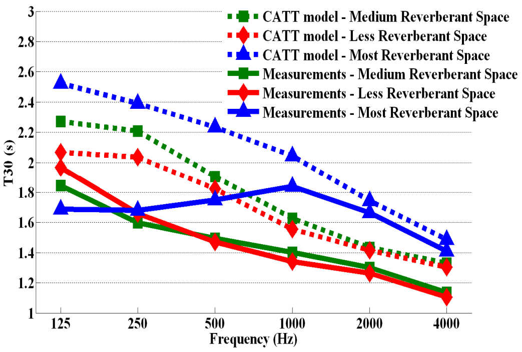

Figure 7 - T30 for the three configurations for the CATT model and measurements

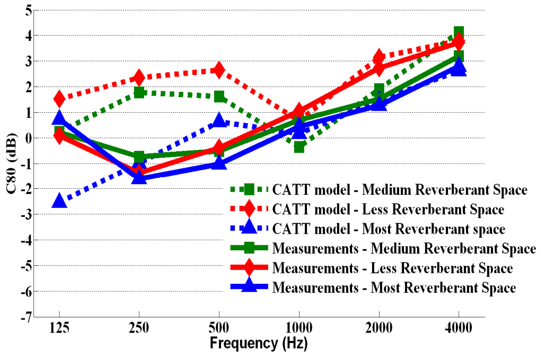

Figure 8 - C80 for the three configurations for the CATT model and measurements

Although the changes observed between the three acoustic configurations follow the logic of the acoustical treatment, the results achieved by both software applications are clearly not satisfactory in objective terms. As described, this is a quite detailed model in terms of surfaces and physical features and this could affect the energy and distribution of the early reflections and therefore the results of related parameters such as C80. An unexpected feature of the acoustical behaviour of the measured space is observed below 500Hz, especially in the most reverberant case. There is no absorption contributed from the acoustical panels, which are closed, and yet the overall reverberation time is reduced. This variation in reverberation time is also observed across several examined receiver positions, although this is not evidenced in the computer models.

3. Subjective evaluation of auralization

Listening tests took place in order to provide some validation of these objective results, using the three different auralization methods obtained for this medieval church. For this purpose, female singing and male speech were used as the anechoic recording stimuli for convolution with the impulse responses. The six participants listened to pairs of samples, 16 examples for each stimulus. The three acoustic configurations for each method were compared with each other, and a comparison was also made between the three different methods of auralization for the first configuration (drapes and 75% of panels in use). Their task was to compare these pairs and express the degree of similarity in terms of the perceived reverberation by marking a point on a scale with values from 1 (very similar) to 10 (very different). Additionally, they were asked to identify the most reverberant example in each pair.

By comparing the auralization of the impulse responses from the actual measurements of the space with those of both software applications, a difference was clearly evidenced between the real and virtual cases. A very interesting point is that without exception all participants selected the measurement results as being more reverberant than either the ODEON or CATT model. Note that both models had significantly longer reverberation times than the actual measurements in the objective results. This could conclude the importance of looking at parameters other than reverberation time when optimising such models. In comparing the perceptual difference between the three acoustic configurations for the measured impulse responses and those obtained from ODEON and CATT separately, the participants were able to identify the most reverberant example even if it was objectively seen to be similar to the compared subject. For the measurements, the differentiation from one configuration to the other was characterised with the marks between 2 and 4 on the given scale. For the impulse responses from the ODEON and CATT models the marks were spread between the values of 1 to 7. Note that the difference between objective parameter curves for the three configurations of the ODEON and CATT models was more significant than those of the measurements, especially for C80. The results for the two stimuli were similar even if the acoustic configuration differed from that suggested for the source (speech/singing).

4. Conclusion

This paper has studied the auralization results obtained from two commercial architectural acoustic simulation software applications for an English medieval church, based on the unique ability to easily change the acoustic characteristics of the actual space itself. It is observed that optimising the computer model with respect to reverberation time does not warrant similar results for other "less important" parameters. Reverberation Time, Clarity and Early Decay Time were observed and their changes based on the applied absorption in the space were studied. Through a series of listening tests, initial conclusions were presented for subjective evaluations by comparing the same space with different acoustic configurations and absorption characteristics. The difference between the three examined configurations were not perceived to the same degree for auralizations based on in-situ measurements when compared with those obtained using ODEON and CATT models.

This study is an initial step towards the validation of the perception of virtual acoustic reconstruction work. Future research will use a less geometrically detailed model in order to further investigate the accuracy of the results obtained. Experiments will be based on more rigorous listening tests in order to give us the confidence for modelling accurately and convincingly the sound of heritage sites as they might have been heard in their historic past.

Acknowledgement

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