The Acoustics of Ancient Theatres Conference
Patras, September 18-21, 2011

VIRTUAL ACOUSTICS AND PERFORMANCE SPACES IN MEDIEVAL ENGLISH DRAMA

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Abstract
The relationship between acoustics and medieval vernacular drama has been somewhat neglected. This is most likely a consequence of the fact that it was performed making use of structures temporarily assembled in outdoor spaces. However, this does not imply that the space available and the structures used could not have been modified and built with the intention of improving acoustic conditions. The present paper investigates the acoustic characteristics of Stonegate, which is a street in central York that was used for the performance of the *York Cycle*. This work explores the difficulties faced when carrying out impulse response measurements in public outdoor spaces. Preliminary results gathered through multiple impulse responses are presented. Finally, the initial stages of the design of a computer model of Stonegate are explained.

Keywords
Impulse responses, virtual acoustics, medieval theatre

1. Medieval Drama and Acoustics

The relationship between acoustics and theatre performances throughout history has been an area of extensive research. Existing literature provides an overview of the differences in individual historical periods [1]. However, research on pre-seventeenth century theatre acoustics has been focussed either on Greek and Roman [2, 3] or Elizabethan theatre [4]. Medieval theatre has been omitted from acoustic studies. Performance spaces in this period had two main characteristics:[1] they were outdoors[2] and no theatres were built, instead temporarily assembled stages were used. Although no lasting structures were constructed for these performances it is reasonable to put forward the hypothesis that the spaces available and the stages assembled could have been modified to improve acoustic conditions, in particular to ensure speech

[1] This paper focuses on the characteristics of medieval vernacular drama in England, which had a religious subject.
[2] An exception is the interludes performed in great halls.

intelligibility and audience engagement. Moreover, medieval plays included music, very often in the form of plainchant items, whose performance would have benefited from any acoustic improvements.

2. The York Mystery Plays

The *York Mystery Plays*, also known as the *York Cycle* is thought to have originated in the late fourteenth century and it was performed annually until the late 1560s. The cycle consists of forty-eight separate plays that narrate events of relevance to the Christian faith. The performances were staged on wagons that were specifically constructed by the guilds for the occasion and manhandled through the streets of York. The wagons followed a predetermined route through the city and they stopped at *stations* (street spaces) where the audience gathered to see the performance.

3. York Now and Then: Stonegate

One of the better-preserved sites of the performances is found at *Stonegate* in central York. The preservation of this site together with the fact that it presented a semi-enclosed space due to its narrow width and its jetties, make it an interesting subject for acoustical analysis. Stonegate is also of interest because it was used for performances during the entire life of the cycle, which suggests that its selection as a playing place might have been related to its acoustic characteristics, as much as by social and economical factors.

In this paper the acoustic characteristics of Stonegate as it stands today are considered. These characteristics will be used in future work to establish a comparison with those of medieval Stonegate. The study of Stonegate today comprises two defined stages: impulse response measurements on site and the design of a virtual model of that same space. The impulse responses obtained from the measurements are used to validate the virtual model.

3.1 Impulse Response (IR) Measurements

Finding a suitable technique for measurements outdoors is a challenging task. Measurements need a sufficient signal-to-noise ratio, requiring the decay curve to start 45dB to 35dB above the background noise for T_{30} and T_{20} measurements [5]. In cultural heritage sites this means measurements are best recorded at times when visitors are not on site. In the case of Stonegate this is rarely possible since it is not only a city street but also a tourist attraction. In order to achieve optimal results the measurements were taken on a Sunday morning, based on background noise level and the restrictions of the York city council.

The excitation signal used for the impulse measurement is of critical importance. Maximum Length Sequences (MLS) are popular choices due to the fact that their autocorrelation is a Kronecker delta function [6]. However, it is generally accepted that the use of a TSP (Time Stretched Pulse) provides several advantages over the MLS technique, namely that it is more robust to time variances and non-linearities of the space [6,7]. TSPs are an exponential sine tone sweep that when played slowly enough, will result in all speaker induced distortion in the impulse turning into pre-delayed signals at the start of the impulse response. The length of the sweep should be greater than that of the space's reverberation time multiplied by the number of octaves (taken as 10).

If we assume a linear and time-invariant (LTI) system, then a summation of multiple sine sweep measurements will improve the signal-to-noise ratio due to the fact that in every measurement the LTI component will remain the same, while the background noise will be random, resulting in an increase of the signal-to-noise ratio by 3dB each time the number of measurements is doubled [8]. However, although time-invariance is assumed as a starting point, we must acknowledge that there will be time-variances introduced due to changes in air temperature and more significantly due to the presence of passers-by. These invariances will produce major errors in the calculation of the acoustical parameters at different frequencies [8]. Furthermore, the presence of a certain number of people at one measurement and a different number at another may produce unwanted changes in the reflection paths as well as differences in sound absorption.

Another technique to improve the signal-to-noise ratio is the use of a single, very long sine sweep. This technique has been shown to provide more reliable results that the averaging technique [8,9]. Practically however, there is usually a limited time-window for outdoor acoustic measurements (in this case, 1 hour for setup and measurement), which has significant implications on the reliability of the chosen technique. For this reason, we utilise multiple 15 second sine sweep measurements in the analysis, eliminating those takes with poor signal-to-noise ratio from the analysis.

In the analysis of acoustic spaces it is customary to present spatially averaged acoustic parameters. However, due to the non-gaussian nature of the noise sources it is more meaningful to present median values (See Section 4.1.7).

3.2 *Sound Source and Receivers*

The sound source utilised was a Genelec 8040A Monitoring System. This source has a relatively flat frequency response and it presents more omnidirectional characteristics at low frequencies but becomes increasingly directional at mid and high frequencies. In these measurements the sound source represents the performers of the plays making it acceptable to use a directional source [10].

The receivers used were a Kemar dummy head and a Soundfield SPS422B microphone. The dummy provided binaural impulse response measurements which were used to calculate the Interaural Cross-Correlation Coefficient (IACC). The B-format Soundfield microphone was selected because it is possible to derive both monoaural acoustic parameters through the W (omni) channel, as well as being possible to use channels X (front/back), Y (left/right) and Z (up/down) to obtain spatial information such as the Early Lateral Energy Fraction (LF).

The soundcard used was a Fireface 800 while Pro Tools 9 was employed for loop playback and recording. The excitation signal employed was a logarithmic sine sweep with a bandwidth of 20-20000Hz, and a length of 15 seconds with a silence of 5 seconds between sweeps, allowing the high frequencies to decay completely before starting a new measurement.

3.3 Source and Receiver Positions

The location chosen for the measurements is the Mulberry Hall area of Stonegate. This coincided with the location of the playing station of the plays [11].

Figure 1 - Setup in Stonegate

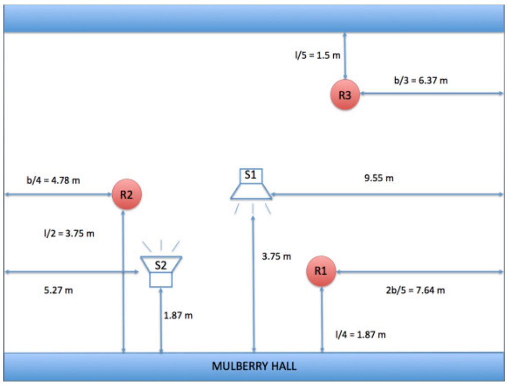

Figure 2 - Source and receiver positions seen from above.
Mulberry Hall has a breadth (b) of 19.11 m. The distance between sides of the street is 7.5 m (l). Ss and Rs at a height of 1.67 m.

Two source positions (**S1** and **S2**) were utilised. The source positions were chosen to reflect that the actors could have been performing to either side of the street, while the receivers (**R1**, **R2** and **R3**) were positioned to reflect the possible areas occupied by the audience on the street. The KEMAR mannequin was always positioned towards the sound source while the Soundfield microphone was positioned in all measurements towards Mulberry Hall.

The selection of the source and receiver positions was challenging since the space studied is not a typical performance space with a clear delimitation between performers' and audience space. Furthermore, the plays studied would have been performed on wagons positioned in the street, but for the measurements in question only the street space was considered, making it more difficult to determine performer and audience positions. However, deliberate efforts were taken to ensure that the source-receiver positions avoided overlapping of first and second order reflections [12]. This is adhered to in all measurements bar the S1-R2 source-receiver combination. In total, ten measurements were recorded at each source-receiver combination.

3.4 Post-processing

The re-recorded swept sines were edited using Pro Tools 9 HD. The editing process consisted of selecting seven takes for each source-receiver combination. The takes selected were those with the least background noise. Once the takes were selected a summed audio file was exported for every combination. Deconvolution was implemented using the programme Voxengo Deconvolver [13] and the IRs were then analysed using the Aurora Suite [14].

4. Analysis

Although the averaging method improved the signal-to-noise ratio difficulties were experienced due to time-variances during the measurements. Evidently erroneous values were detected when analysing the results for the reverberation time, for instance a value of 74 seconds for T_{20} was recorded in S2-R1 at 1kHz.

As a consequence the results presented below (with the exception of IACC) are given considering median values. Although these values do not provide a definite description of the acoustics of Stonegate they provide preliminary results which will then be validated through further measurements.

The present paper considers reverberation time (T_{20}), Clarity (C_{50}/C_{80}) and the InterAural Cross-Correlation Coefficient (IACC). Although reverberation time is mostly considered when studying enclosed spaces it was deemed of importance to allow the fast comparison of the performance space studied with other enclosed spaces used for theatre performances, as well as those used for the performance of medieval music. Clarity (C_{50}/C_{80}) has been selected due to the relevance of speech intelligibility and music performance in the plays. Finally, IACC is used to assess spatial impression, which includes Apparent Source Width (ASW) and Listener Envelopment (LEV)[15].

The analysis of the median values calculated across all the source-receiver combinations indicate a T_{20} reverberation time of 0.72 seconds at 1kHz (Figure 4). Clarity values (C_{50} and C_{80}) (Figure 3) are very high with a result of 6.37 dB at 1kHz for C50 and 9.121 dB at 1kHz for C80. These high values of clarity were expected due to the greater amount of early energy in comparison to late energy due to the space being open, sound dispersed quickly and the reverberation times short. The IACC values at 1 kHz range from 0.14 to 0.97 (Figure 4). Higher values, as expected, correspond to the measurements in which the receiver is closer to the source (S2-R2), indicating the clear recognition of its position. Receiver positions further from the source record higher levels of listener envelopment and greater ASW.

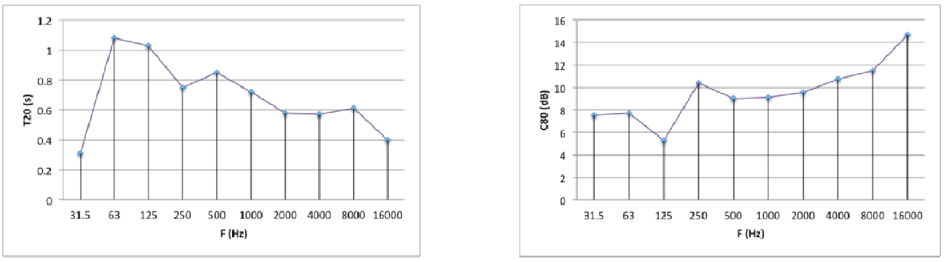

Figure 3 - T_{20} (s) median values (left) / C_{80} (right), median values

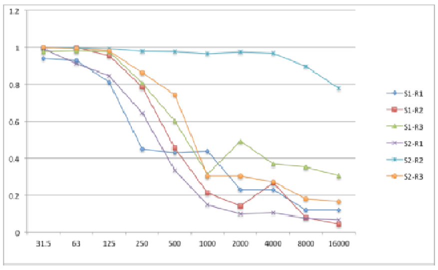

Figure 4 – Comparison of IACC values for different source-receiver combinations

4.2 Virtual Model and Future Work

A preliminary virtual model of Stonegate as it is today and consisting of 231 planes was constructed with CATT-A [16]. Data on surfaces was gathered using a laser distance metre, video footage and photographs. Further geometric and acoustic measures are required to corroborate the results here presented, and a comparison will be conducted between the results of the measurements on site and the results derived from the virtual model. The next stage of this work will be the alteration of the virtual model to approximate the characteristics of the same space during the performances of the *York Mystery Plays*. The model will be informed by extensive research on the area in the years in question.

5. Conclusions

The present paper introduced the difficulties faced when reconstruction the acoustics of spaces used for the *York Mystery Plays*. The results obtained through averaging impulse responses in Stonegate indicate the need for a measuring technique and a way of analysing data that is optimised for measurement in outdoor public spaces. Work has been started on developing a technique that significantly improves signal-to-noise ratio by incorporating automated bandpass filtering of the recorded sweeps such that the reverberation decay at any given frequency is preserved, whilst rejecting out-of-band noise. This is achieved by automating the upper bound cut-off frequency of the filter such that it is just above the instantaneous sweep frequency. The lower cutoff frequency may be set such that it time-lags the instantaneous sweep frequency by RT_{max} seconds, where RT_{max} is the maximum predicted reverberation time, empirically chosen here as 5 seconds.

The preliminary results here presented showed a reverberation time (T_{20}) of 0.72s and consequently high levels of clarity. This indicates that the space would have been more suitable for the spoken parts of the plays than for the sung parts. This reverberation time would have been particularly challenging for the performance of plainchant items which with their monophonic texture and slow melodic lines are suited to the long reverberation times of the cathedrals they were composed for. The values presented for the IACC seem to indicate a tendency to listener envelopment which might have benefitted audience involvement.

Further research into the acoustics of medieval Stonegate will help determine whether the characteristics of the space at the time of the performances provided acoustic characteristics that more favourable to the performances.

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