DOI: 10.61782/fa.2025.0415

FORUM ACUSTICUM EURONOISE 2025

FROM MEASUREMENT TO MUSIC: REVIVING THE ACOUSTIC HERITAGE OF ST. MICHAEL'S CHURCH, COVENTRY, UK

Islah Ali-MacLachlan* **Helen Roberts** **Benjamin West**
Simon Hall **Jamie Savan**
Birmingham City University, Birmingham, UK

ABSTRACT

This paper presents findings from the Aural Histories project, which explores how music was experienced in historical ecclesiastical spaces through acoustic modelling and auralisation. Focusing on St Michael's Church, Coventry, UK, digital reconstructions of the building as it may have stood in 1451 and 1617 were created using archival and typological evidence, and analysed using Odeon software. Simulations suggest that architectural changes between these dates had only minor impact on acoustic conditions in the chancel, with reverberation and clarity metrics remaining consistent. To support auralisation, recordings of an eight-voice choir performing Tallis's *Why Fum'th in Fight* were captured in both studio and anechoic settings. Spectral and cepstral analyses revealed minimal differences between the two, particularly in mid and high frequencies. Expert listening tests showed no statistically significant perceptual differences between auralisations using either source supporting the practical use of studio recordings in virtual acoustic reconstructions. Future work will explore additional repertoire and conduct further perceptual testing in immersive environments such as the Birmingham SoundLab® to assess the impact of recording choices on spatial perception and listener experience.

Keywords: *auralisation, church acoustics, historical reconstruction, perceptual listening tests*

1. INTRODUCTION

'Aural Histories: Coventry, *c.*1451-1642' is an interdisciplinary research project, funded by the UK's Arts and Humanities Research Council (2022-25), investigating the experience of music in late-medieval and early modern Coventry through performance and recording in digital reconstructions of its lost performing spaces. The project brings together a team of experts in historical musicology and performance practice, architectural history, acoustics and sound recording, and 3D modelling and computer games design. The research focuses on music that might have been heard within and between the buildings at the civic and ecclesiastical centre of the city, most notably including St Michael's parish church (raised to cathedral status in 1918) which was destroyed in the blitz of 1940, together with neighbouring Holy Trinity parish church and St Mary's Hall, shown in Figure 1. Taking a long chronological view over two centuries of religious and political upheaval, these buildings can be understood as dynamic spaces that change both through different phases of construction and furnishing, and in their use as ritual and performative space.

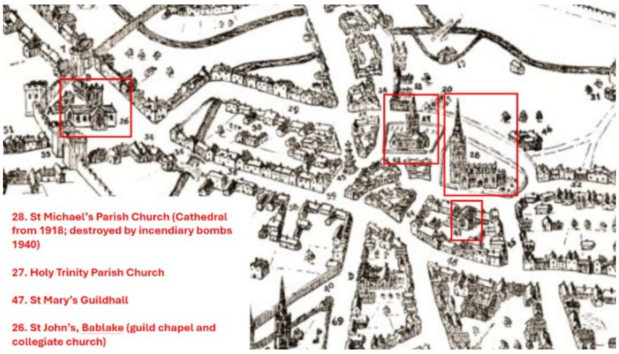

Figure 1. Map of Coventry in 1656.

The purpose of this paper is to report on the methodological underpinnings of the project relating to

***Corresponding author**: islah.ali-maclachlan@bcu.ac.uk

aspects of archaeo-acoustic restitution, through which we seek to address the following research questions:

- What were the essential acoustic characteristics of St Michael's church, and how did these change over time?
- How do changes in the architecture alter sound perception?
- How can auralisation techniques enhance historical understanding?
- How can our recording techniques be optimised to best represent ensembles of voices and/or instruments within the virtual performing space?

2. HISTORICAL CONTEXT AND ARCHITECTURAL EVOLUTION

St Michael's was one of the largest parish churches in England, unusually co-located with Holy Trinity Church at their parish boundary which runs through the centre of Coventry, mirroring the historic division of the city into the Earl's and Prior's halves. Whereas Holy Trinity Church survived the blitz of 14 November 1940, thanks to the vigilance of its vicar-turned-firewarden and no small amount of luck [1], St Michael's was tragically destroyed by incendiary bombs, and its ruined shell has since become recognised as an international symbol of peace and reconciliation.

St Michael's holds a particular interest for our project because it is known that King Henry VI went on procession to hear Mass sung there in 1451, the year in which he granted Coventry a charter elevating it to county status [2]. It was also the site of a further royal visit in 1617, on which occasion King James I is likely to have heard Evensong sung in the church, prior to dinner at St Mary's Hall [3]. We therefore have the opportunity to stage two specific musical scenarios within the building as it may have appeared on these different dates.
Central to our project is the idea that historic buildings are dynamic spaces: they change over time, both in their geometry through different phases of construction and alteration, and in their internal configuration including hard and soft furnishings.

In 1451 the principal structure of St Michael's had not yet reached its final form (see Figure 2). At this time, it was essentially a rectangular, basilica shape. The side chapels associated with the city's guilds and craft fellowships, which extended the north and south aisles in the nave were not completed until *c.*1500 [4]. The great majority of musical and ritual activity took place at the chancel, which was an area of privileged access for the choir and priests at the east end of the church, separated from the nave by the wooden choir screen, a substantial structure, above which was a loft containing the rood (a carved image of the crucified Christ, flanked by Mary and John).

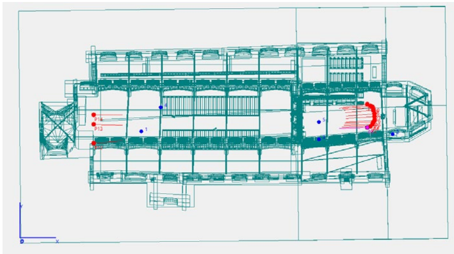

Figure 2. Geometry for St. Michael's Church 1451.

By 1617, the principal structure of the church had been complete for over a century, but its internal configuration continued to change (see Figure 3). Its 'new' side chapels enjoyed a relatively brief period of use and had stood empty since the dissolution of the guilds and chantries in 1547, a direct consequence of the Reformation. The rood loft would have been removed in 1560, although the screen likely remained [5]. The altar was removed at this time, and a shift towards speech (i.e., preaching), rather than song, as the principal mode of worship resulted in a reorientation of the focus of activity from the east end of the church to the pulpit, which was located one column west of the rood pillar, on the north side of the church. The desirability of a sight line to the pulpit perhaps explains why a raised gallery was built along the south aisle in 1614, and a further gallery built above the Mercers' chapel in 1616, creating new acoustic as well as visual vantage points [6-7].

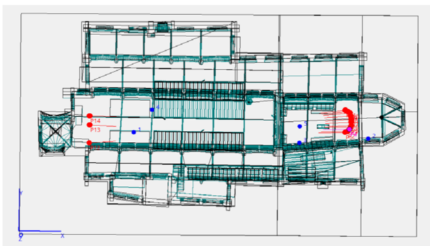

Figure 3. Geometry for St. Michael's Church 1617.

Soft furnishings in 1451 would likely have included tapestries adorning the choir furniture, and banners likely adorning the eight altars and six chantries known to have existed by this date. We also know that the Lady Chapel (Draper's Chapel), and perhaps other parts of the church, had a floor covering of straw or rushes at this time [8]. All these factors are likely to have affected the acoustic response of the building, and the way in which music was experienced. We imagine the most striking acoustic intervention might have been experienced by King Henry VI himself, since he is known to have sat within his 'closet', a fabric-sided enclosure, during the service.

We imagine soft furnishings adorning the ceremony in 1617 to have been rather more sparse, although seats associated with important civic personnel, the mayor especially, may well have involved cushions and even curtains, and King James is likely to have sat under a canopy of silk [3].

3. RECORDING METHODOLOGY FOR HISTORICALLY INFORMED PERFORMANCE

A key objective of this practice-based research is to recreate the sound of vocal and instrumental performances as they may have occurred in Coventry's historical spaces. Achieving this synthesis of historical musicological research, performance practice, and historical acoustic modeling requires a distinct approach to ensemble recording, differing significantly from traditional methods used in the capture of historically informed performance.

Conventional recordings in this field typically follow century-old practices, where all performers are recorded simultaneously within a live space. This 'classical Decca' approach prioritises acoustically appropriate environments, such as concert halls or sacred spaces, using microphone techniques to capture the live, natural acoustic resonance [9-10].

By contrast, recording for auralisation demands a fundamentally different methodology. To successfully integrate performances into a virtual acoustic environment, recordings must be captured in a dry, neutral, and acoustically isolated setting.

The ideal method is to record each performer individually in an anechoic chamber, totally eliminating acoustic colouration and sound spill. However, this approach presents challenges in ensemble cohesion and musical effectiveness. The ability to see, hear, and respond to fellow musicians in real-time is fundamental to expressive performance, and isolation can limit this interaction.

Reference test recordings were conducted with members of His Majestys Sagbutts and Cornetts at Holy Trinity Church and St Mary's Guildhall in Coventry. Subsequent recordings of the instrumental ensemble and a student vocal consort (RBC Ex Cathedra Scholars) took place in the Royal Birmingham Conservatoire studios.

Studio recording employed directional, low-sensitivity dynamic microphones placed close to performers, with acoustic screens minimising sound spill. This setup allowed musicians to maintain visual contact with each other and the musical director, closely replicating a traditional rehearsal or performance setting. Performers also used a personal foldback system through closed-back headphones, allowing them to hear a blend of the performing ensemble and an artificial reverb impulse response of the current Holy Trinity Church or Guildhall.

Following these studio sessions, individual overdubbing was conducted at the University of Birmingham's anechoic chamber. Using flat frequency-response microphones, musicians recorded their parts in isolation, guided by the studio recordings as backing tracks. This approach produced entirely dry versions of the material, free from sound spill or acoustic colouration. Multiple takes were recorded for each part, enabling precise postproduction editing. This method also facilitated additional double-tracking, pertinent for increasing the number of voices for choral repertoire, enhancing the perceived size of the virtual choir and providing a 'gold-standard' reference for sonic comparison.

The studio recordings resulted in musically compelling performances with high-quality representations of the repertoire. Sonically, the anechoic recordings exhibit exceptional acoustic purity. While studio isolation booths significantly reduce sound spill, some residual spill remains, typically measuring between -24 dB and -30 dB—equivalent to performers being at least 30 meters apart in a free-field environment.

Recording each performer individually in an anechoic chamber yields the cleanest acoustic results but is highly time-intensive and physically demanding for both musicians and production teams. This method also significantly limits the volume of material that can be recorded within the scope, timeframe and budget constraints of the project.

The use of dynamic microphones in the studio introduces some acoustic colouration, as do early reflections from recording booths. Although this differs from recording in a resonant sacred space, it remains a preferable approach for extended-duration works. This is especially pertinent when recording newly produced editions produced by the musicological team, which are being performed and recorded for the first time.

Recording multiple performers simultaneously in an anechoic chamber, as explored by other researchers [11] presents an alternative. However, due to chamber size limitations and consequent ensemble interaction challenges, this method offers little advantage over a fully studio-based approach.

A fundamental tension exists between sonic neutrality and musical cohesion when selecting recording strategies for projects of this kind. Whilst anechoic recordings provide the most acoustically neutral data for auralisation, studio-based capture remains the more practical and effective method for achieving musical effectiveness with performance authenticity. It is therefore the preferred approach for the majority of the repertoire to be developed within this project.

4. ACOUSTIC MODELLING AND AURALISATION

The process of modelling St Michael's church as it may have stood in 1451 and 1617 had 4 principal stages: Lidar scanning of the surviving ruins using a Matterport Pro 3 scanner; collation of archival materials—primarily eighteenth- and nineteenth-century plans and drawings, and some photographs—that depict the building as it stood before 1940 [4, pp. 64–65], see also [12].
Production of Sketchup models combining Lidar mesh data with archival evidence about the structure of the space and typological evidence from other sites about acoustic-critical material contents; export of models from Sketchup as .par files (using Odeon's Sketchup extension) for import into Odeon. Objects within the Sketchup model were tagged by material, these tags imported into Odeon and then assigned acoustic properties. Visualisations of the space were created by doing cosmetic work and additional detailed modelling work in Blender and ultimately rendered using Unreal Engine.

The ruins of St Michael's provide enough information about the height of the clerestory, the placing of pillars in the nave, and the position of the rood screen to allow for a well-informed reconstruction of the shell of the building in 1617, which then remained largely structurally unchanged until 1940. The unusual additional north aisle housing the Smiths' and Girdlers' Chapels, plus the Cappers' and Dyers' Chapels on the south side of the church were not complete until just after the middle of the fifteenth century [4] and the footprint and acoustic volume of the space in 1451 is therefore different to that in 1617 (see Fig. 2 and Fig. 3). Iconographical and archival evidence detailing the interior of English churches before the Reformation is highly fragmentary, as are surviving examples of woodwork, fabrics, and wall decorations and this is no less the case for St Michael's. As such, certain aspects of our reconstructed space such as the placement of some windows, the precise arrangement of side chapels (1451), and the exact form of the screen (both periods) remain necessarily speculative. Several continental sources were, therefore, consulted to re-imagine the acoustic environment of the royal visit of 1451, including the addition of tapestries, carpets, and the King's Closet to the space [13-15] and surviving wall treatments at St Mary's, Fairford (Gloucestershire), St Peter's, Wootton Wawen (Warwickshire), and St Thomas's, Salisbury (Wiltshire) have informed the addition of plaster to the majority of stonework in the interior of the church. For the 1617 model, strong visual distinctions can be drawn between the pre-Reformation space through the likely whitewashing of interior walls to cover over the existing wall decorations, confirmed by archival references to this practice at neighboring Holy Trinity Church. The major acoustic intervention between 1451 and 1617 of pews and galleries introduced a large volume of timber into the space. These items have been modelled on surviving examples at St Mary the Virgin, Croscombe (Somerset), St Mary the Virgin, Puddletown (Dorset) and on a surviving set of seating plans from Holy Trinity Church, along with an eighteenth-century watercolour depicting the interior of St Michael's [4, p. 64]. The screen itself is modelled on surviving fifteenth-century woodwork in Manchester Cathedral.

For the purposes of acoustic modelling in Odeon, three key differences exist between the Sketchup models and those used for visualisations in order to improve performance and minimise unnecessary geometry: all fabrics are modelled as flat planes; no tracery is included in the windows; people are represented as solid blocks

(1.8m high for people standing and 1.4m high for people sitting).

This study focuses on the choir in the chancel, shown as a semi-circular cluster of sources on the right of Figure 2 and Figure 3. The receiver was also in the chancel, approximately 10 metres in front of the choir. All congregation areas were modelled using absorption characteristics corresponding to a seated audience on wooden chairs, at a density of two persons per square metre.

T(30) reverberation times are shown in Table 1. D(50) and C(80) averages were 0.59 and 3.8dB using the 1451 geometry, and 0.60 and 4.0dB using the 1617 geometry. Source recordings of an eight-voice choir performing Tallis's *Why Fum'th in Fight*, captured in both studio and anechoic chamber settings, were used for auralisation.

Table 1. Comparison of T(30) reverberation times, St. Michael's church chancel 1451 and 1617.

	T(30)(s)							
Frequency	63	125	250	500	1000	2000	4000	8000
1451	2.32	2.31	2.15	1.85	1.66	1.39	1.15	0.74
1617	2.63	2.61	2.42	2.06	1.86	1.59	1.29	0.79

The comparison of Mel Frequency Cepstral Coefficients (MFCCs) and spectral energy are common in musical instrument [16] and singing voice [17] classification. The spectral and cepstral analyses of anechoic and studio recordings show similar characteristics, supporting the use of studio recordings in auralisation processes traditionally dependent on anechoic sources. The 1/24 octave smoothed spectral energy comparison demonstrates close alignment across the frequency spectrum, particularly in mid to high frequencies (see Figure 4). The spectrum plot illustrates the relative energy distribution across various frequencies of the audio signal, with each point on the plot indicating the magnitude in decibels (dB) relative to the reference level.

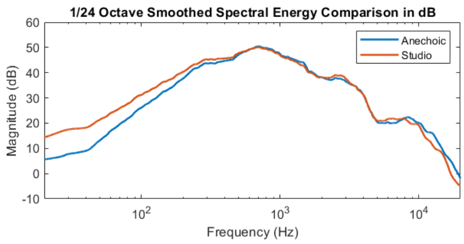

Figure 4. Comparison of 1/24 octave smoothed spectrum plots of anechoic and studio recordings of *Why Fum'th* (Tallis).

Further analysis of the MFCCs show comparable patterns between the two environments (see Figure 5). The first two coefficients, which represent the overall spectral roll-off and general spectral shape, are nearly identical with the anechoic recording displaying means of -42.4 and 3.02, and the studio recording presenting -42 and 3.01 respectively. For clarity and to avoid distorting the scale of the graph, the first coefficient, which is significantly larger than the others, is omitted from the figure. These minimal differences suggest a negligible impact of studio acoustics on the key spectral features relevant to auralisation. This supports broader findings that MFCCs remain robust across varying acoustic conditions, and continue to provide strong classification performance in musical and speech contexts [18].

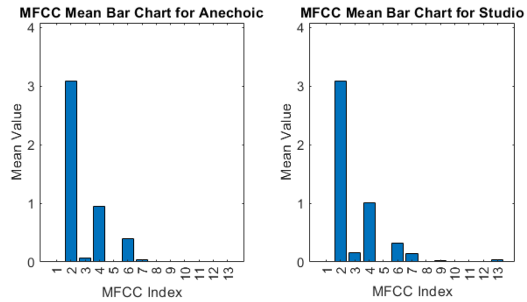

Figure 5. MFCC coefficients for pre-auralisation recordings, comparing data for anechoic and studio recordings of *Why Fum'th* (Tallis).

Similar results can be seen in post-auralisation results. Figure 6 and Figure 7 show spectral and cepstral analyses.

A spectral energy graph for the 1617 geometry can be seen in Figure 8.

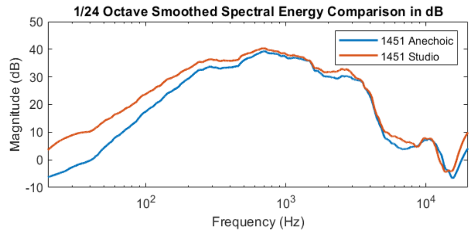

Figure 6. Comparison of 1/24 octave smoothed spectrum plots of auralisations using St. Michael's church 1451 geometry with anechoic and studio recordings of *Why Fum'th* (Tallis).

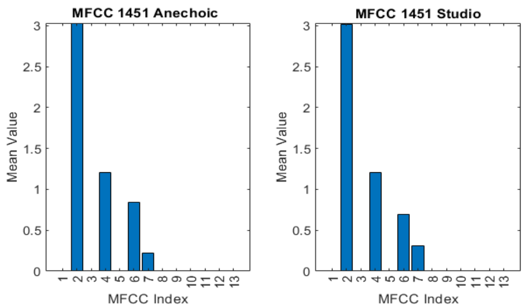

Figure 7. MFCC coefficients for auralisations using St. Michael's church 1451 geometry with anechoic and studio recordings of *Why Fum'th* (Tallis).

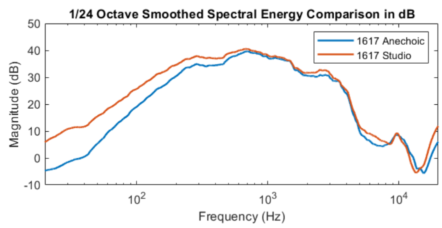

Figure 8. Comparison of 1/24 octave smoothed spectrum plots of auralisations using St. Michael's church 1617 geometry with anechoic and studio recordings of *Why Fum'th* (Tallis).

Given these findings, and considering the increased comfort and performance musicians experience in studio settings—where they can deliver more natural and expressive renditions—studio recordings not only serve as a practical alternative but may also enhance the overall quality and authenticity of auralised environments. The comfort of the performer directly affects the recording's expressiveness, which is vital in creating immersive and realistic aural experiences.

This analysis confirms that studio recordings, by closely matching the acoustic fidelity of anechoic recordings and enhancing musician comfort, provide a solid basis for their use in auralisation, supporting a shift towards more practical and artistically conducive recording practices in acoustic research.

5. EXPERT LISTENING TESTS AND PERCEPTUAL ANALYSIS

To explore the perceptual impact of using studio recordings for the auralisation of historical spaces, a pilot listening study was completed with 8 expert listeners. Participants were recruited from within the research groups associated with the project and were asked to assess auralisations developed using studio and anechoic recordings, for both the 1451 and 1617 geometries. Videos[1] were prepared for each auralisation, including a static image generated using Unreal Engine (see Figure 9). The image displayed was constant for all auralisations so that participants could not visually determine which geometry was being presented. The study was presented using Microsoft Forms with accompanying videos available for download. Participants were asked to complete the study using an audio interface and over-ear headphones. A fifth auralisation was included as a familiarisation task at the start of the test.
The semantic scales used for the questionnaire were inspired by research on the perception of historical acoustics, where it is argued that the acoustic perception of worship spaces operates on a continuum (see Figure 10), from the extremes of semantic: clear, intelligible and direct, to aesthetic: enveloping, immersive and spacious [19]. Five-point Likert scales were used to demonstrate agreement with each of

[1] https://github.com/izzymaclachlan/AuralHistories/tree/main/Euronoise25

these descriptors, assess the sound environment overall, and its overall appropriateness to the displayed location, for each of the auralisations developed. A free text question was included for each auralisation to allow participants to identify other words they would use to describe the presented sound environment.

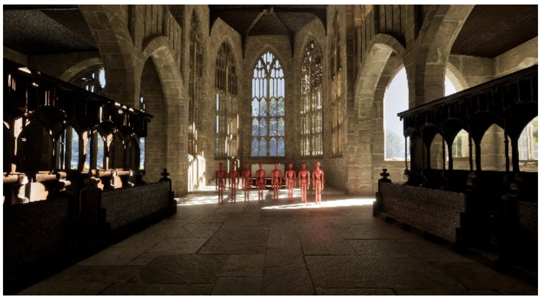

Figure 9. Visualisation of St. Michael's church choir position from listener position.

Figure 10. Boren's (2021) acoustic perception of worship spaces continuum

T-tests were performed for each of the perceptual assessment scales using the software environment *R* (version 4.2.1), to identify whether there was a significant difference between the studio and anechoic recordings, using both the 1451 and 1617 geometries. The only significant difference found between anechoic recordings (M = 1.000, SD = 0.00) and studio recordings (M = 1.375, SD = 0.52) was for 'immersive' scores with the 1451 geometry; $t(7) = -2.049$, $p = 0.0796$. The boxplot in Figure 11 displays this relationship graphically, and shows that the median for the two conditions is the same, with the studio recording environment receiving a larger interquartile range.

The statistical results from the pilot listening study indicate that for almost all assessed dimensions there is no perceptual difference between auralisations developed using studio and anechoic recordings.

The free text question identified themes of strong consonants and 'metallic sibilants' and truncation of the reverberant tail for all auralisations. Both of these effects will be explored before any full listening study is conducted.

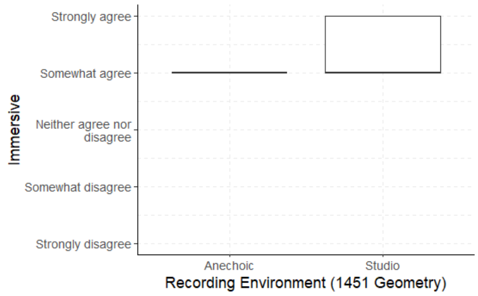

Figure 11. Boxplot of participant ratings of 'Immersive' by recording environment for the 1451 geometry. The central line within the boxes indicates the statistical median.

6. RESULTS AND DISCUSSION

The Odeon simulations show negligible acoustic differences between the 1451 and 1617 models when analysed from the chancel as evidenced by comparable T30, D50 and C80 values (see Table 1). Despite changes in furnishings and layout, the large volume and reflective surfaces of the space dominate its acoustic response.

Spectral and cepstral analyses (Figures 4–8) show a high degree of similarity between studio and anechoic recordings, especially in the mid to high frequency range. Minor differences at low frequencies are unlikely to significantly impact perceptual outcomes in headphone-based listening environments.

Expert listening tests (Section 4) revealed no statistically significant perceptual differences between auralisations using studio or anechoic sources, except for a small effect on perceived immersiveness in the 1451 geometry. This supports the use of high-quality studio recordings in auralisation workflows, particularly when musical expressiveness and ensemble cohesion are priorities.

7. CONCLUSION AND FUTURE WORK

Statistical analysis of perceptual assessments indicates that studio recordings are suitable for the auralisation of historical spaces with long reverberation times, such as churches, offering a practical and expressive alternative to anechoic recordings. While minor spectral differences were observed, these did not produce significant perceptual effects in headphone-based listening tests. However, this conclusion may not extend to smaller or more acoustically neutral historical spaces, where early reflections and fine spectral details play a more critical role in perception.

Future studies will include expanded listening tests in immersive environments such as the Birmingham SoundLab®, where low-frequency and spatial differences may be more perceptible. This work forms part of a wider project exploring a range of period-appropriate music within both the 1451 and 1617 models, providing a richer dataset to examine the relationship between historical acoustics, performance practice, and aural perception.

8. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Arts and Humanities Research Council (AHRC) for funding the Aural Histories: Coventry 1451-1642 project (grant ref: AH/W010186/1), which underpinned the research presented in this paper.

9. REFERENCES

[1] G. W. Clitheroe, *Coventry Under Fire*. Gloucester: British Publishing Company, 1941.

[2] R. W. Ingram, Ed., *Records of Early English Drama: Coventry*. Toronto: University of Toronto Press, 1981.

[3] J. Nichols, *The Progresses, Processions, and Magnificent Festivities, of King James the First: His Royal Consort, Family, and Court; Collected from Original Manuscripts (4 vols)*. London: Nichols, 1828.

[4] G. Demidowicz and H. Gilderdale Scott, *St. Michael's Coventry: The Rise and Fall of the Old Cathedral*. Coventry: Scala, 2015.

[5] G. W. O. Addleshaw and F. Etchells, *The Architectural Setting of Anglican Worship.* London: Faber, 1948.

[6] 'Coventry City Annals', Birmingham Central Reference Library, MS 3180/2/6, 1614.

[7] 'Coventry City Annals', Bodleian Library, Oxford, MS Top. Warwickshire d4, 1616.

[8] T. Sharp and W. G. Fretton, *Illustrative Papers on the History and Antiquities of the City of Coventry.* Birmingham: Hall and English, 1871.

[9] C. Haigh, J. Dunkerley, M. Rogers, *Classical Recording: A Practical Guide in the Decca Tradition*. London: Focal Press, 2020.

[10] H. Massey, *The Great British Recording Studios*. Milwaukee: Hal Leonard Corporation, 2015.

[11] J. Cook, A. Kirkman, K. McAlpine, and R. Selfridge, "Hearing historic Scotland: Reflections on recording in virtually reconstructed acoustics", *Journal of the Alamire Foundation*, vol. 15, no. 1, pp. 109–126, 2023.

[12] "St Michael's Cathedral." [Online] Available: https://www.coventryatlas.org/map/collections/st-michael-s-cathedral. Accessed: Apr. 04, 2025.

[13] "Traité sur l'oraison dominicale", Bibliothèque Royale de Belgique, Brussels, Ms. 9092, f. 9 (Philip the Good at Mass by Jean Le Tavernier), c 1457.

[14] "Missale secundum usum fratrum ordinis beate dei genetricis Marie de Monte Carmeli", Princeton University Library, USA, Garrett Ms. 40, f. 124v, 1440.

[15] "Fleurs des histoires", Bibliothèque nationale de France (BnF), Paris, MS Français 299, folio, c 1479.

[16] P. S. Jadhav, "Classification of Musical Instruments sounds by Using MFCC and Timbral Audio Descriptors", *International Journal on Recent and Innovation Trends in Computing and Communication*, vol. 3, no. 7, pp. 5001-5006, 2015.

[17] M. Rocamora and P. Herrera, "Comparing audio descriptors for singing voice detection in music audio files", in *Brazilian Symp. on Comp. Music, 11th. San Pablo, Brazil*, 2007, p. 27.

[18] B. Bischl, M. Eichhoff, and C. Weihs, "Selecting Groups of Audio Features by Statistical Tests and the Group Lasso.", in *Sprachkommunikation*, 2010, pp. 1–4.

[19] B. Boren, "Word and mystery: The acoustics of cultural transmission during the Protestant Reformation", *Front. Psychol.*, vol. 12, 2021.