THE HISTORICAL AURALISATION OF LICHFIELD CATHEDRAL'S QUIRE.

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1 INTRODUCTION

This project concerns acoustic models of Lichfield Cathedral's Quire, both in its modern state and at three points throughout its history; these being a theoretical reconstruction of how it may have sounded from its Anglo-Saxon Christian roots and a model of its soundscape when the Quire was blocked off from the rest of the wider Cathedral. Once these models were constructed with adequate detail and accuracy, suitable auralisations were used to conduct a listening test, with listeners being asked to rate the soundscape of each model using a metric devised from contemporary research into an acoustic understanding of relevant religious history. Listener responses as well as raw data from the models allow determination on what differences present themselves between historical periods, as well as make conclusions as to the historical and cultural reasons behind those differences.

This project bears a heavy influence from reasonably new advances in the sociological understanding of religion. In a break from its philosophical/theological roots, religious discourse since the turn of the century has begun to incorporate sociological ideas, studying religion from the outside rather than the inside, looking at the ways worship is performed between cultures or even between various religions.[23] This came to a certain crystallisation with Whitehouse's writings concerning "modes of religosity" at the turn of the millennium, designating two general categories of religion across all of human culture: "imagistic" and "doctrinal"[22]. This all is relevant to this project on account of a development of these categories that ties the theory together with acoustic theory. Braxton Boren's 2021 paper "Word and Mystery" undergoes a psychoacoustic analysis of the Protestant Reformation, discussing how the radical differences in doctrine between the established Catholic Church and the burgeoning Protestant Reformation are actually echoed in the soundscapes present in their churches/cathedrals. In order to demonstrate this, he creates a two-point continuum along the descriptors "Semantic" and "Aesthetic". In this continuum, a semantic space favours clarity of speech (exemplified by the free field "open air" acoustic) in order to deliver religious revelation by way of scripture, to encourage a direct understanding of the religion by an individual – the "word" portion of Boren's paper. Conversely, an aesthetic space favours the "mystery" portion of Boren's paper, which means a space that focuses instead on creating an appropriate atmosphere for music and other more emotive religious factors, encouraging a personal relation with God experienced through emotional revelation, rather than an intellectualised understanding of religion (exemplified by the diffuse field "cave" acoustic)[9]. This semantic/aesthetic idea is used in the listening test in order to provide a metric for participants to understand and judge the auralisations by.

Two snapshots of the history of the Cathedral were chosen to be recreated for the historic models. The first is its history as a Saxon Church. BBC History and the Victoria History of Lichfield state that prior to the Norman Conquest of England, the site that is now the Cathedral was a Saxon wooden church, roughly in the area which is now the Quire. Whilst detailed architectural details of the area at this time are not available, an approximation of the distinct soundscape present at this early point in its history is created by modelling a very simplified version of the Quire as a wooden construction. The second point relates to a large reconstruction performed in the Cathedral around the 16/1700s, introducing neo-gothic architectural approaches to the Cathedral. In a controversial "modernisation",

James Wyatt performed a drastic change specific to the Quire area. Prior to this reconstruction, the Quire was separated from the rest of the Cathedral proper by a heavy stone screen, which created an isolated acoustic environment within the Quire. A drawing by Wyatt from before his reconstruction was used to recreate the Quire in this isolated state, allowing auralisations to show the sound in the Cathedral prior to its neo-gothic modernisation.[7, 10, 18]

2 METHODOLOGY

2.1 Measurements

Acoustic measurements of the Quire were taken in accordance with ISO 3382-1. In order to take measurements more appropriate to the unique acoustic character of a worship space[2], Martellotta's 2009 guidelines for the acoustic measurement of churches were followed. The equipment used was specified deliberately to satisfy Martellotta's "intermediate" configuration in his paper concerning the acoustic measurement of churches. This configuration calls for an omni-directional electro-acoustic sound source, a receiver measurement microphone with an omni-directional pattern, and a deterministic noise source (in this case a sine sweep) recording in octave bands up to 8kHz[17]. The chosen sound source for this task was the NTi DS3 dodecahedronal loudspeaker, and the microphone chosen was an Earthworks M32mp measurement microphone. The sine sweep was generated via "Room EQ Wizard", a powerful piece of freeware that allows for extensive acoustic measurement within spaces using a source/receiver configuration like this. The metrics it measures also satisfy Martelotta's "intermediate" requirements. It measures reverberation in T20 and T30, as well as measuring many other metrics such as early reflections, as well as generating an SPL curve to determine which frequencies are amplified and which are attenuated within the space.

The measurements were arranged for early 2024. Ben Lamb, director of music at the Cathedral, kindly facilitated for measurement equipment to be let into the Cathedral and for it to stay open after Evensong. Eight receiver positions in the benches were used across two source positions, one towards the entrance of the quire and another towards where the altar is in the current space. Receiver positions were placed in the pews as discussed – these locations were chosen as influenced by Autio's 2021 approach; this is to identify "points of interest" in the space that would hold significance within the normal operation of the church[5]. In this spirit, the source/receiver configuration was designed to represent a religious speaker as the source position, and the congregation to be sat in the pews. This is the typical arrangement when the Quire is used for a religious service. An image of these measurements is attached, with the source being placed in the location of the religious speaker's music stand and a microphone in the location of a congregation member:

Figure 1 Image of the Measurement In Process

An overlay of all 16 SPL curves and a table of average RT60 across both sources is shown here:

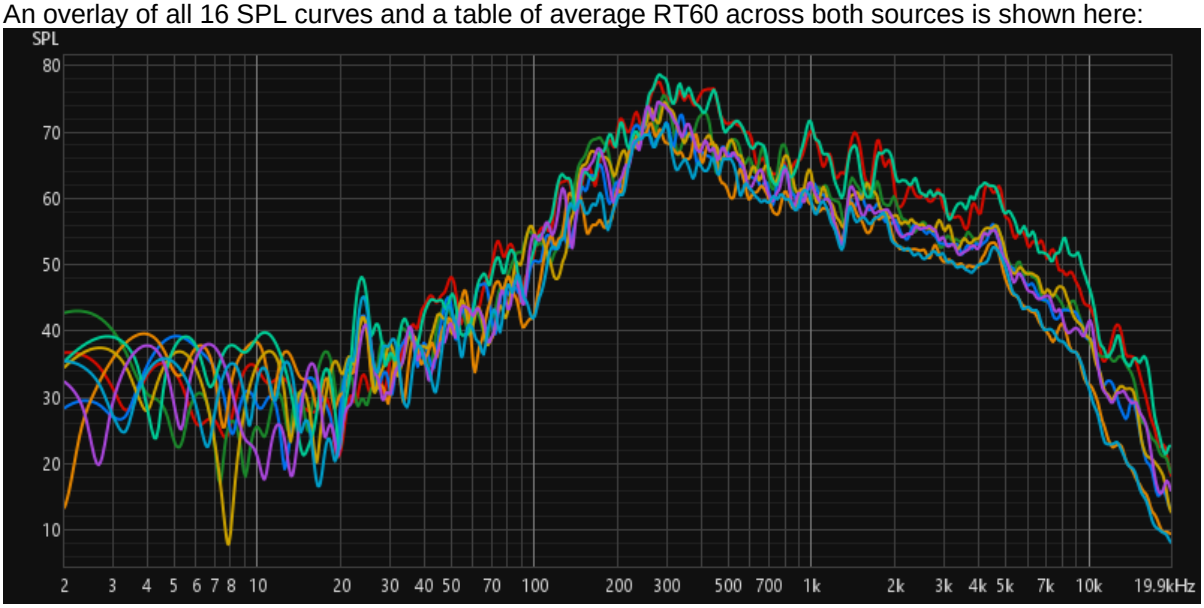


Figure 2 Measured SPL Curve of Lichfield Cathedral's Quire

Frequency	T30	T20
125	2.69	2.49
250	2.67	2.47
500	2.53	2.39
1000	2.42	2.21
2000	2.07	1.88
4000	1.45	1.32
8000	0.8	0.74

Figure 3 Table of Lichfield Cathedral Quire's Average RT60

These graphs show frequencies amplified rising steadily up until a peak at 300hz, then steadily dropping off until 20kHz. The difference between the two positions is minimal, although there is a notable boost in frequencies between 100 and 200hz in the second position. The reverberation time shows a reverberation time usually above 2 seconds, with higher frequencies having a fairly consistent drop-off.

2.2 Modelling

2.2.1 SketchUp

Physical measurements of Lichfield Cathedral were taken, using a RockSeed laser distance measure. Photographs were taken of the space, and then measurements were written onto those photographs. From these photographs, a model was constructed in SketchUp, a 3D CAD modelling software. Certain parts of the Cathedral couldn't be modelled exactly in SketchUp; for example, the model lacks the "ribbing" on the Cathedrals ceiling, and certain details of the model that are higher than ground level such as the exact measurements of the arches and height of the windows were not able to be measured, due to their height.
Additionally, more ornate details were not modelled, following principles discussed in Pelzer's 2010 paper "Frequency and Time dependent Geometry for Real-time auralisations". This paper discusses

the importance of keeping in mind basic acoustic principles when modelling for auralisations, rather than small and more detailed ornamentation. Specifically, it quantifies that because of the range of wavelengths deemed acoustically significant for human hearing, details below 1.7cm are generally acoustically irrelevant.[20]

Some predefined objects were used in the creation of the model. Aldo's model of a metal grate was used to create the underside of the bench altars, Nono H's model of a gate, Joaquin Ignacio's model of an altar, Carlo Roberto S' model of a church bench, and Hooofman's model of a music stand.

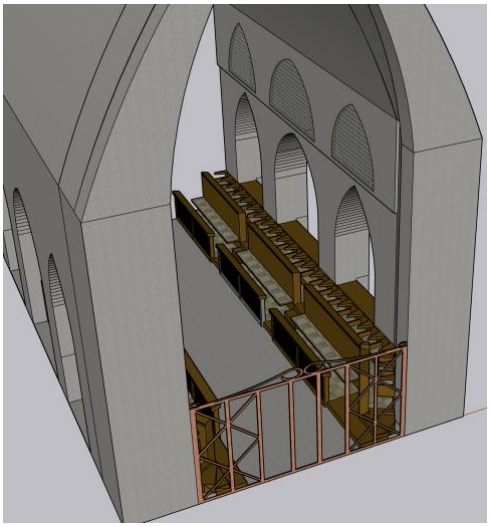


Figure 4 SketchUp Model of Lichfield Cathedral Quire

2.2.2 ODEON

ODEON is a powerful piece of acoustics modelling software, allowing for acoustic predictions of rooms modelled in CAD software. It uses ray tracing to simulate sound travelling through a room, allowing rays to reflect across a model and potentially be absorbed by surfaces given their specific absorption coefficients. The model of the Quire was converted from SketchUp's proprietary .skp format into ODEON's .par geometry format using SU2ODEON, a SketchUp plugin developed by the ODEON team. The model was leak proofed successfully to ensure the model has no ray loss between cracks in its geometry. Absorption coefficients corresponding to the materials the building is constructed from were applied, sourced from Acoustics.ua and from ODEON's inbuilt coefficient information. As only a specific portion of the Cathedral was modelled rather than the whole building, the areas that would represent sound travelling to non-modelled parts of the building were instead defined as absorbing 100% of soundwaves. The following images show the .par geometry once imported and ODEON's room setup

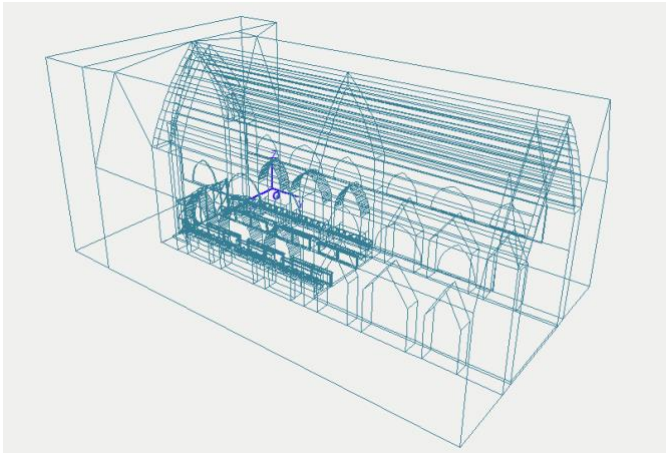


Figure 5 ODEON .par Geometry Model of Lichfield Cathedral Quire

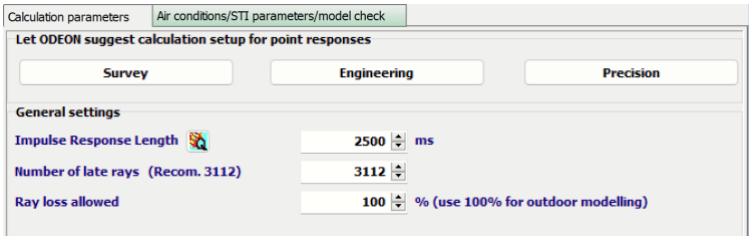


Figure 6 ODEON Model Room Setup

Three separate ODEON features were used to achieve RT60 results from the model. The first is a quick estimate, checking the result based solely on Sabine's Equation (0.161*Volume/Equivalent Absorption Surface). The second uses ODEON's raytracing features in a general estimate, sending out rays across the modelled room and measuring the time taken for reverberation, factoring in each individual surface's absorption. The final is its single-receiver measure, which takes an individual receiver point designated on the model and generates acoustic details from that specific point.

3 VALIDATION AND HISTORIC MODELLING

3.1 Evaluation of Model

In order to measure the success of the model created, RT60 results taken from ODEON were compared against the ISO-3382 measurements compared. Three separate measurement methodologies for RT60 were used from ODEON's features. The first is a quick estimate, checking the result based solely on Sabine's Equation (0.161*Volume/Equivalent Absorption Surface). The second uses ODEON's raytracing features in a general estimate, sending out rays across the modelled room and measuring the time taken for reverberation, factoring in each individual surface's absorption. The final is its single-receiver measure, which takes an individual receiver point designated on the model and generates acoustic details from that specific point.

Approaches for evaluating the model were based on the JND principle. A JND approach is a psychological principle determining the lowest possible change to a given stimulus needed to make 50% of people to notice a change has occurred. For this evaluation methodology, the model is a success at a given data point if the difference between measured and modelled RT60 does not exceed what the JND value is. Two prior studies were looked at to determine what values for this JND should be used. ISO 3382 does give a JND for reverberation time, 5%, but this is based on research conducted in 1958, so a value based on current research was desired.

The first study used is by Buck, Blevins et al. in 2012, which conducted listening studies and concluded that the average JND for reverberation time to be +/-24.5%, at 1khz[8]. Measured T20 and T30 1khz reverberation results will be checked against T20 and T30 general estimate and single-receiver results from the ODEON models.
The alternative approach is based off of a paper by Dorrego from 2022. Rather than quantifying a single JND at a single frequency band, it seeks to quantify a varied JND for different frequency bands, with lower frequencies requiring a much larger shift in reverberation time.[11]

Tested against the former approach, the model succeeds at 21 points out of a possible 24, making for an 87.5% accuracy.
Tested against the latter approach, the model succeeds at 85 points out of a possible 92, making for a 92.4% accuracy.
Averaged together, the model shows a success rate of **89.945%**.

3.2 Historic Models

Following acceptable results in terms of modelling the current space, the historic models were constructed. As discussed, another two distinct models were constructed to showcase two important points in the Cathedral's history. The first was a model of its Saxon roots, made by modelling a simplified version of the current Quire as a solely wooden construction. This model is shown below:

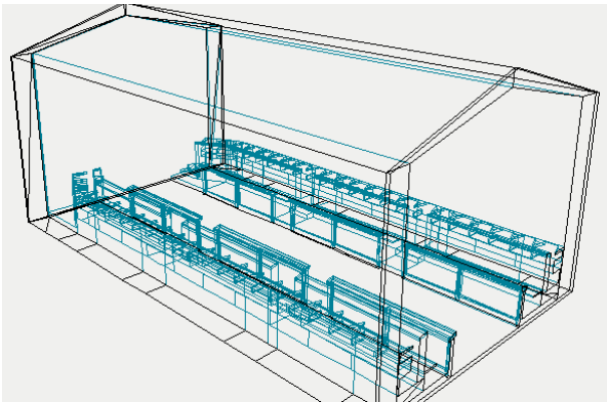


Figure 7 ODEON .par Geometry of the Saxon Model

This model is much smaller and made of significantly more absorbative material[1], causing a much shorter and intimate reverberation time. It has an average RT60 of 1.5s shorter than how the space is nowadays. The second model shows the Quire prior to its James Wyatt reconstruction towards the end of the 1600s, before which it was a space closed off from the rest of the space by a stone screen. This model, as well as the plans drawn up by Wyatt, is shown below:

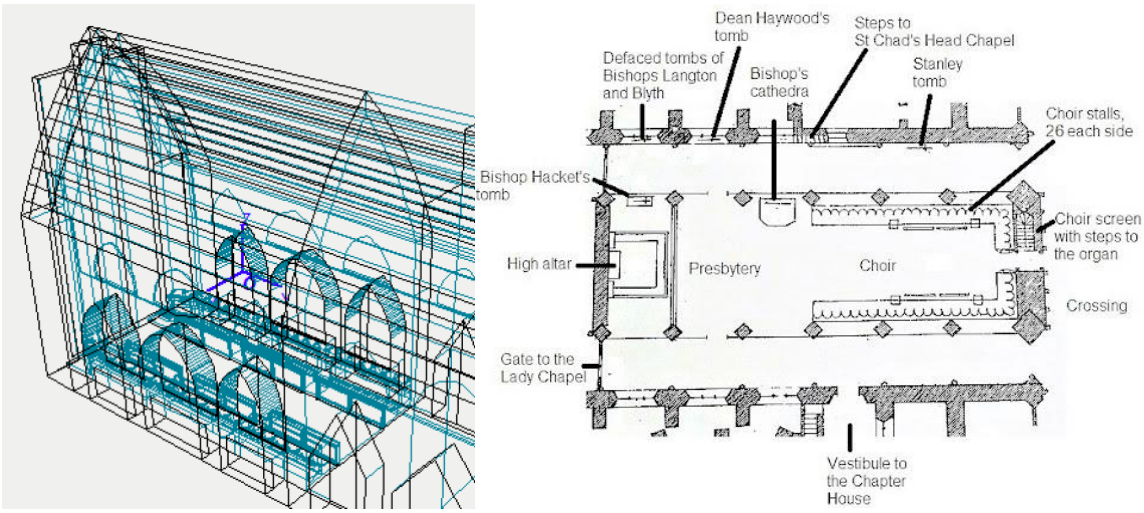
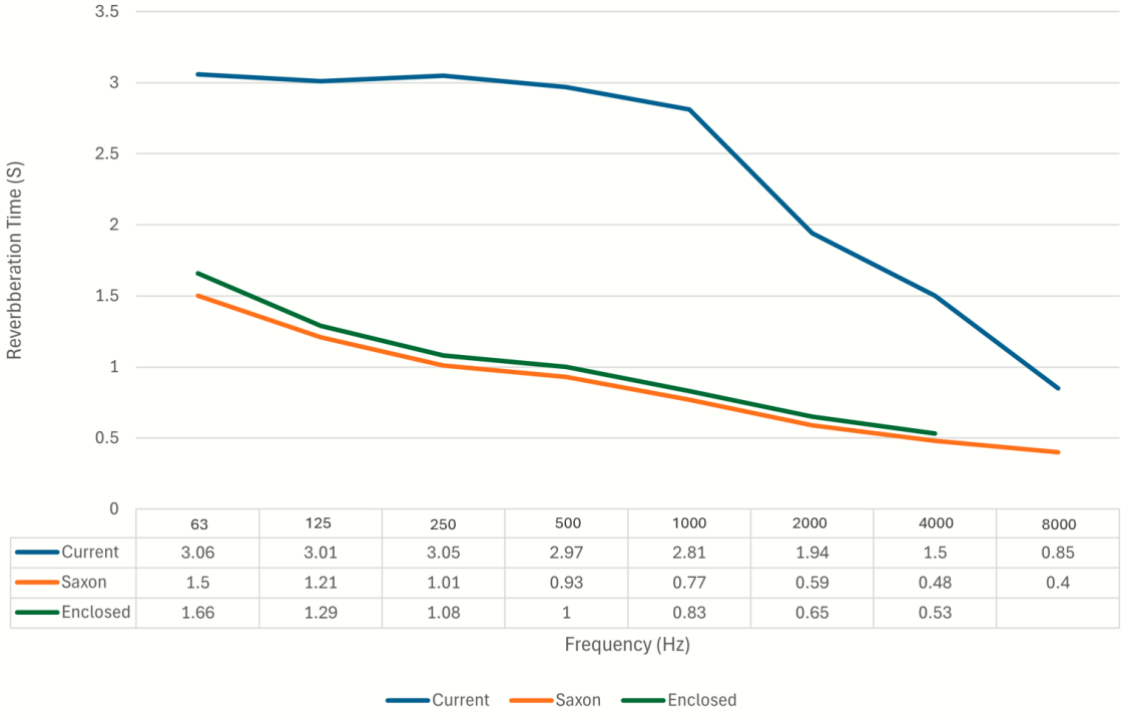


Figure 8 ODEON .par Geometry of the Enclosed Quire and Wyatt's Diagram

The large metal gate present in the current model was replaced by a stone screen with a narrow aperture, and the access to the rest of the Cathedral was replaced by the 100% absorbative material, to demonstrate that the Quire was a space cordoned off from the remainder of the Cathedral. Results trend to being 0.2-0.3s longer across the frequency spectrum than the Saxon Church, longer likely due to the construction being in large part stone rather than wood. The following graphs show global estimate T30 results for each space compared to each other:



	63	125	250	500	1000	2000	4000	8000
Current	3.06	3.01	3.05	2.97	2.81	1.94	1.5	0.85
Saxon	1.5	1.21	1.01	0.93	0.77	0.59	0.48	0.4
Enclosed	1.66	1.29	1.08	1	0.83	0.65	0.53	

Figure 9 Graph and Table of Each Model's RT60 Results

3.2.1 Auralisations

Auralisations were generated for each model. Images of the auralisation setup are shown below:

Active sources for job: 1

P1 Position 2, Jan 31 Measurements - Point source at: (x,y,z) = (10.193, 15.704, 0.200)

P2 Position 1 Jan 31 Measurements - Point source at: (x,y,z) = (10.193, 3.892, 0.200)

Job	Job description	Receiver pointing towards source	Grid	Multi	Single point response receiver	
1	Auralisation Modern Space	Direction towards main axis, -X	☐	☐	1 Mic Position 4	(x,y,z) = (6.600, 15.385, 2.000)
2	Test	Direction towards main axis, -X	☐	☑	1 Mic Position 4	(x,y,z) = (6.600, 15.385, 2.000)

Convolve Binaural RIR with Signal file

Conv. no.	Enabled	Signal Sub Path	Signal file	Time	Channel	Calib.	Job no.	Receiver	Job descr.	Rcd. lev.	Max. out
1	☑	Piano recordings\	Piano Autumn Leaves Mic2	0:51'04	Average	☐	1	1 towards -X	No description	-50.00	-2.87
2	☑	Speech (language	The Emperor's Clothes (en	1:00'28	Average	☐	1	1 towards -X	No description	-60.00	-8.41
3	☑	George Installed\	Allemande anechoic	1:13'39	Average	☐	1	1 towards -X	No description	-50.00	-1.88

Figure 10 ODEON Model Auralisation Setup

This setup reflects the ISO-3382 measurements, in the second source position and fourth receiver position (sat in a bench). This was kept consistent across all auralisations. Three audio files were auralised, each being an anechoic recording. These were a recording of a male voice reading “The Emperor’s Clothes”, a solo piano performing the jazz standard “Autumn Leaves”, and an ensemble recording of an “Allemande” (a style of Baroque dance), recorded as a part of co-author Islah Ali-MacLachlan’s early music project. This configuration was chosen to give listeners the perspective a member of a congregation would have at each given snapshot in history, the receiver location being placed where a member of the congregation would sit in reality.

4 DISCUSSION

4.1 Listening Test

In order to quantify differences between the spaces from the point of view of a listener within the space, a listening test was performed. Aforementioned auralisations were provided to participants, who were asked to use Braxton Boren’s „Aesthetic/Semantic”[9] dichotomy to describe how they responded to each space. This scale is shown below, along with Boren’s ratings of certain well known religious spaces:

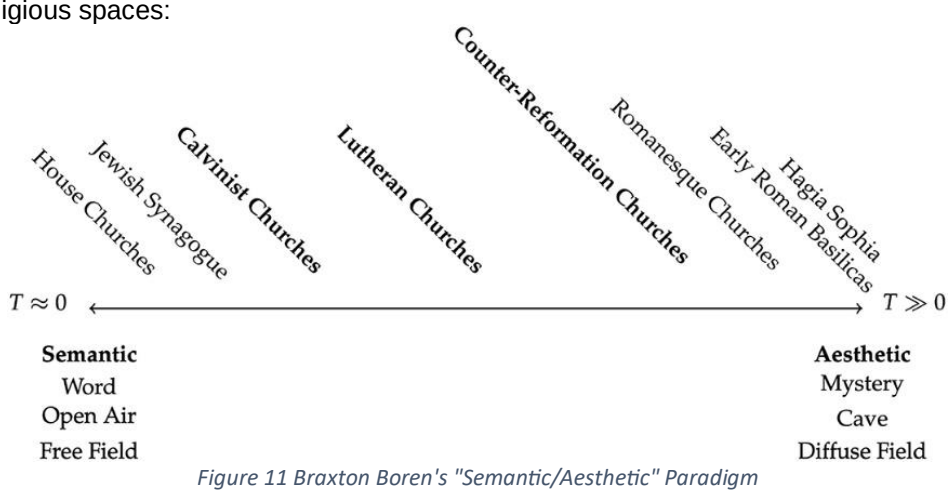


Figure 11 Braxton Boren's "Semantic/Aesthetic" Paradigm

Participants were then asked to rate the space from 1-10, using this scale, as well as an explanation of Boren’s theory, to guide their rating. They were also optionally invited to give a brief description in their own words of how they respond emotionally to each space.
The test had 27 respondents, each rating all 3 spaces on a scale from 1 (most semantic) to 10 (most aesthetic). Of these responses, the average rating for the modern space was 7.33, for the Saxon Church 3.78, and for the enclosed quire 6.22. According to Boren’s scale, this means the modern space was considered slightly more aesthetic than conventional counter-reformation churches, the Saxon church similar to a Jewish Synagogue, and the enclosed quire a little more aesthetic than a Lutheran church.

A one-way ANOVA was performed to compare the relative aesthetic/semantic according to listeners between the models used.
This ANOVA revealed that there was a statistically significant difference in [dependent variable] between at least two groups (F(2, 78) = [29.36], p = [3.12E-10]).
A Tukey post-hoc determined a critical Q value of 1.13. This was used to determine pairwise differences in listener responses each model, comparing this value to the absolute mean differences between models. This comparison demonstrated statistically significant differences comparing the Saxon space both to the Modern and Enclosed space. Respectively, these demonstrated absolute mean differences of 3.56 and 2.44, both higher than the Q-crit value.
There was no statistically significant difference between listener responses to the Enclosed space and the Modern space, showing an absolute difference of 1.11, 0.02 lower than Q-crit value.

4.2 Further Discussion

The Saxon Church is the only space of three that after statistical testing can be shown to be of significant distinction compared to both other spaces. At the same time, it is also the space furthest from the other two in terms of time. This difference is made more apparent when taking into account the language used by respondents in their response to the optional question. Whilst there is a notable (if not statistically significant) difference in character between responses to the enclosed and modern spaces, responses given to them still tend to operate along the same language – 13 counts of respondents to the modern space and eight to the enclosed space reference the space's size or reverberance – adjectives such as "echoic", "spacious", and "atmospheric". However, outside of two responses referring to it as "intimate", responses to the Saxon space instead focus upon an emotional response to the space, or what they feel the use-case of the space may be (a communal area/meeting space typically is what respondents decided upon). Not enough information is available from this specific testing in order to draw a full conclusion on the matter, but it is potentially the case here that the soundscape of a given space makes an immediate impact upon what metrics a listener may judge it upon, rather than simply based upon the non-aural information they have about the sound or other biases.
The Saxon Church modelled is, statistically provably, far more "semantic" in response than "aesthetic"; it focuses the vocal aspect of the space, likely more suited to smaller gatherings between communities in a more relaxed social sense, rather than a space like the modern Cathedral that ends up being a space more focused upon the aesthetic. *Anglo-Saxon Christianity is a wide topic (a topic that is perhaps beyond the scope of this project*), but what is interesting to note is how this intimate space reflects the Anglo-Saxon Christianity. This specific model refers to the space in and around the 600s, which was also very shortly after the Anglo-Saxons embraced Christianity as a culture. Given this was a culture that was still in its Christian infancy, the ways they practiced Christianity bore a lot of the hallmarks of the pagan religions that predated it. Anglo-Saxon paganism trended towards a more communal attitude, far more based in specific ancestors than how we now understand modern Christianity (indeed, the construction the wooden model attempts to emulate is by some scholars assumed to have served a funereal purpose). In this respect, the intimate, "word-focused" environment this soundscape presents with would have reflected the form of worship in this building.[14]

It is noted by Frew that Wyatt's reconstruction of the space (that is to say, roughly speaking the change from the modelled "enclosed space" to the modern space) was unpopular with the congregation at the time, as it served to remove from the space a certain ritualistic purpose it had held prior in favour of Wyatt's aesthetic concerns. However, the modern listeners who were asked to fill in the questionnaire who gave their opinions on their emotional response to the spaces were often rather negative about the sound of the enclosed Quire. 5 respondents used a negative adjective to describe the enclosed space, whereas only 1 referred to the modern or Saxon spaces in an overtly negative way. Without further interview (made impossible by the anonymous nature of the survey) it is not possible to discuss exactly *why* this space was considered particularly unpleasant, but it allows a tentative idea to be made that the sensibilities of modern listeners for their liturgical spaces have almost become reversed from the point in time this emulates. Further

research would be needed to draw any serious conclusions, but this lends itself to ideas laid out by Boren that acoustic and religious histories are inherently connected – sensibilities at the time of this change were such that they favoured the enclosed, shut off atmosphere of the Quire at that point, but religious development has evolved to an extent that it's now undesirable. The question Boren's approach invites us to ask is to what extent these changes worked in tandem; that this section here shows us religious and acoustical history co-occurring and affecting each other holistically.
Wyatt is described to have wished to open the space up, to create a space equally more mysterious and beautiful – it could be said that these architectural values being thrust upon religious spaces by their contemporary architects had the effect of beginning to impact the sensibilities of the congregations of those spaces; the soundscape within which religion was delivered to them having its impact alongside with the words being spoken.[7, 10, 18]

5 CONCLUSIONS

This project aimed to measure and model Lichfield Cathedral's Quire, to create models of the space across two points in history and determine how those historical spaces differ from the modern. Three models were successfully constructed, and the model of the modern space (when compared to ISO 3382-1 measurements of the space in reality) showed success in satisfying an evaluation methodology based upon the JND psychological concept.
This project can be summarised with the following conclusion: Using Braxton Boren's "Aesthetic/Semantic" paradigm as a metric to measure religious spaces by, Lichfield Cathedral's Quire has become significantly more "Aesthetic" as history has gone on. It's soundscape in its Saxon roots was described by respondents to a listening test to be strongly to the "semantic" side of this paradigm, whereas the modern space is on the opposite end of this scale. This can be shown to be reflected also in the contemporary religious practices within each space, with Anglo-Saxon Christianity being far more community based and thus focused upon speech, whereas Christianity in the Medieval and onward periods had a far stronger focus upon music and aesthetic. This can be viewed as a demonstration of Braxton Boren's ideas in his paper "Word and Mystery", where he outlines the way in which the history religious cultural exchange is shown as a mirror image on the history of acoustics within religious spaces.

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