

INVESTIGATION OF FACTORS INFLUENCING ACOUSTIC CHARACTERISTICS IN GEOMETRIC ACOUSTICS BASED AURALIZATION

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ABSTRACT

Most room acoustics simulations and auralization techniques are based on geometric acoustic algorithms, commonly combining image-source and ray-tracing methods for impulse response calculation. This paper investigates the acoustics of a medieval English church and compares a geometric acoustic computer based auralization with measurements obtained from the actual space. More specifically, it focuses on the determination of the influence of different aspects and factors on typical objective room acoustic characteristics. These results are presented and then discussed in terms of how they can be improved and optimized when compared with the measured results.

1. INTRODUCTION

Geometric acoustic techniques have often been studied based on a comparison with measured results from existing spaces [1]. However this is problematic in the case of ruined heritage sites where measurements are not available for analysis. It is required thus to investigate the factors involved in this process and the way they influence geometric acoustics based auralization.

The aim of this study is to examine the effects of simulated early reflections, and the scattering effects of particular surfaces, and evaluate them for their accuracy and influence on obtained metrics. Also, the importance of the geometrical detailing in this particular studied space with regards the vaulting present in the roof has been investigated.

For the purpose of this work St. Patrick's Church in Patrington, Humberside, also known as the "Queen of Holderness", was studied. Following the highly ornamented design of the early 14th century, walls, arches and buttresses are decorated with stoned figures and crocheted pinnacles. The most important characteristic of the space, uncommon for a parish church, is its cruciform plan and the overall size, with an external length of 46 meters, a breadth of 27 meters and a height of 57.5 meters up to the very top of the central tower. All of them provide a unique sound, particularly for musical performance and convolution based reverberation, and hence an interesting subject for further study.

2. COMPUTER SIMULATION

For the results obtained from simulation ODEON 7.0 Auditorium was used. Odeon is based on a hybrid calculation algorithm, combining image-source and ray-tracing methods, for the calculation of early reflections and ray-tracing for the late reflections. The Transition Order (T.O.) defines the reflection order of the early reflections below which the image-source method is used and above which ray tracing takes over. Transition Order is ideally estimated by the complexity and the shape of the room. The CAD model of the church used was based on a medieval reconstruction obtained from an archaeological survey [2]. This was reformed to represent the current state of the church, by replacing medieval objects and surfaces with those considered the most acoustically important as part of the architectural characteristics and features of the 21st century building.

Due to limitations in the available surface material libraries in terms of appropriate definitions for absorption and scattering coefficients, these values were estimated to match as closely as possible corresponding measured values of T_{30} . Initially, scattering coefficients with values of between 0.2 and 0.4 were assigned to all surfaces. A relatively high value of 0.7 was however used for the highly ornamented carved screen (reredos) at the rear of the Chancel in order to take account of these very irregular surfaces.

In general, the model was kept as simple as possible with appropriate use and definition of scattering coefficients for those surfaces with some ornamentation or decoration. However the roof was simulated with different levels of detail in order to study the influence of such geometrical details on the acoustic results obtained and in particular the influence of the complex wooden vaulting in the roof. In the basic model the vaults were replaced by planar sloped surfaces, defined with a high value of 0.9 for their associated scattering coefficient and with 0.5 used for all other included surfaces. The detailed model used 8,400 surfaces and the simplified model 1,490, while the number of rays used was 138,897 for both.

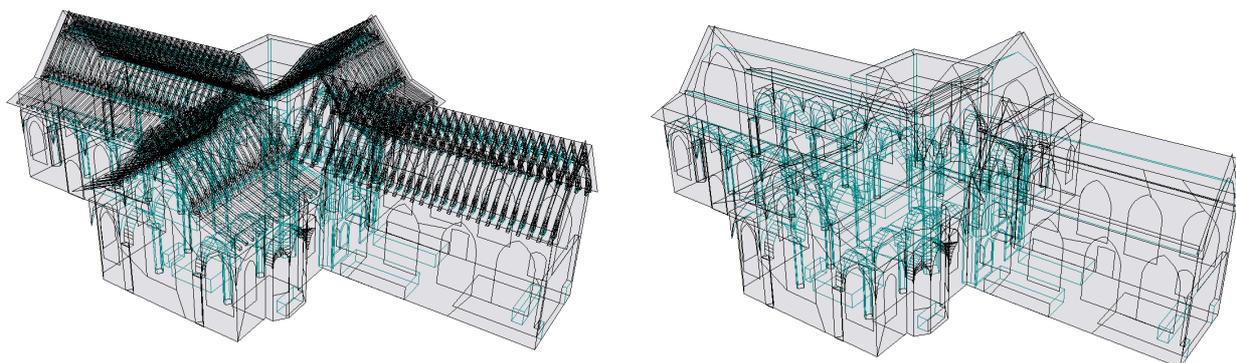


Figure 1: St. Patrick's Church, Holderness, as modelled in ODEON a) the detailed model b) the simplified model.

3. RIR MEASUREMENTS

Room impulse response measurements are usually based on the methods presented in ISO3382 [3], however more recent studies suggest different approaches that provide better and more accurate results [4], [5]. For this project, a Genelec S30D was used as the source transducer - a directional three-way active tri-amplified system with 96 kHz/24-bit AES/EBU digital input. Its directivity tends to be omni-directional at low frequencies while at mid-range frequencies it has a more cardioid characteristic. Despite its directivity, the frequency response, rated from 37Hz to 44 kHz, varies only +/-3 dB and it is considered that it has an almost flat response for the audible spectrum [6]. The microphones used for capturing the sound are appropriate for multiple possible final auralizations of the measured 3-D space. A cardioid Neumann KM140 and a Soundfield SPS422B are both installed on a rotating turntable. The Neumann is positioned with the capsule end 10.4cm from the central axis of the rotation while the Soundfield was 1m away from the rotational axis of the boom arm, both at a height of 1.5m. The turntable is programmed to trigger after an appropriate interval after each excitation signal in 5° increments, resulting in a set of 72 RIR measurements captured around the circle. Using this data, it is possible to record ORTF stereo sound by collecting the RIR pairs of the cardioid microphone at ±55° and B-Format signals from the 4-channel Soundfield. Other methods are also possible when derived appropriately from these signals. The excitation signal, based on the Exponential-Swept Sine (ESS) Method [7], is a log sine sweep, with frequency range from 22Hz to 22 kHz, lasting 15 seconds. For post-recording inverse filtering of the log sine sweep, deconvolution and calculations of objective parameters (based on ISO3382 [3]), Aurora plug-in [8] in Adobe Audition was used, while for playback and recording, Steinberg Nuendo 2 was used.

4. SOURCE AND RECEIVERS LOCATED IN THE ACTUAL AND VIRTUAL SPACE

For an appropriate coverage of the acoustic characteristics of the space, three sets of measurements were taken in different positions. For each, acoustical parameters were obtained from RIRs at 0°, 90°, 180° and 270° around the central axis of the turntable using the W-channel of the Soundfield microphone (Fig. 2).

The first measurements represent the priest and the congregation in the medieval mass, with the source within the Chancel,

facing down the nave, and the receivers positioned at the middle of the crossing of the nave and the transepts. The distance between the loudspeaker and the rotating table was 18.5 meters. The second set represents a music performance with the source located at the middle of the crossing, facing the audience (microphones) in the centre of the nave. The distance between them was 8.7 meters. For the third set, the sound source was placed in the Lady Chapel, facing the wall, while the microphones were placed 8.3 meters away from the source, in the audience space of the south transept, in order to represent part of the priest's devotions. The same positions for the source/receivers were simulated in ODEON taking into account also the different positions of the Soundfield microphone at angles 0°, 90°, 180° and 270° around the central axis of the turntable.

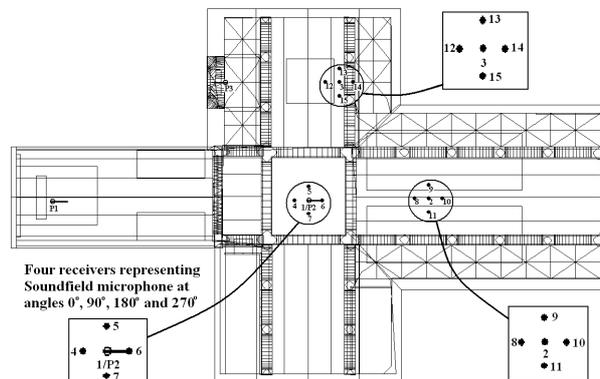


Figure 2: Three sets of source/receivers placed in the church model corresponding to the locations used in the actual measurements.

In order to determine of the influence of different aspects on the acoustic characteristics of the studied space, the analysis is based on results obtained from the Soundfield microphone W-channel impulse responses, averaged across the four angles 0°, 90°, 180° and 270° from each of the three measured positions, from both model and the real space, and the mean values and standard deviation of each are presented. The acoustic parameters considered are T_{30} (s), EDT (s) and C_{80} (dB), observed in five octave bands. In the latter case C_{80} is used as opposed to C_{50} as the space is also being considered in its role as a performance space for live music and hence for auralization. The source in the model was created with a directivity characteristic of the Genelec loudspeaker based on a measured directivity plot [6].

5. ACOUSTIC PROPERTIES OF THE SPACE

The mean reverberation time T_{30} from the twelve measured positions in the real space is defined as 1.73s at 1 kHz. A reduction in T_{30} is observed in the 2 kHz and 4 kHz octave bands. It is important to note that the twelve measured positions, at very different locations within the church, do not have directly similar acoustic characteristics and this is not unexpected considering the cruciform shape and the large size of the church. This can be observed in the standard deviations of the mean values of T_{30} , EDT and C_{80} for the twelve measured positions. Note that as EDT is observed to correlate to T_{30} in these examples it is omitted here for brevity.

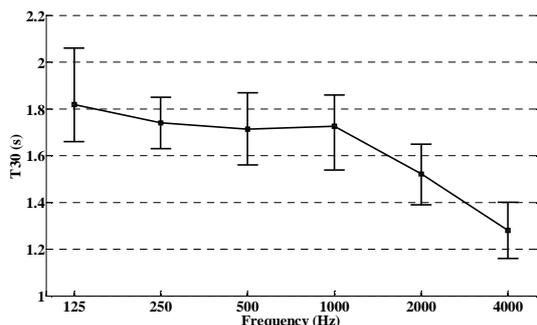


Figure 3: Mean values and standard deviation for T_{30} across the 12 measured positions in the real space.

For C_{80} , it can be seen that standard deviation values vary even across individual measured angles for each of the three measurement sets. That is, significant variation in C_{80} is observed across all 12 measured positions.

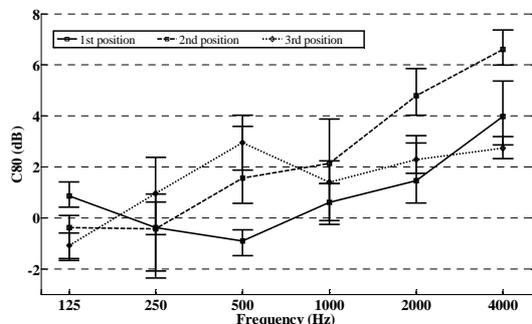


Figure 4: Mean values and standard deviation for C_{80} across the four angles for each of the three measured receiver set positions.

6. RESULTS AND DISCUSSION

6.1. Calculation method

For studying the most appropriate Transition Order, values of 0, 1, 2 and 5 were defined in the detailed model. It is observed that Transition Order only has a small influence on the results for T_{30} and EDT. However the indication from Fig. 5 is that a Transition Order of 5 gives results closest to that of the real space when considering octave bands above 500Hz. Note that the Schroeder frequency for this model is about 30 Hz, thus the observed deviation

is due to the approximately estimated values of absorption and scattering coefficients based on the material libraries available within ODEON.

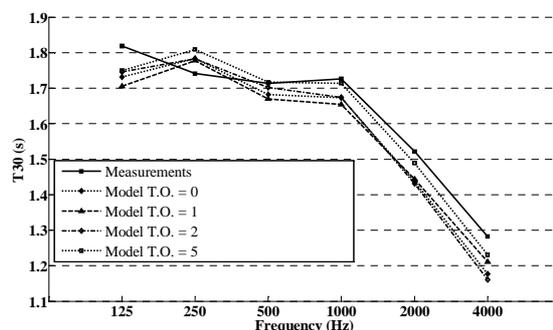


Figure 5: Mean values of T_{30} with different values of Transition Order (T.O). (EDT behaves similarly but is omitted here for brevity).

However, a closer inspection of the actual simulated time domain impulse responses also indicates that Transition Orders of 2 or 5 more successfully represents the early reflections than with Transition Orders of 0 and 1.

6.2. Scattering Coefficient

The influence of the scattering coefficient on the results obtained was also investigated by changing the default values from 0.2 and 0.4 to 0.5 and 0.7 respectively for all surfaces (apart from reredos which remained at 0.7). For both of these cases, Transition Orders of 2 and 5 were tested. As with the previous Fig. 5, and shown in Fig. 6 there were minimal differences in the results for T_{30} and EDT, indicated by the low standard deviation values. This indicates that T_{30} and EDT are not strongly influenced by changes in Transition Order or use of higher scattering coefficients. It is concluded that a Transition Order of 5 tends to give results closest to the actual measurements.

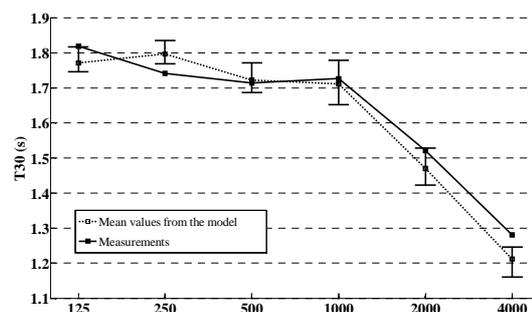


Figure 6: Mean values and standard deviation of T_{30} varying across assigned scattering coefficient values a) between 0.2 and 0.4, b) values of 0.5, c) values of 0.7, and T.O. of 2 and 5, compared with T_{30} obtained from the actual measurements. (EDT behaves similarly but is omitted here for brevity).

The parameter which does seem to be significantly influenced by changes in scattering coefficient and/or Transition Order is C_{80} , shown in Fig. 7. It can be concluded that higher scattering coefficients yield results closer to those C_{80} values obtained from the actual measurements. Optimal values appear to

be a scattering coefficient of 0.7 and a Transition Order of 5. Also, it seems that with the same Transition Order but different values of scattering coefficient, C_{80} does not behave similarly which confirms the need for the scattering coefficient to be determined in a frequency dependent manner, which is not the case with the current implementation of the algorithm used for this research.

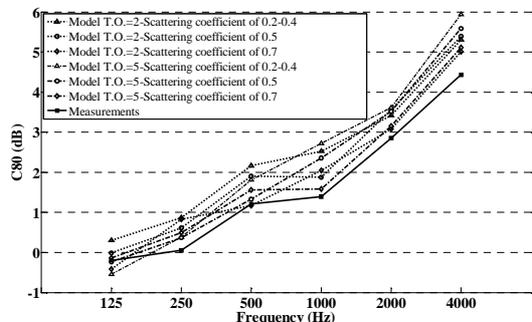


Figure 7: Mean values of C_{80} varying across assigned scattering coefficient values a) between 0.2 and 0.4, b) values of 0.5, c) values of 0.7, and T.O. of 2 and 5, compared with C_{80} obtained from the actual measurements.

6.3. Geometrical Detail

In order to study the importance of the detailed simulation of the wooden vaults of the roof, the two versions of the church model were compared with the measured results. The simplified model was also simulated using a varying Transition Order of 0, 1, 2 and 5 while the detailed model used Transition Order of 5 and scattering coefficient of 0.7 as determined previously.

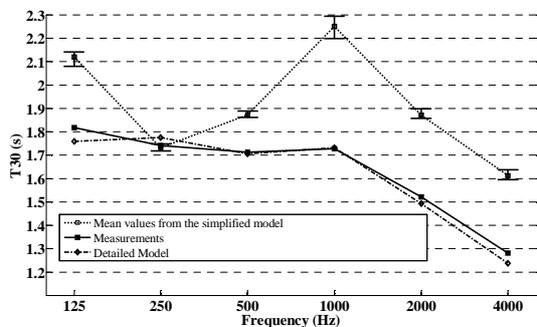


Figure 8: Mean results for T_{30} obtained from the simplified model with T.O. set to 0, 1, 2, and 5, compared with T_{30} obtained from the detailed model (T.O.=5, scattering coefficient=0.7) and from the actual measurements.

As before, changes in Transition Order have little influence on T_{30} for the simplified model. However, mean T_{30} values for the simplified model do not match well with the reference curve from the measurements. This indicates that the diffusing behavior of the wooden vaults in the roof can be simulated much more accurately with a detailed model than a simplified one using a high scattering coefficient.

7. CONCLUSIONS

A range of acoustic properties have been studied using a geometric acoustic simulation and auralization in ODEON 7.0 Auditorium, of an English gothic church. It has been shown that in terms of Transition Order, the values of T_{30} and EDT are not sufficient to provide information about the most appropriate calculation method for the space, as the changes are marginal, for both the simplified and detailed model. Varying scattering coefficients also has a minimal influence on these two acoustical parameters. It was decided that a Transition Order of 5 and scattering coefficient of 0.7 are optimal for this model. However C_{80} is shown to be more directly affected by changes of Transition Order and scattering coefficient. Their influence on the obtained values of C_{80} confirmed that scattering coefficient is better determined as a frequency dependent quantity and necessary for improved accuracy. A simplified model of the vaulted roof fails to accurately represent the diffusion effect attributed to this area compared with the detailed model. These results will be used for future work to achieve more accurate and optimal simulations, especially for reconstructed sites where actual measurements cannot be made in the real space.

8. ACKNOWLEDGMENTS

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9. REFERENCES

- [1] Lisa, M., Rindel, J., Christensen C., "Predicting the Acoustics of Ancient Open-Air Theaters: The importance of Calculation Methods and Geometrical Details", Joint Baltic-Nordic Acoustics Meeting, 2004.
- [2] Masinton, A., "Sacred Space: Priorities, perception and the presence of God in late medieval Yorkshire parish churches", Medieval Studies Ph.D. Thesis, York, 2006.
- [3] ISO3382, International Standard 3383, "Acoustics—measurement of reverberation time of rooms with reference to other acoustical parameters", ISO, Second Edition, 1997.
- [4] Farina, A., Ayalon, R., "Recording Concert Hall Acoustics for Posterity", AES 24th International Conference on Multi-channel Audio, Banff, Canada, June 26-28 2003.
- [5] Murphy, D., "Archaeological Acoustic Space Measurement for Convolution Reverberation and Auralization Applications", Proc. Of the 9th Int. Conference on Digital Effects (DAFx-06), Montreal, Canada, Sept. 2006, pp. 221-226.
- [6] Angelo Farina's Home Page, Accessed August 7th, 2009, [Online] - slide 16 from http://pcfarina.eng.unipr.it/Public/Presentations/AES24-Presentation_files/frame.htm
- [7] Farina, A. "Simultaneous Measurement of Impulse Response and Distortion with a Swept-Sine Technique", 108th AES Convention, Paris, France, February 18-22, 2000.
- [8] AURORA Plug-ins, Accessed August 7th, 2009, [Online] <http://www.aurora-plugins.com/>