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Hearing Historic Scotland: Reflections on Recording in Virtually Reconstructed Acoustics

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This article discusses the process and wider implications of a new project by The Binchois Consort that situates an entire CD recording in a virtually reconstructed acoustic. We believe our recording is the first complete commercial CD to reproduce virtually an acoustical experience of a particular space, place, and time: in our case, the chapel royal of Linlithgow palace as it stood at the turn of the sixteenth century.¹ Now a ruined shell, with no roof or windows, clinging to the side of the peel above Linlithgow Loch, Linlithgow palace was once the great pleasure palace of the kings and queens of Scotland and the birthplace of James V and Mary Queen of Scots. As a refuge for the royal family from the bustle of the capital, Edinburgh, and the main royal residence in Stirling, the building once resounded to music sung by the skilled musicians of the itinerant chapel royal, surrounded by magnificent decorations and sculptures. Almost none of this—the music or the building’s furnishings—survives.

The project was initially part of the Arts and Humanities Research Council-funded ‘Space, Place, Sound, and Memory: Immersive Experiences of the Past’, which sought to produce two detailed virtual reality reconstructions, one of the chapel of Linlithgow palace and the other of St. Cecilia’s Hall, Edinburgh. The CD resulted from a follow-on project, ‘Hearing Historic Scotland’, aimed at increasing impact and engagement.² This same project developed a full virtual reality (VR) headset experience of the chapel reconstruction, designed for permanent installation at Linlithgow palace.

¹ An earlier example of something partly analogous to our project was the recording of Obrecht’s *Missa de Sancto Donatiane* by Cappella Pratensis (<<https://sites.williams.edu/obrechtmass/>>); see also M. Jennifer Bloxam and Stratton Bull, ‘Obrecht and the Mass for St. Donatian: A Multi-Media Triptych’, in this *Journal* 2 (2010), 111–25. Similar projects have also explored the furnishings of the Sistine Chapel (see Lisa Pon, ‘Raphael’s “Acts of the Apostles” Tapestries for Leo X: Sight, Sound, and Space in the Sistine Chapel’, in *The Art Bulletin* 97 [2015], 388–408) and Venetian churches (see Deborah Howard and Laura Moretti, *Sound and Space in Renaissance Venice: Architecture, Music, Acoustics* [New Haven, CT, 2010]). Similar physical reconstructions of liturgical events include the *Experience of Worship* project (<<http://www.experienceofworship.org.uk/>>), which sought to reconstruct the late medieval Sarum liturgy in Salisbury cathedral and within the church of St. Teilo now at St. Fagan’s National Museum of History; see also Magnus Williamson, ‘The Fate of Choirbooks in Protestant Europe’, in this *Journal* 7 (2015), 117–31 for a specific aspect of this project. Examples similar to our project that have used digital reconstruction techniques include: *Musique et musiciens dans les Saintes-Chapelles, XIIIe-XVIIIe siècles*, which virtually reconstructed the acoustic of the Dijon Sainte-Chapelle, with music by Du Fay, chant plus improvised counterpoint, and organ improvisation (presented at the Musée des Beaux-Arts de Dijon, 17 May–13 October, 2014); and *ReViSMartin – Renaissance virtuelle de la collégiale Saint-Martin de Tours*, which virtually reconstructed the acoustic of the abbey of St. Martin in Tours, using an excerpt from Okeghem’s Requiem (available from <<https://ricercar.cesr.univ-tours.fr/ReViSMartin/>>). As noted below, our CD belongs to a broader project that combined visual and acoustic reconstruction as part of a permanent visitors’ experience Linlithgow, and that sought to bring a not-usually-seen degree of interactivity to the experience by allowing the user to control their positioning in the space and to transition freely between past and present reconstructions.

² On these projects see <<https://gtr.ukri.org/projects?ref=AH%2FR009228%2F1>> and <<https://gtr.ukri.org/projects?ref=AH%2FS010653%2F1>>.

Our purpose in the present article is to give an overview not only of our production process for the CD but also of the broader historical and aesthetic rationale for the project, as well as some thoughts on possible future ramifications. Some consideration of the broader project and, especially, of the creation of the Linlithgow chapel VR experience, is necessary, since this was an initial step in producing the virtual acoustic later used for the CD.³

Our hope with the CD was to capture something of the experience of listening to a performance in Linlithgow chapel in a plausible reconstruction of its state at a particular point in time. An experience designed for CD is different from one designed for VR. The principal difference is the static point of audition and sound which, though robbing us of the chance to explore different positionings, nonetheless affords a more accurate acoustic model. In order to give a sense of the audio-visual interaction that we wish to invoke, the CD comes with a downloadable application that allows one to see the spot in which the listener is positioned, as well as the positioning of the singers. This app also allows users to transition between a reconstruction of the chapel's past acoustics, and how performances there sound today, in a building without windows or roof, and lacking soft furnishings.

Historical and Aesthetic Rationale

Before going any further we should offer a caveat: we do not indulge in the romantic notion that what results from our project must be directly akin to fifteenth- or sixteenth-century experience. The tone qualities, blend (however that might have been perceived), tempi, phrasing, etc. of music-making at that time were in every likelihood a far cry from anything we, more than half a millennium later, can imagine. Yet it is nonetheless worth considering how this experience encourages us to think about the kinds of spaces in which music then was initially heard, and what aural effects that may have had. Crucially, it prompts us to step away from the largely unquestioned notion of the 'best seat in the house' typically employed in CD recordings (on which more below), and to focus instead on the shifting relationship between the singing and non-singing protagonists of any event involving music.

There can be no doubt that those who intensively used late medieval buildings understood and exploited their resonances. An obvious example of this concerns the positioning of organs. Dorothea Baumann has pointed out that placing large instruments high on walls reflected acoustical concerns: a raised sound-source has access to the flat (and therefore most effective) sonic reflectors above the level of pillars and screens, and thus affords direct sound-transmission to more, and more widely dispersed, listeners.⁴ Crucially, it allows simpler, more direct sound reflections from vaults into side chapels and chancel. These places thus have unimpeded access to sound that would otherwise have been interrupted by (much lower) masonry screens and stalls. Besides this, the higher the organ pipes were, the closer they were to the vault, and hence the briefer the

³ For more information on the VR project, see Kenneth B. McAlpine, James Cook, and Rod Selfridge, 'Hearing History: A Virtual Perspective on Music Performance', in *3D Audio*, ed. Justin Paterson and Hyunkook Lee (Abingdon, 2022), 207-27.

⁴ Dorothea Baumann, 'Acoustics in Gothic Cathedrals: Theory and Practical Experience in the Middle Ages', in *Les orgues gothiques: Actes du colloque de Royaumont 1995*, ed. Marcel Pérès (Paris, 2000), 37-48.

time interval between soundwaves traveling directly down to the floor and those bouncing down from the roof. As a consequence the sound perceived on the ground was louder.

Gothic vaulting is conducive to certain acoustical effects. Baumann points out how—in marked contrast to the earthward sound reflections of rounded, Romanesque vaults—pointed gothic vaults trap sound waves issuing from the floor, resulting in a much thinner and drier acoustic.⁵ We will address specific locations shortly, but for now it suffices to note that, whatever their other parameters, a very large proportion of ecclesiastical spaces used for music making were vaulted. While rather little verbal testimony has come down to us concerning how singers exploited these spaces, we can reasonably expect that they had a good sense of how best to work with the spaces in which they habitually sang, both for their own benefit and for that of whomever their auditors were.

Some fundamental acoustic factors, as valid now as in the past, are easily observable in practice: first, high-pitched sounds (and hence short sound-waves) have more pronounced directionality than low sounds, which radiate more broadly; second, loud sounds have a greater propensity to excite disturbing resonances; and third, in gothic buildings, due to the reflective nature of stonework, reverberation time is considerably longer at bass frequencies.⁶ Given these circumstances it is no surprise that documented polyphonic ensembles in our period usually pitted a relatively large number of choirboys against single performers on each of the lower parts.⁷ For the same reasons, undivided *Blockwerks* of late-medieval organs combine small numbers of pipes for lower pitches with (often very) large numbers for higher ones. Experience demonstrates that singers in concert in the nave of a church are best configured with the lower voices in the middle of an arch shape facing directly out at the audience, and the higher voices at the side and pointing slightly inwards. Configured thus, lower pitches, with their broader radiation and longer wavelengths, are more clearly perceived by listeners positioned directly ahead, without undue favour to the higher pitches, which with shorter soundwaves and greater directionality are easily perceived anyway.

At the heart of our initial project was an intention to reintroduce several aspects of performance that we felt had often been overlooked in historically informed performance projects: in particular, space and place as integral performance dimensions, and the multimodality that these entail. Late-medieval liturgical music took place as part of a multimedia spectacle;⁸ an auditor moving through a sacred space (which was unencumbered by pews) would have been surrounded by a richly decorated world of wall paintings, tapestries, and sculptures with decorative, instructive, and devotional functions. Such visual elements, lit by the variable natural light afforded by windows plus the play of flickering candle- and torch-light, could be dramatically vivified for the viewer. In parallel fashion the saints, similarly enlivened in sculpture, would be animated

⁵ 'Acoustics in Gothic Cathedrals', 42-46.

⁶ On the last of these points see Raf Orłowski, 'Acoustics and Architectural Form', in *Architettura e musica nella Venezia del Rinascimento*, ed. Deborah Howard and Laura Moretti (Milan, 2006), 48, plus Figure 8 at p. 47. Orłowski suggests a reverberation time of up to ten seconds at 100 Hz.

⁷ Though it should be noted that nuns' choirs tended to do the opposite, with a greater number on the lower parts. This likely reflects the greater weight of higher ranges in adult female voices. Our thanks to Laurie Stras for this observation.

⁸ Andrew Kirkman and Philip Weller, 'Music and Image/Image and Music: The Creation and Meaning of Visual-Aural Force Fields in the Later Middle Ages', in *Early Music* 45 (2017), 55-75.

by sound. Drawing on the theories of Roger Bacon, Kirkman and Weller argue that the eye of the beholder did not just passively regard the object on which it gazed, but was instead united with it, assimilating something of its essence: '[t]he result thus resonates closely with the idea of a "charged space" of meaning conjured by contemplation, one in which what—to our eyes—appear as miracles of transformation or simply metaphors may to at least some in the late Middle Ages have been conceived as much more palpable.⁹ Late medieval accounts of religious experiences often narrate events as though they happened in real-time, with the viewer in the direct presence of the events as they unfolded. For example, Julian of Norwich attests that:

I saw His swete face as it was drye and blodeles with pale deyeng, and sithen more pale, dede, langoring, and than turned more dede into blew, and sithen more browne blew, and the flesh turnyd more depe dede. For His passion shewid to me most properly in His blissid face, and namly in His lippis. There I saw these four colowres, tho that were aforn freshe, redy, and liking to my sigte. This was a swemful chonge to sene, this depe deyeng, and also the nose clange and dried, to my sigte, and the swete body was brown and blak, al turnyd oute of faire lifely colour of Hymselfe on to drye deyeng.¹⁰

Pre-modern performance—as an irreducible facet of religious experience—was therefore a fully-immersive, perhaps even overwhelming, multi-modal sensory experience in which sight and sound worked reciprocally to full effect.

The manner in which the contemporary performance space was used is alien to our modern experience of listening in a concert hall or to a CD. Listeners had more agency to explore its bounds, contingent upon the role and location of each actor in the scene. Projects similar to ours have explored music's audibility for different people experiencing the same act of devotion.¹¹ VR allows us to explore this effect at leisure and with enhanced control, tracing the acoustical impact of listening in various positions, of movement during performance, and even of positions that are in reality impossible (or at least wildly impractical): for example, occupying the same physical space as a particular singer.

One other vital dimension of performance concerns its acoustic setting. Composers of the past clearly knew the kinds of spaces for which they were writing. This knowledge informed many of their compositional decisions, which thereby emphasized certain spatial characteristics and looked to exploit the nature of their acoustic effects. Most pieces were composed with specific types of locations in mind—side chapels, altar chapels, and other fixed chantries. Even when music travelled beyond the site of its original performance, we contend that it would predominantly have been performed in spaces of the same kind as those for which it was originally conceived: that is, relatively small spaces, decorated with soft furnishings. Today, commercial records demonstrate a broad consensus in favour of generous performance acoustics for late medieval and Renaissance polyphony. However, scholarly opinions have begun

⁹ Kirkman and Weller, 'Music and Image/Image and Music', 57.

¹⁰ *The Shewings of Julian of Norwich*, ed. Georgia Ronan Crampton, TEAMS Middle English Text Series (Kalamazoo, MI, 1993), 59. Quoted in Susan Arvay, 'Private Passions: The Contemplation of Suffering in Medieval Affective Devotions' (Ph.D. diss., Rutgers University, 2008), 86. For a more fully developed consideration of this point see Andrew Kirkman, 'Image, Music and Lived Reality in Fifteenth-Century Midlands Alabaster' in *Performance, Ceremony and Display in Late Medieval England*, ed. Julia Boffey, Harlaxton Medieval Studies 30 (Donington, 2020), 255-72.

¹¹ See 'The Experience of Worship' project.

to challenge this.¹² Our project aimed to illuminate modern performance-practice conceptions by contrasting them with past acoustics.

In seeking to recapture the multimodal, the peripatetic, and the acoustic aspects of performance, we turned to VR technology. VR's ability to embody music performance in a virtual environment that encourages a sense of presence and agency in the listener makes it possible to bring together key experiential dimensions of live performance with the reproducibility and accessibility of a recording. In the same way that historic performance spaces created immersive sensory experiences, modern VR technology provides a digital mechanism to do likewise. Using this technology, we are able to reconstruct now-lost performance spaces. In doing so, we problematize the assumption that many of the still-extant performance spaces that we might use today have retained configurations that would have been familiar to our musical forebears.

The stakes for this kind of reconstructive exercise are high. While we acknowledge the truism that no past performance of a piece of music can be fully recoverable, this should not blind us to the fact that the performances and recordings we experience today pre-condition the sounding possibilities we are able to entertain. To take that one step further, preconceptions of 'how a piece of music sounds' inevitably inform our written as well as our sounding interpretations, however strenuously we might resist them.

Anyone who accepts this basic tenet would presumably also accept that there is much to be gained from thinking about where we are positioned as we listen to the music of the past: in what building, or part of a building, and whether as auditor, singer, director, or—in the case of a liturgical event—celebrant, dean, or subdeacon, and so on. In the case of a project in virtual-sounding reconstruction such as ours, one has no choice but to consider these variants, and it is that consideration that informs our discussion here.

Perhaps the most pervasive assumption we tend to make about recordings (so pervasive, in fact, that it rarely even enters our consciousness) concerns the position of the notional listener: that they occupy the 'best seat in the house'. For recordings of late medieval music that seat is typically some distance from the source of the sound, allowing for the kind of churchy 'medieval sound' comprised of either cavernous recording environments or heavy artificial reverb that lies at the root of comments made recently by Anna Zayaruznaya regarding the intelligibility of text and differentiation of parts in many early music recordings.¹³ Unfortunate casualties of this 'medieval sound' are the contrapuntal complexities that attract many of us to the music in the first place and—the source of Zayaruznaya's particular criticism—the words.

We make the above points in a deliberately general way, as a basis for the more particular considerations engendered by the 'Hearing Historic Scotland' recording project. We hope to have demonstrated why we consider the exercise to have been valuable, and to have opened up a space to consider possible future ramifications. The following section offers an introduction to the process of reconstruction which underpinned the project.

¹² Anna Zayaruznaya, 'Intelligibility Redux: Motets and the Modern Medieval Sound', in *Music Theory Online* 23/2 (2017), <<https://mtosmt.org/issues/mto.17.23.2/mto.17.23.2.zayaruznaya.html>>.

¹³ Zayaruznaya, 'Intelligibility Redux'.

The Process of Virtual Reconstruction

Our discussion must necessarily begin with our virtual reconstruction of the visual and architectural representation of the space, even if this is merely an invisible underpinning to our CD project. The reconstruction began life as highly detailed LIDAR scans of Linlithgow palace chapel produced in partnership with Historic Environment Scotland. LIDAR uses a rotating laser gun to take measurements of the building, accurate to a fraction of a millimetre. In principle such accuracy allows for a minutely detailed model of the scanned building, consisting of hundreds of thousands of polygons (see Figure 1).¹⁴ However, this level of detail is computationally expensive, and does not leave sufficient processor power to compute acoustics at the same time.¹⁵ Thankfully, however, an acoustic model does not require such detail. We therefore streamlined the results by vastly reducing the number of polygons whilst maintaining the structural details required for modelling (see Figure 2). Our LIDAR scanning also recorded high-resolution photographic images which could be overlaid on the structural model, to give it the required texture (see Figure 3).

This process gave us a detailed recreation of the building in its current state, but unfortunately gave little idea of what the building might have looked like in the past. We therefore used the measurements as a structural basis, and began to reconstruct the former building around this skeleton.

Working with standing-building archeologists, historians, and art historians, as well as the archival records, we were able to reconstruct the layers of building work on the chapel. Two archways occupy the east wall of the chapel which, according to Historic Environment Scotland's archaeological survey of the site, show no sign of ever having had doorways, since there is no evidence of anything onto which these could have been affixed.¹⁶ It is therefore assumed that the area beyond these archways forms a part of the liturgical space, potentially functioning as an ambulatory allowing for a processional route behind the altar, such as the one in the new Chapel Royal at Windsor, erected by Edward IV c. 1477-83.¹⁷

Given the limited width of the space, it is hard to see how it could have functioned for anything other than the smallest of processions; hence, rather than leaving these archways entirely open, we chose to close them with drapes, on the assumption that limited size would have inhibited any kind of regular ritual use.¹⁸ There are no specific mentions of fabric for Linlithgow palace; there are, however, notable mentions in the treasurer's accounts of large purchases of material that relate to the king's household, but which are not assigned to particular parts of the building. One possibly relevant

¹⁴ Lyn Wilson et al., '3D Documentation of Global Historic Sites: The "Scottish Ten" Project and its Applications for Cultural Heritage', in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 38/5 (2011), 39-44.

¹⁵ Markus Schütz, Katharina Krösl, and Michael Wimmer, 'Real-Time Continuous Level of Detail Rendering of Point Clouds', in 2019 *Institute of Electrical and Electronics Engineers Conference on Virtual Reality and 3D User Interfaces (VR)* (conference proceedings), online at <<https://ieeexplore.ieee.org/document/8798284>>.

¹⁶ *Linlithgow Palace: Archaeological Survey and Historical Research*, unpublished report to Historic Environment Scotland by Kirkdale Archaeology (2015), vol. 1, 188.

¹⁷ Tim Tatton-Brown, 'The Building of the New Chapel: The First Phase', in *St George's Chapel, Windsor: History and Heritage*, ed. Nigel Saul and Tim Tatton-Brown (Wimborne Minster, 2010), 69-80.

¹⁸ This same arrangement was independently assumed in Historic Environment Scotland's interpretational historical drawing.

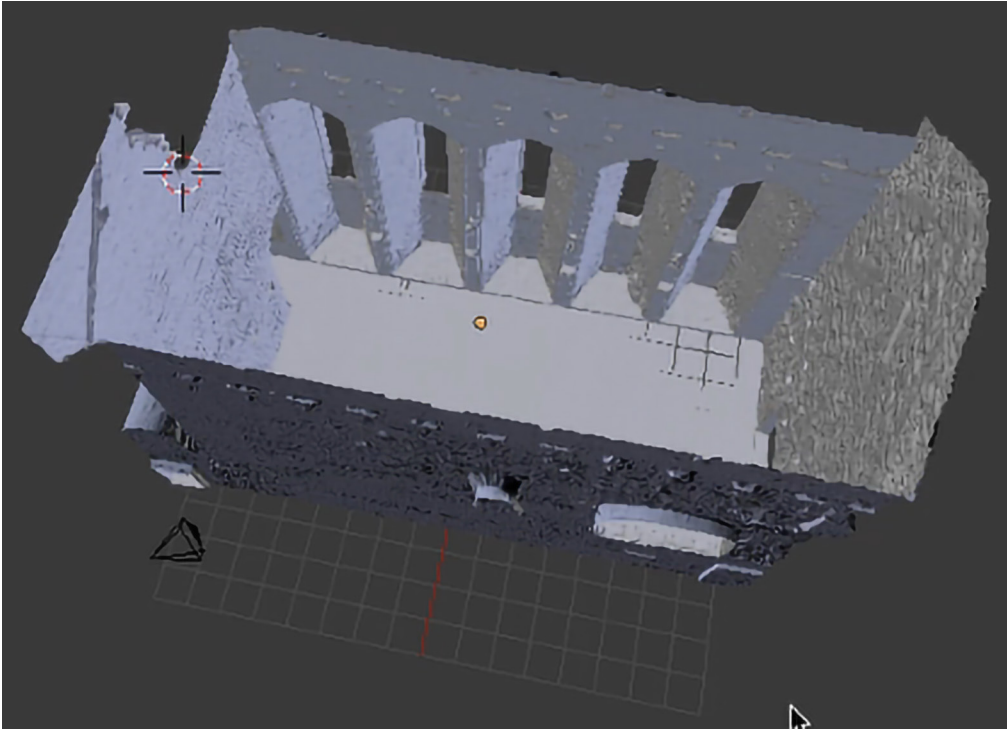


Figure 1. A highly detailed LIDAR scan of Linlithgow palace chapel

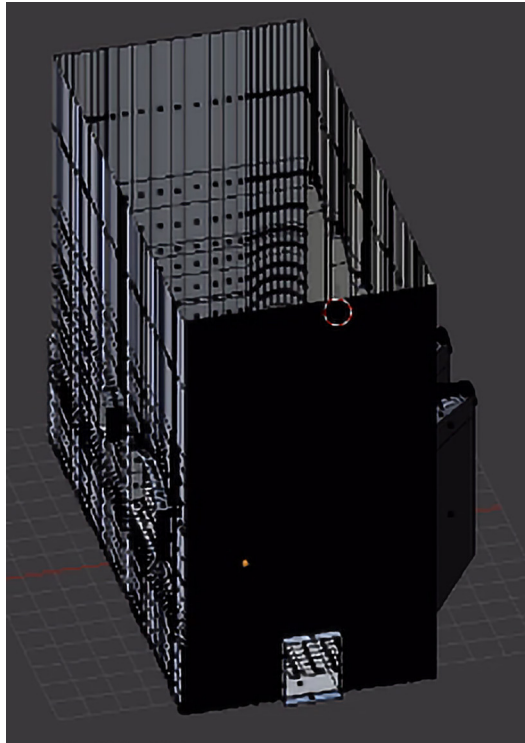


Figure 2. The LIDAR scan following a reduction in polygon count



Figure 3. Linlithgow palace chapel as it stands today, reconstructed from LIDAR scanning with overlaid textures

record is the following: ‘Item, for xij elne taffetj to be ane trevis to the King; ilk elne xvj s.; summa [...] ix It. xij s.’ Eleven elne of material gives a total of forty-four feet, easily sufficient for our purposes. The term ‘trevis’ is often used to describe a dividing curtain in a chapel, though it can also refer to more domestic uses, such as in bedrooms. After 1529, with the appointment of the master of works to the crown of Scotland, we have rather more information surviving for the construction and refitting of royal buildings through the surviving accounts for this office.¹⁹ It is, however, clear that before this date not all expenses related to these buildings survive in the treasurer’s accounts.

The archway on the west wall, like those on the east, has no surviving evidence of attachments for doors. It is nonetheless unlikely that the chapel ante-room, into which it leads, would have constituted one unbroken space with the chapel. We therefore chose to cover this wall with a drape, similar to that on the east wall; the surviving stone rail at the top of the wall would offer the method of attachment for this drape.

Trace evidence, consisting of joist holes, of two different roofs from different periods can be seen within the chapel. The first, current at the date of our reconstruction, was slightly lower than the second. No payment records survive for the building of the earlier roof, since it took place before the appointment of the master of works, but copious details for the building of the second survive.²⁰

This second ceiling was certainly painted. John Ross painted the ‘lyning’ of the chapel ‘syloring’ in ‘fine assur’ as well as twelve pendant knobs under the chapel loft.²¹ Whilst no records survive for the decoration of the first layer of work, we do not take this to be evidence of a lack of decoration since we also lack any payment records for

¹⁹ Edited in Henry Paton (ed.), *Accounts of the Master of Works for Building and Repairing Royal Palaces and Castles in Scotland, Volume 1: 1529-1615* (Edinburgh, 1957), and John Imrie and John Dunbar (eds.), *Accounts of the Master of Works for Building and Repairing Royal Palaces and Castles in Scotland, Volume 2: 1616-1649* (Edinburgh, 1982).

²⁰ Paton (ed.), *Accounts of the Master of Works*, 123-24.

²¹ Paton (ed.), *Accounts of the Master of Works*, 128.

the construction of this version of the roof in the first place. We therefore followed a similar decoration scheme to that of the second layer of work.

Detailed accounts survive for the arrangement and decoration of the five glass windows in the south wall from the mid-1530s,²² but none before this date. In contrast to the ceiling, there was no practical need to replace the glass in the 1530s; this must have been an aesthetic choice, so we decided to glaze the windows with predominantly clear glass, decorated simply with the coat of arms of James IV on each window, following a contemporary pattern found at Stirling palace.

There are small surviving remnants of plaster on the walls in the chapel. This suggests that all of its walls were plastered, an approach that we applied to our virtual model. There is no indication of how the plaster was decorated, but we chose to apply *trompe-l'oeil* painted tiles, as in Stirling palace, which was decorated around the same time.

The south wall has a number of niches that clearly once held statues of saints. There is, again, no explicit reference to these in the literature, so we chose saints who we believe to have been likely choices, given the context. These include St. Andrew, the patron saint of Scotland, and Sts. James and Margaret, patron saints of James IV and his wife, respectively. St. Michael, chosen as the dedicatee of Linlithgow parish church (which is next to the palace), seems to have been a figure of special reverence in Scotland around this period, as the patron of the Chapel Royal in Stirling, of Robert Carver's *Missa Dum sacrum mysterium*, and of James IV's colossal warship 'The Great Michael'.

Some 500 fragments of clay floor tiles had been found during archaeological digs in the palace by 1996, including one adorned with the intertwined letters I and M. These initials suggest the tiles were made in the years immediately following 1503, the year in which James IV and Margaret Tudor were married. Linlithgow chapel was completed shortly after this marriage. Such tiles would thus have been for its flooring.²³ The masons responsible for the 'paythment' of the chapel were part-paid in February 1507, with a further payment in April.²⁴ On James IV's visit to Linlithgow in August of the same year, the masons were paid 42 shillings 'in drinksilver', a common practice of paying a gratuity that was to be spent on drink.²⁵

The positioning of choir stalls proved to be problematic, eventually calling into question whether they could have been present and leading us to discard them. The archaeological survey suggested that they would have been placed along the north and south walls (the traditional arrangement), though there is no surviving physical evidence of this.²⁶ In itself, that is not necessarily significant. Sometimes the decorative backings would leave evidence of fixings in the wall, but not always. As noted in the survey, placing stalls along the north and south walls creates a problem since they would then entirely hide the deep window bays, and block out much of the light coming through

²² Paton (ed.), *Accounts of the Master of Works*, 128.

²³ For a full account of the archaeological digs, see David Caldwell and John Lewis, 'Linlithgow Palace: An Excavation in the West Range and a Note on Finds from the Palace', in *Proceedings of the Society of Antiquaries of Scotland* 126 (1997), 823-69. For an image of the tile, see *ibid.*, 837.

²⁴ James Balfour Paul (ed.), *Compota Thesaurariorum Regum Scotorum: Accounts of the Lord High Treasurer of Scotland*, vol. 3: 1506-1507 (Edinburgh, 1901), 297-98.

²⁵ Paul (ed.), *Compota Thesaurariorum Regum Scotorum*, vol. 3, 411.

²⁶ *Linlithgow Palace: Archaeological Survey and Historical Research*, vol. 1, unpublished report to the Historic Environment Scotland by Kirkdale Archaeology (2015), 189.

the stained glass. Positioning the stalls closer to the altar produced logistical issues for access to the ambulatory, and got in the way of the lectern. No matter where the stalls were placed, very little space was left between them due to the narrowness of the chapel.

The question must therefore be asked as to whether the chapel could have operated without them. We know that the older chapel at Stirling castle—serviced by the same personnel as Linlithgow—included wooden choir stalls with canopies, since these were used as the model for the stalls in Glasgow cathedral in 1506.²⁷ We might therefore expect that Linlithgow would also have had stalls. However, Linlithgow was significantly smaller than Stirling. The latter measured more than 9m × 29m, giving it a total area of some 261m², versus only 120m² for Linlithgow (8m × 15m, with a height of 11m). The personnel in Linlithgow also seems to have been somewhat more peripatetic. It is possible that James IV was attended by less than a full complement of the Chapel Royal when there: Robert Lindsay of Pitscottie notes that half of the canons of the Chapel Royal would travel with the older James III.²⁸ Documentary evidence for transporting the ‘chapele geir, organis and eucharist’ to Linlithgow in 1512 suggests an impermanent set-up there, at least until the later installation of a built-in organ.²⁹

Alongside the above concerns, one final problem caused us to discard our choir stalls: the positioning of seating for the royal couple. Many of Historic Environment Scotland’s on-site interpretative drawings suggest that the royal family may have watched proceedings from a wooden loft above the chapel’s west wall. It nonetheless seems unlikely that the loft was built at the same time as the structure of the chapel. The positions of the surviving joists show that the loft must have inelegantly obscured one of the original windows, making it an expensive waste of glass and masonry. Archival evidence supports this. When the newer roof was built in May 1535, 19 wooden joists of the same width as the chapel were purchased.³⁰ 13 joist sockets for the wall can be found for the roof, leaving 6 to support the loft. The work began a month later, in June, following the purchase of birch scaffolding.³¹ In the end, we put the seating for the royal couple on the north and south walls, one on each side, a position also indicated in some of Historic Environment Scotland’s interpretative reconstructions, leaving no room for choir stalls.

As should be clear from the above discussion, some aspects of how the chapel was arranged are entirely obvious from the surviving archaeological and archival record; others are the product of what we hope is intelligent guesswork, building upon the firm points of information that we do have. Many of the less certain aspects have little relevance for the acoustic features of the space, though some, such as the inclusion and placement of choir stalls, would obviously have some impact. One great advantage of virtual over physical reconstruction is that it is possible to re-arrange the physical space with relative ease and to use this facility to explore aspects of liturgical re-enactment.

²⁷ John Dunbar, *Scottish Royal Palaces* (Glasgow, 1999), 126.

²⁸ Aeneas James George Mackay (ed.), *The Historie and Cronicles of Scotland: From the Slaughtre of King James the First To the Ane thousande fyve hundreith thrie scoir fyftein zeir, written and collected by Robert Lindesay of Pitscottie*, 3 vols. (Edinburgh and London, 1899), vol. 1, 200.

²⁹ James Balfour Paul (ed.), *Compota Thesaurariorum Regum Scotorum: Accounts of the Lord High Treasurer of Scotland, vol. 4: 1507-1513* (Edinburgh, 1902), 347. The transport was organized by David Trail, the Chapel Royal’s sacristan. A permanent organ was installed in Linlithgow in April 1513. A French organ builder, named Gilyem, was paid 10 ‘licht Franche crownis’ for its construction. A detailed description of its method of attachment to the wall of the chapel, and the associated costs, may be found in Paul (ed.), *Compota Thesaurariorum Regum Scotorum*, vol. 4, 523.

³⁰ Paton (ed.), *Accounts of the Master of Works*, 123.

³¹ Paton (ed.), *Accounts of the Master of Works*, 124.

Acoustic Reconstruction

Once we had a sense of how the interior of the building might have looked, we were able to begin our acoustic reconstruction. This relied on a detailed understanding of the acoustic properties of the materials used to construct the building. Different materials reflect and absorb sound by different amounts at different frequencies; those with rough surfaces will also scatter the reflected sound more than those with a smooth surface. We therefore tagged all surfaces in our reconstruction with a) a number of coefficients relating to absorbency over the range of audible frequencies; and b) a scatter coefficient so that we were able to model how sounds would interact with them.

Once all the surfaces in the model had been tagged with the required acoustic information, we were able to derive an impulse response for the room. This is a measure of all the reflections at all audible frequencies between the sound source and receiver (see Figures 4 and 5). These reflections can be plotted graphically, as shown in Figure 5, but they can also be saved as a .wav file that can be loaded into a convolution reverb plugin, which allows for the application of this room-sound from a fixed point of audition to any recorded sound source. In our reconstruction, a process known as ‘ray-tracing’ was employed, whereby reflections from all the surfaces and objects in the space were simulated to produce this impulse response. Once this was obtained, we were able to imprint the acoustic characteristics of the modelled space, for a set positioning of our sound sources and listener, on our recorded music.

We tested the accuracy of our Linlithgow acoustic reconstruction through comparison with a related project, at St. Cecilia’s Hall, Edinburgh. This hall, the oldest purpose-built concert hall in Scotland, still survives, allowing a VR reconstruction to be compared directly to the building itself. We compared an impulse response derived from acoustic ray-tracing in our model of the hall with an impulse response derived from a sine sweep (i.e., a tone derived from a sine wave which moves across all audible frequencies) in the actual hall, using Odeon, the industry-standard software for acoustic modelling. By placing both the sound source and the receiver identically in each setting, we were able to compare the two acoustics and judge that our reconstruction process had been sufficiently accurate to be indistinguishable for almost all listeners.³² This demonstrated that our process of reconstruction was accurate even if we did not test it on the specific Linlithgow model, the process of which was rendered too difficult to achieve accurately due to external sound leakage through the open roof and windows, and due to the presence of a colony of rare bats.

For an initial pilot project, we produced an interactive virtual reality application that allowed the user to move around in the space freely whilst appropriate music was performed. A version of this application can be experienced through VR headsets on-site at Linlithgow palace. This necessitated simulation of acoustic models that allowed for movement of the auditor, not something which was required for our CD application.

We therefore also ran a comparison of Odeon with Steam Audio and Google Resonance, since Odeon was computationally very intensive and therefore unsuitable

³² For a detailed discussion of the process of evaluation and a mathematical rendering of the proximity of the model to reality, see Rod Selfridge, James Cook, Kenneth B. McAlpine, and Michael Newton, ‘Creating Historic Spaces in Virtual Reality Using Off-The-Shelf Audio Plugins’, in *Proceedings of the Audio Engineering Society International Conference on Immersive and Interactive Audio* (2019), available at <<https://www.aes.org/e-lib/>>.

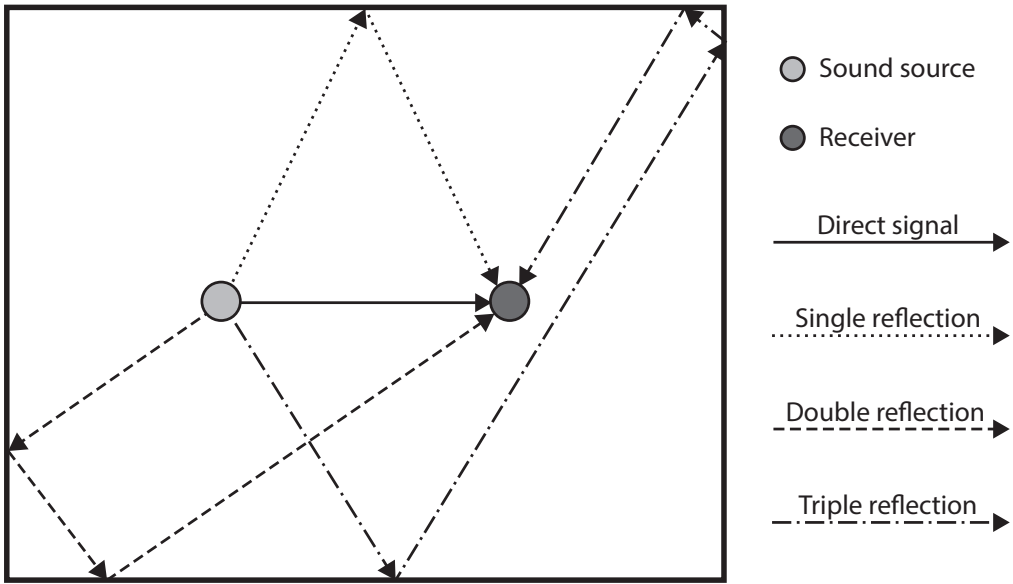


Figure 4. A graphical representation of how sound interacts with a space in its travel from sound source to receiver

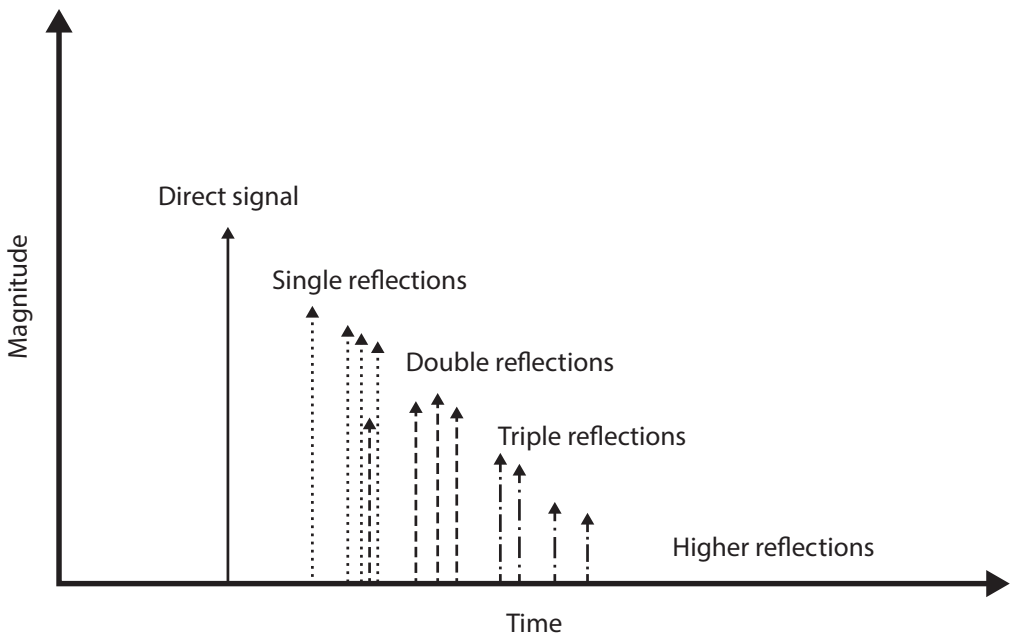


Figure 5. The reflections from Figure 4 mapped on to a graph (the traditional visual presentation of an impulse response)

for the real-time acoustic rendering with moving sound sources or listeners. Steam Audio and Google Resonance, as game-engine applications, are optimized for this usage, although at the expense of some accuracy, both in terms of sound localisation and

acoustic modelling. As expected, Odeon was slightly more accurate than Steam Audio, though both produced similar reverberation times to the real-world room impulse response generated via a sine sweep, well within perceivable tolerances for almost all listeners. The slight deviations in reverberation times between the real-world impulse response and those produced by Odeon and Steam Audio result from the differences between industry-standard absorption coefficients and actual ones, the presence of two investigators in the space during the real-world experiment, and the characteristics of the microphones and speakers. We found that Google Resonance relied unduly on pre-set conditions and was far less accurate.³³ Accordingly, we chose Steam for live-simulated VR contexts. The CD project did not need audio to be responsive to listener-movement, or to evaluate acoustics in real time, and could therefore use Odeon for greater accuracy.

Recording Process

In order to produce as clean a reconstruction of the acoustics as possible, it was important to record the music in a setting which had close to no natural acoustic. We therefore recorded in an anechoic chamber at the University of York. This kind of space is more typically used by engineers and physicists to test materials (see Figure 6). It allowed us to produce a performance as though it were taking place in our reconstructed space without also overlaying the acoustic of a studio or other venue. An anechoic chamber does not make for the most natural performance space. The environment is claustrophobic, hot, often—as in this case—with springy floors, and it offers very little in the way of feedback to the performer. What feedback the performer does receive is related to the chamber and not the intended eventual reconstructed acoustic. It is therefore also important to ensure that performance decisions reflect the intended reconstructed acoustic, rather than the acoustic of the chamber. As a result our entire production process was therefore significantly changed for this recording.

As director of the Binchois Consort, Andrew Kirkman has often commented on how frequently he has implored the singers, in one of the many cavernous churches where they have performed, to make more of the consonants, since past the closest members of the audience these become all but inaudible with anything approaching standard enunciation. Similarly frequent is the experience, after the sound check in a recording session, of having the engineer push the mics closer to the throats producing the sounds. Inevitably the agreed positioning always comes down to a compromise, not least because—to put it bluntly—close-micing can be terrifying for the singers and hence impede musicianship.³⁴

The experience of recording in an anechoic chamber was therefore one that we approached with a certain temerity: as director, engineer, producer, researcher, and

³³ For a full discussion of this experiment and its results, see Selfridge et al., 'Creating Historic Spaces in Virtual Reality.'

³⁴ For a discussion of the impact of mic position on early music performance, see Kirsten Yri, 'Remaking the Past: Feminist Spirituality in Anonymous 4 and Sequentia's *Vox Feminae*', in *Women and Music: A Journal of Gender and Culture* 12 (2008), 1-21. She notes how the close micing technique applied on recordings by Anonymous 4, in comparison to the more distanced placement on recordings by *Vox Feminae*, produces a 'subjective "I"' voice, in comparison to an 'objective "other"' voice. Both sets of recordings, nonetheless, are markedly more reverberant than the recording discussed here. In Anonymous 4's case, artificial reverb was added, such that the music appears to 'radiate out' from the close mic'd performer. Our mic placement sits somewhere between these two extremes, intimate—due to the nature of the reconstructed space—but still objective.



Figure 6. The Binchois Consort with Andrew Kirkman in rehearsal in the anechoic chamber at York University

singer. Some of us had tried it the year before in Edinburgh as part of the same project, but no one would claim that such an experience is ‘enjoyable’; and while we all approached it in good faith, it is fair to say that singers (and directors) who attempt to record in such a space need to be prepared for an experience which is quite distinct from, and a fair degree more challenging than, that of recording in any other space. A degree of trust between the performers and the research team was certainly necessary, and so too was a high degree of patience and perseverance for all involved.

Once the heavily padded door thuds shut there is essentially no reverberation at all, and the surrounding—of spiked foam (on five sides) and sprung floor above spiked foam (on the other)—can be daunting. To paraphrase our engineer Phil Hobbs, the setting feels like ‘a bunch of large blokes standing on a trampoline in a cupboard.’³⁵ The experience is claustrophobic, but, more than that, it serves to strip the performer of any illusions. The slightest infelicity of intonation was starkly clear. Skill, and supreme confidence in that skill, as well as that of your fellow performers, was required.

When the singing stops, there is nothing to hear except the sound of one’s own breathing and the blood pumping in one’s ears. How does one approach singing in such an environment? The initial urge, at least for some, was subconsciously to push the tempo in a (vain) effort to ‘get something back’. That phase over, however, it was surprising how quickly and how strongly the singers’ attention shifted onto each other, giving a much more intense focus on sound production than one usually experiences. Absence of any acoustical distraction, or perhaps scope for evasion, forces a focus on intonation and blend that, while intimidating, is ultimately very productive: matching of vowels becomes so obviously integrated with issues of pitching that it is impossible

³⁵ For a short film showing the process of recording in the anechoic chamber, see <https://www.youtube.com/watch?v=Z-tXrE_cFit8>.

to ignore. As a result, while there is an inevitable sense of ‘walking on eggshells’ since every error is instantly, vividly present, there is also a degree of listening that is unusually concentrated. Progress, while inevitably quite slow, assumes its own pace as everyone acclimatizes to the new situation. Yet blend does not equate to bland: what one is left with is the irreducibly distinctive timbre of each individual voice, chiselling out its line with due deference to the tuning and uniformity of the whole, a pertinent reflection, one might venture to suggest, of the kind of interplay that is inherent to late-medieval polyphony.

The elephant in the room in such a scenario is obviously how one arrives at performance decisions, such as tempo, phrasing, diction, and blend, for an environment that, to all intents and purposes, does not really exist. We experimented with many approaches, initially recording with headphones that fed back a real-time rendering of the singers with the acoustic overlaid. The singers found this distracting. After experimenting with one ear off and one ear on, with only the director using headphones, and with the director with one ear off and one ear on, we eventually continued with no artificially supplied acoustic. Instead, performance decisions were discussed in advance. Short sections were recorded and then reviewed in the control room with the overlaid acoustic. By regularly listening back to the recordings with the overlaid acoustic between takes we were able to maintain a musically appropriate approach to the reconstructed acoustic.

Overall, we were keen that this project be more than an exercise in sonic reproduction: we sought to produce something distinctive and musical in its own right, with due deference to historically informed performance practice. Finding a workable balance between the scientifically recoverable and the artistic, which often had different priorities, was very much at the heart of this project.

For others seeking to approach work of this kind, there are a number of aspects which should be taken into account. Firstly, more time than usual is required for the recording: extra time is needed to acclimatize to the chamber, as well as for more frequent, shorter takes, for more regular breaks from the oppressive environment, and for checking performance decisions against the artificial acoustic. Secondly, performers require a high degree of self-confidence both in their intonation and their rhythm. Thirdly, there has to be real buy-in from the performers in the overall project, and an understanding that the difficulties are worth it. Nonetheless, we would consider it an extremely worthwhile exercise, not only for the manner in which it supports scientific accuracy, but also for the unusual level of attention-to-detail it enabled in the recording process.

Further Implications of the Project

To close the current account and simultaneously to open it out to future possibilities, we wish to turn again to the putative environment with which our sonic experiment sought to interact. The reconstruction of the chapel of Linlithgow Palace is narrow (8m) and high (11m), but comparatively long (15m), with a coffered ceiling of wood, and significant soft furnishing, especially towards either end of the chapel. This creates an environment with little reverberation: the sound has little distance to travel either side of the choir, and where it would have more room for reverberation, reflecting between the east and west walls, it is largely absorbed (particularly at higher frequencies) by the

hangings.³⁶ It is towards these hangings, moreover, that the direct sound of the singers is first aimed, since they would have directed their singing towards the altar which stood in front of them. The roof, too, in its use of coffering, tends to produce a relatively uniform sound, while wood by its nature is more absorbent (especially of lower frequencies) than stone. Nonetheless, the fact that the building is tall and long offers some acoustic support, and the tiled floor is relatively reflective. The acoustic effect therefore stands somewhere between that of the chancel in a large cathedral and that of a side chapel, which was the typical original location of privately endowed polyphony of the fifteenth and sixteenth centuries, and hence of much of the grander repertory of the era. It is, nonetheless, a world away from the kind of acoustic that would normally be used for a commercial CD of late-medieval vocal polyphony, especially those made by larger record producers, and using similar forces to those found in The Binchois Consort.

The larger point, acoustically speaking, that our experiment addresses is that many of the most ornate and highly valued pieces of music from the era—mass settings, Marian antiphons, and so on—were originally fashioned for performance in enclosed spaces, frequently with wall-mounted hangings, of very limited square footage and commonly with roofs considerably lower than those of adjoining naves (in the case of side chapels); spaces, in other words, that were acoustically much less resonant than those in which we are accustomed to experiencing the same music today. To this we might add the absorbent effect on that acoustic of whatever proximate human bodies were occupying this already limited space.

Vaulted roofing is an interesting complication to the overall picture here, since it tends both to increase reflection time and decrease clarity due to the interaction of reflections from separate vaults. Some people certainly valued the effect of vaulting on music, as seen in Francesco Giorgi's comments, in 1535, on San Francisco della Vigna in Venice: 'I recommend that all chapels and the choir should be vaulted, because the words or the songs of the clerics [are] better reflected from a vault than from a wooden ceiling.'³⁷ Presumably what was esteemed here was the amplification and relative spread of the sound throughout the space, rather than its tendency to decrease clarity. Giorgi clearly was aware of the negative aspects of vaulting too, since he also noted that

for the nave of the church, where there will be sermons, I recommend a flat ceiling (so that the voice of the preacher is not lost in or reflected from the vaults). I wish for a coffered ceiling with as many squares as possible...and I recommend these coffers because, among other things, one can preach well beneath them. The experts know this and experience will justify it.³⁸

Vaulting within larger buildings (a cathedral nave, for instance) tends to have a lesser impact on the clarity of the sound, since spaces of very large volume seldom receive enough energy in them to excite their acoustics. It seems clear that architects and

³⁶ On this point see the discussion of the effect of wall hangings in Alicia Alonso and Francesco Martellotta, 'Room Acoustic Modeling of Textile Materials Hung Freely in Space: From the Reverberation Chamber to Ancient Churches', in *Journal of Building Performance Simulation* 9 (2016), 469-86. Key to our discussion here is the finding that absorptency of sound by fabric is directly related to its distance from walls, with fabric being considerably more absorbent when freely hanging than when adjacent to a solid surface.

³⁷ Lewcock et al., 'Acoustics'.

³⁸ Baumann, 'Musical Acoustics', 208-9.

musicians of the period were quite capable of negotiating both acoustically deadening effects and their opposites in order to produce the kinds of sounds for which they were looking. Small side chapel spaces, with their close walls and soft furnishings, are offered a little additional resonance by vaulting, whilst the resonance of comparatively large spaces could be dampened by coffered ceilings (as was apparently the case at Linlithgow).

Our experiments are obviously far from exhaustive. There is certainly more to be done exploring the practicalities of liturgical re-enactment in virtually reconstructed spaces, and especially in side chapels. Nonetheless, our work has yielded important insights. Perhaps the most salient of these is that our reconstructed acoustic is a world away from that in which we, and indeed most professional groups with similar forces and working on similar repertoire, would typically have recorded a CD. The acoustic allows for a compellingly close focus on the interweaving of voices and the fine detail of the counterpoint, and we feel that the absence of the extra reverberation usually experienced in this repertoire is more than compensated for by the up-close engagement with musical precision that it affords.

Equally striking, however, is the effect of rehearsing and recording in an anechoic space: the sharply enhanced listening resulted in a crispness of consonants, uniformity of vowel sounds, and speed of responsiveness both to text and musical events that is unexpectedly vivid and exhilarating. Both performers and director experienced a level of engagement and musical ‘honesty’ that could truly be described as revelatory. Though inevitably more labour-intensive, the results offer a musical immediacy unmatched by our prior recordings, produced in more forgiving surroundings; and while it is well to beware of possible hubris in drawing historical inferences, we would venture to suggest that such uniformity might offer at least some insight into the experience of our medieval musical forebears, accustomed to singing the same small repertoire day after day, year after year, in the same company and in the same close surroundings.

One must of course allow that a more distanced, ‘ethereal’ experience of late medieval music may be some listeners’ preference. How could it be otherwise: they have grown to love the music in the context of the spacious sound more customarily experienced in connection with this repertoire, both in recordings and, crucially, in concert venues.

Whatever may be determined regarding original performance locations, the reality is that concerts of this music are typically mounted not in intimate chapels, but in cavernous nave spaces not only more in keeping with familiar modern experience but also capable of accommodating the sizes of audiences that permit their financial viability. In the UK, as elsewhere in northern Europe, moreover, successive generations of confessional reform, alongside sacred architectural and interior design movements, have left such spaces devoid of their original screens and soft furnishings, leaving them still more open and reverberant than would have been the case at the time of the music’s composition. The reality of concert and festival promotion means that this situation is unlikely to change; but as musical experimentation with virtual reality becomes increasingly the norm we can surely look forward to further experiments with ambient sound in spaces more attuned to those of the late Middle Ages, with attendant gains in aural vividness and, perhaps, historical insight.³⁹

³⁹ *Hearing Historic Scotland: Inside the Pleasure Palace of James IV*, The Binchois Consort, dir by Andrew Kirkman (CD: Hyperion Records CDA68333) is available at <https://www.hyperion-records.co.uk/dc.asp?dc=D_CDA68333>.

Abstract

This article discusses the process and wider implications of a new project by The Binchois Consort that situates an entire CD recording in a virtually reconstructed acoustic. We believe our recording is the first complete commercial CD to reproduce virtually an acoustical experience of a particular space, place, and time: in our case, the chapel royal of Linlithgow palace as it stood at the beginning of the sixteenth century. Now a ruined shell, with no roof or windows, clinging to the side of the peel above Linlithgow Loch, Linlithgow palace was once the great pleasure palace of the kings and queens of Scotland and the birthplace of James V and Mary Queen of Scots. As a refuge for the royal family from the bustle of the capital, Edinburgh, and the main royal residence in Stirling, the building once resounded to music sung by the skilled musicians of the itinerant chapel royal, surrounded by magnificent decorations and sculptures. Almost none of this—the music or the building’s furnishings—survives. We seek to give an overview not only of our production process for the CD but also of the broader historical and aesthetic rationale for the project, as well as some thoughts on possible future ramifications. Some consideration of the broader project and, especially, of the creation of the Linlithgow chapel VR experience, is also given.