

Point Cloud to Sound Cloud Digital Innovation and Historic Sound at Linlithgow Palace

James Cook

Edinburgh College of Art, The University of Edinburgh, Scotland, UK

Sophia Mirashrafi

Historic Environment Scotland, UK

Abstract *The Space, Place, Sound, and Memory: Immersive Experiences of the Past* project was led by dr James Cook, in collaboration with the Digital Documentation and Innovation team at Historic Environment Scotland, Soluis Heritage, the Binchois Consort, and scholars at the universities of Birmingham and Melbourne. It used cutting-edge technology to reconstruct the visuals and acoustics of Linlithgow Palace chapel, before situating reconstructions of liturgical music within it. Beginning with HES' 3D scan of the chapel, the project then used archival, archaeological, and musicological research to bring to life the sights and sounds of the 16th-century chapel. This chapter explores how Digital Documentation can be harnessed in the production of innovative interpretation and research material.

Keywords Linlithgow Palace. Chapel. Digital heritage. Laser scanning. Digital documentation. 3d model. Reconstruction. Virtual. 3D. Technology. Acoustic. Music. Archaeological. Musicological. Sound. Audio. 16th century. Virtual reality. Interpretation.

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1 Introduction

This essay discusses aspects of a recent AHRC-funded research project entitled *Space, Place, Sound, and Memory: Immersive Experiences of the Past*, and its impact and engagement follow-on *Hearing Historic Scotland*, which was carried out in collaboration with Historic Environment Scotland (HES), The Binchois Consort, Soluis Heritage, and Hyperion Records. This project sought to use a combination of terrestrial laser scanning, undertaken by HES's Digital Documentation and Innovation team, virtual reality (VR), and acoustic reconstruction to interpret a historically informed musical performance within the context of a now-ruined building: the Chapel Royal at Linlithgow Palace.

At the heart of this project were many of the conceptual issues that have been envisaged as central to the themed essays within these two volumes, especially the idea of reconfiguring lost realities, rebuilding likely scenarios, and recovering disappeared traces of historical and cultural value. Almost all aspects of this project – the visual, the acoustic, and the musical – involved quite literal reconstruction and recomposition, piecing together fragmentary evidence into something that could serve at once as a site for the interrogation of further research questions, and as an attractive aid to visitor interpretation in a popular heritage setting.

2 Historical Context

2.1 The Palace

The ruins of Linlithgow Palace, cared for by Historic Environment Scotland, currently cling to the peel above the loch which sits at the centre of the historic royal burgh of Linlithgow (see figure 1 for a map which situates this in relation to Edinburgh) [fig. 1]. Even in its ruined state, the palace has its own charm, immortalised, for instance, in JMW Turner's 1806 oil-on-canvas painting, which currently hangs in the Walker Art Gallery, Liverpool. Before its ruination, it was the magnificent pleasure palace of the kings and queens of Scotland, its building work having been started in 1424, by King James I, on the site of an earlier building of rather more military significance. Perhaps most famous as the birthplace of both James V and Mary Queen of Scots, it underwent a number of layers of building work under various monarchs, before falling out of favour and into disrepair. On September 6 1607, the north range, already noted as being in poor condition in 1583 (Paton 1957, 311) and ruinous in 1599 (Calendar State Papers 1969, 623), collapsed (Maidment 1844, 369), though it was later rebuilt between 1618 and 1622 on the orders of King James VI/I

(Burton 1895, 335). Despite this, it never again served as a frequent home for royalty – King James never returned and the last reigning monarch to reside there was King Charles I, for a single night in 1633. By October 1641, an English visitor noted that the roof of the great hall was no longer present, and that the grand fountain had been vandalised, and by 1668 it was once again described as a ruin. The palace’s fate was sealed on the night of 31 January 1746, when troops of the army of the Duke of Cumberland, who were quartered there, accidentally started a fire which destroyed much of what remained (Bateson et al. 1904, 275).



Figure 1 A map showing Linlithgow Palace in relation to Edinburgh. Timothy Pont and Hendrick Hondius, *A New Description of the Shyres Lothian and Linlitquo*. Amsterdam: H. Hondius, 1630. National Library of Scotland, EMS.s.676. Reproduced with the permission of the National Library of Scotland

The difficulty of conveying the lost interiors of ruined buildings is something well-known to heritage researchers,¹ and arguably exacerbated in Scottish heritage. There is a clear historiographical trend which treats Scotland as culturally lacking in comparison to England, and indeed the rest of the world. This has a distinct history in academic literature which may arguably be seen as dating back to Anthony Weldon’s account of James VI/I’s progress to Scotland whose, in the words of Wormald (1983), “brilliant and deeply biased character sketch” which “arose out of a hatred for the Scots ... has never quite failed to influence later attitudes to James I” (191-2). Similar trends may be seen in the early reception of the king in Peyton’s (1652) *Divine Catastrophe of the Kingly Family of the House of Stuarts*, or the less polemically titled, but still overtly critical Wilson’s

1 An issue which is incidentally often directly confronted in the digital heritage sphere, as an example with further discussion here see: Brůha et al. 2020.

(1658) *History of Great Britain, Being the Life and Reign of King James I* and Osborne's (1658) *Historical Memoirs of the Reigns of Queen Elizabeth and King James*. This reception has carried into the middle of the twentieth century in Wilson's (1956) *King James VI and I*, even if it is becoming more balanced in recent literature.² The idea of the barbaric northern king being foisted on the more cultured southern lands seems to have rubbed off on reception of the land of James' birth more generally. This historiographical lens, which has tended to diminish Scotland's artistic and cultural output, has been further focused through more recent historiophotical means (to borrow Haydn White's formulation of the construction of historical narrative through image rather than the written word). Scotland boasts, of course, an overabundance of Castles which are, in the main, in a state of ruin. This makes it a particularly common venue for filming of historical and fantasy drama. The historiophotical issues this can engender can be illustrated by considering the recent films *Mary Queen of Scots* (2018), *Outlaw King* (2018), or the TV series *Outlander* (2014-). They all seek an air of 'authenticity', both to their historical and geographical subjects, by filming on location at a number of Scottish castles and palaces, including Linlithgow Palace, and Blackness, Doune, and Craigmillar Castles. These locations are presented in their current ruined states, with bare stone walls, and sometimes lacking ceilings and windows. Even if the absolute state of their ruination is somewhat covered by clever camera work, they still leave the prevailing sense that the pre-modern interior of the important dwelling places of the temporal and spiritual magnates of Scotland were dark, dingy, draughty and undecorated. In short, pre-modern Scotland was ruined by design, rather than by time.

Our project therefore sought to use cutting-edge technology to provide a visitor experience which would emphasize the visual splendour that once characterised Linlithgow Palace. It also attempted two rather more musicological ends – i). to combat the prevailing sense, often given by heritage sites, that these buildings were historically silent,³ and ii). to attempt to address the common misconception, given by modern concert and recording conventions, that music of this period was heard and should be heard in cavernous acoustics.

² See, for instance, Stewart 2003, a popular biography which makes copious use of primary sources to redress some of this balance, or Rhodes, Richards, Marshall 2003, which demonstrates his contribution as a writer and patron.

³ This problem is perhaps emphasized for Scotland, which is often overlooked by musicologists interested in early music. Consider, for instance, Harrison's (1958) *Music in Medieval Britain*, which makes almost no mention of Scotland.

2.2 The Music

For this project, we chose to centre our reconstructed event around the celebration of Easter in 1512. This was largely to cover the fragmentary nature of the surviving musical repertoire from this period, and indeed more generally in Scotland. Pre-reformation Scotland can boast only three substantially complete surviving musical sources:⁴ D-W Cod. Guelf. 628, or W1 as it is more commonly known, which was written c. 300 years before the period of our reconstruction, and GB-EN MS Adv. 5. 1. 15, better known as the Carver choirbook, and GB-EU 64, better known as the Douglas-Fisher Partbooks, from slightly after it. To this may be added a handful of fragments: S-Uu C233, which contains two liturgical songs inserted into a thirteenth-century codex of texts, and which may be related to Orkney (Beveridge 1939); GB-A 2379/1 two strips of vellum which contain part of a two-voice organum setting of an alleluia from c. 1300, which may be from either London or Aberdeen (Chew 1978); D-W Helmstedt 499, which contains two fragments of fourteenth-century troped alleluia motets, which may be English but which came from a binding associated with Arbroath Abbey (Woods-Preece 2000, 304-24); GB-PA which consists of two slate fragments, found in a drain at Paisley Abbey, with fragments of fifteenth-century notation (Elliot 1996 and Elliot 2000); and GB-EN acc.11218.6.1.H-L (*The Inverness Music Fragments*), which comprise of fifteen mid-sixteenth century paper fragments of liturgical faburden and chant for the liturgy of Holy Week and the office of Compline during lent, possibly from the sangschool at Inverness parish church (Allenson 1989).

What should be clear from the above list is that we have almost no music surviving from Scotland in this period, though it is extremely clear from surviving documentary evidence that there was a thriving musical environment in Scotland throughout this period. Returning to the practical consideration of choosing repertoire for our project, we therefore had to take some creative approaches to produce something both coherent and historically informed. Since Scotland followed the Sarum Rite in its worship (the Latin liturgical rite which developed at Salisbury Cathedral), which was also followed in England, we have a good sense of what music would have been heard for a particular liturgical celebration, as well as surviving copies of chant from the same Rite, found over the border in England.

By selecting Easter Sunday as the core of our reconstruction, a period where we know that James IV was present and celebrated Mass with the chapel royal, we were able to pin a real historical event to

⁴ For a comprehensive list of all Scottish Liturgical books and fragments from before 1560, see Holmes 2011.

some surviving versions of music that we know would have been part of it. The knowledge we have of that particular Easter and the days surrounding it are rich.⁵ Indeed, details like the fact that the organs (which had been in need of repair), candelabra and the king's cupboard were carried from Edinburgh to Linlithgow, and the 'chapel graith' carried from Stirling, records of food arriving for feasts and celebrations, all come together to paint a vivid picture of what the festivities would have been like that day (Harrison 2016, 77-8).

At the core of these Easter festivities, of course, were the religious celebrations within the Palace chapel, and the core of our repertoire, therefore, is the Sarum chant liturgy for Easter Sunday. This did, nonetheless, cause issues for some of the stated aims of our project, since we wanted to emphasize the richness and cultural significance of Scotland's musical heritage. For all its qualities, monophonic chant is perhaps not the best vehicle for making this point – and indeed it is probably not historically informed to suggest that the King would have had no polyphony on the most important date in the liturgical calendar. We therefore took an approach that was founded on historical practice, and used the quasi-improvisational technique of *faburden*, as described by the contemporary theorist known as the 'Scottish Anonymous' (author of *The Art of Music Collectit out of All Ancient Doctouris of Music*, from c. 1580 and now carrying the siglum GB-Lbl Add. MS 4911) to 'thicken' some of our monophonic chant into simple polyphony. This approach – which essentially provides a framework for homophonic improvised embellishment in three or four voices – seems analogous to that which would have been taken by contemporary performers, if they had found themselves similarly lacking in appropriate polyphony for a certain event.

Nonetheless, even this lacked a degree of the magnificence that is endowed by composed polyphony. We therefore chose to add a single movement from one of the two earliest Mass cycles found in the Carver choirbook. Both have been recently argued to be Scottish in origin (Cook 2019), rather than continental, as had previously been suggested, and they certainly seem to represent the repertoire available in Scotland towards the end of the fifteenth century. It has been argued that Robert Carver, the scribe of the manuscript, was employed by the chapel royal in Stirling (Woods 1984), precisely the same singers who would have staffed the chapel royal in Linlithgow. It is therefore quite possible that these two Mass cycles would have been performed by the singers we know sang in our reconstructed chapel.⁶

5 To read a more in-depth account of this particular event as well as other insights into Linlithgow Palace's rich past, see Harrison 2016.

6 It should nonetheless be noted that neither Mass cycle is entirely appropriate for the occasion of Easter. We chose the "Sine nomine" cycle, since the other was clearly

The overall effect of our musical choices, therefore, are to pin our performance on a particular event, for which we were able to provide the appropriate liturgical chant - alongside a demonstration of how Scottish polyphony would have sounded in an accurate reconstruction of the kind of acoustic for which it was initially composed.

This project exists in two discrete versions - one an explicitly audio-visual and interactive experience, the other a commercial CD output which makes use of the same reconstructed acoustic. These two different experiences therefore had different priorities and required different approaches, even if working on essentially the same material. It is the VR (i.e. audio-visual) experience on which we will focus predominantly in this essay, beginning with the digital documentation of the site as it currently stands.⁷

3 Digital Documentation

Before the sights and sounds of the past could be reconstructed at Linlithgow, the Digital Documentation and Innovation team at Historic Environment Scotland first documented in 3D the chapel and antechamber at Linlithgow Palace as it stood in 2018 [fig. 2]. This baseline dataset would act as the real-world foundation from which the reconstructed visuals and sounds would be virtually built.

intended for St Catherine. The presence of the Kyrie trope "Rex virginum" in the Sine nomine cycle, nonetheless should really preclude its use for Easter - but nothing more appropriate survives.

⁷ For a more in-depth account of the CD process, see Cook et al. forthcoming.



Figure 2 An aerial view of the palace as it stands today. The Palace Chapel is located along the middle of the South facade, to the right of the image

Digitally documenting the historic environment of Scotland is a key element in how HES cares for, learns about, and shares the wide variety of assets in their care. For context, the Digital Documentation and Innovation team at HES are in the midst of a project entitled the Rae Project wherein they are endeavouring to document in 3D all 336 of their properties in care and the artefacts which they house.⁸ While this is a massive undertaking, this work provides not only a foundation of highly accurate resources to be utilised by heritage professionals and visitors alike, it can aid in education and learning, virtual accessibility, site management, interpretation, conservation decisions, and monitoring changes over time. Digital heritage is an ever-growing tool for the sector to tell more complex stories about the past in innovative ways. This particular project at Linlithgow Palace is an excellent example of how the virtual space can act as a stage on which to layer multiple forms of interpretation and accessibility.

The creation of the 3D model began with a visit to the palace itself, armed with the necessary tools to document the relevant rooms of the site: a terrestrial laser scanner (in this instance a Z+F 5016, which records colour data as well as intensity), and a Nikon D850

8 To learn more about the Rae Project and the work of the Digital Documentation and Innovation teams at HES, see: <https://blog.historicenvironment.scot/2020/05/re-cording-scotlands-history-in-3d-with-the-rae-project/>.

camera. Over the course of a day, the team utilised the laser scanner to record with up to millimetre accuracy the existing geometry of the chapel as it stands today, roof missing and stones bare. The scanner works by line of sight, rapidly recording points of a surface in 3D space, assigning each an xyz coordinate up to a million times per second. Each of the points come together in what is called a point cloud, representing the surface geometry of the building in a kind of highly accurate three-dimensional pointillism [fig. 3].



Figure 3 3D point cloud of the Palace Chapel at Linlithgow, Historic Environment Scotland

In addition to scanning the geometry of the chapel, the team supplemented the scans with hundreds of photographs in order to capture fully the photorealistic texture of the space. These images were taken when the light was overcast and even in order pre-emptively to eliminate any harsh shadows in the final model.

Back in the office, using specialist software, the teams at HES registered the individual scans and photography together, forming a large, colorized point cloud. From there, it was processed into a solid model by connecting each of the separate points together to create many polygons on a solid surface, or mesh. The texture from the photography was wrapped onto that highly accurate mesh to create a photorealistic digital representation of the chapel [fig. 4].



Figure 4 A photorealistic 3D model of Linlithgow Palace Chapel, created by combining the accurate geometry of the laser scan, and the colour imagery from the photographs, Historic Environment Scotland

Without further processing, this large dataset is an excellent foundation of spatial information of the structure, but is highly impractical to wield on anything but a specialist machine. In order to make it more accessible to explore, the model was decimated into a lighter model with fewer polygons, borrowing workflows from the gaming industry. Thus, just like in a video game, the new lightweight model is easier to load on personal computers or mobile devices (see figure 4). In order to trick the viewer into thinking they are looking at a much more detailed mesh, we can use different maps, such as normal maps, to create the illusion of detail on a relatively simple model.

From this baseline dataset representing the current chapel in its ruinous state, it was then time virtually to layer on the sights and sounds of Linlithgow in 1512 [fig. 5].



Figure 5 A reduced-resolution version of the present-day palace, rendered in Unity (and haunted by the ghostly figures of our singers)

4 Virtual Reconstruction

The process of digital documentation gave us a platform from which to build our reconstruction. Looking to virtual reconstructions is an increasingly accessible way of exploring historical representations of different aspects of the past. The virtual space allows for the rebuilding of lost heritage and restoration of visual and auditory assets in a reversible and non-invasive way (Pietroni, Fernandi 2021, 4). Indeed, it lends itself perfectly for a viewer to engage immersively with a space digitally across time, a concept explored in archaeological and heritage contexts for years (Morgan 2009). For this project, we decided that the ability to transition seamlessly from the past to the present would be an important part of bridging across time, affording the user the ability to explore how the vestiges of how the building once may have looked could still be traced in its current ruined state.

A typical issue in reconstruction (virtual or otherwise) is what time to represent. Buildings encounter many iterations throughout their history and choosing one version to reconstruct can often be difficult. This project, however, thanks to the rich history available to us, discussed in the second section, was able to set its sights on a specific day. In order to build a reasonable model of how the chapel may have once looked, the research team worked with standing-building archaeologists, historians, and the archival and archaeological record

to attempt to reconstruct the palace c. 1512, on which date James IV is known to have been present, with the singers of the chapel royal, to celebrate Easter, and for the baptism of his son, the future James V.

As is often the case in this type of work, our reconstruction work can be described as having varying degrees of confidence, ranging from relatively certain to intelligent guess work. The evidential basis for all of our decisions will be outlined below as we walk through the user experience step by step.⁹

One of the most readily apparent aspects of our reconstruction, since the user begins the experience directly facing it, is the handling of the two archways which occupy the East wall [fig. 6]. According to Historic Environment Scotland's Archaeological Survey of the site (2015, 188), they show no sign of ever having had doors. We have therefore assumed that they function as an ambulatory, essentially extending the liturgical space into a processional route behind the altar. With the size of the space, it is hard to see how it could have functioned for anything other than the smallest of processions, without an inordinate amount of pacing back and forth. Rather than leaving these archways entirely open, given that it is hard to imagine the ambulatory being regularly used, we chose to close them with drapes. For the period on which we have based our reconstruction not all building expenses for Linlithgow survive and there are no explicit mentions of fabric purchased for Linlithgow palace chapel at an appropriate date, but there are, however, notable mentions in the treasurer's accounts of large purchases of material that relate to the King's household more generally. For instance: "*Item, for xij elne taf-fetj to be ane trevis to the King; ilk elne xvj s.; summa... ix It. xij s*". 11 *elne* of material gives a total of 44 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. After the appointment of the Master of Works to the Crown of Scotland in 1529, his accounts give us rather more detailed information.¹⁰

On the facing wall opposite the altar, the user can see that the wall may have been covered with drapes in much the same way. As with the West wall, there is no surviving evidence of door attachments, though it is unlikely that the chapel ante-room, into which it leads, would have constituted one unbroken space with the chapel. The surviving stone rail at the top of the wall seems to offer the method of attachment for the proposed drapes.

⁹ For a more detailed account of this, see Cook et al. forthcoming.

¹⁰ Edited in Paton 1957, and Imrie, Dunbar 1982.



Figure 6 The Altar on the Eastern wall in VR, the arches hidden behind tapestry and altar, seen in the 3D model on the right



Figures 7-8 The virtual oak ceiling in VR from the user's point of view; a virtual view of the South wall, with windows and statues in place

Looking up, the user sees a rather impressive oak ceiling [fig. 7]. To reconstruct this, we had to unpick two different stages of roof building; the first, most relevant to our reconstruction date, was slightly lower, but we know far more about the construction of the second. In May 1535, there were payments for nineteen 36 foot joists for the chapel (Paton 1957, 123). There are 13 joist sockets still visible, allowing for 6 joists left over for supporting the gallery/loft, completed around this time. The following month, payment was made for birch scaffolding for the ceiling (124). No payment records survive relating to the earlier roof, but its arrangement is obvious from the surviving joist sockets (once the two layers of building work are disambiguated).

We have explicit records for the decoration of the second layer of ceiling construction: John Ross painted the “lyning” of the chapel “sylvoring” in “fine assur” as well as twelve pendant knobs under the chapel loft (128). 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. We do, after all, lack the payment records for the construction of this version of the roof in the first place! A similar decoration scheme to that deployed in the rebuilt ceiling has therefore been followed.

More evidence survives of a later reglazing of the windows than its initial disposition. In the mid-1530s, the five windows had 268 ft² of clear glass and 29 ft² of painted images (128), roughly 60 ft² of clear glass in each window with a 6 ft² panel of coloured glass. In contrast to the ceiling, there was no practical need to replace the glass in the 1530s – the fundamental architecture of that wall did not change; this must have been an aesthetic choice. We therefore followed a pattern found in the relatively contemporary windows at Stirling Palace and gave clear glazed panels, decorated with the Coat of Arms of James IV on each.

Stirling Palace also served as a model for the decorative scheme we used on the walls, specifically the use of *trompe-l'œil* painted tiles. There are small surviving remnants of plaster on the chapel walls and all walls have therefore been replastered in our reconstruction. No evidence of decoration survives on these remnants and so the decoration scheme is taken from an analogous site. The South wall, which also holds the windows, has a number of niches that clearly once held saintly statues [fig. 8]. We have chosen to fill these with saints which make contextual sense: St Andrew, the patron Saint of Scotland; St Michael, the dedicatee of Linlithgow Parish Church, which sits next door to the palace (and also the dedicatee of the chapel Royal in Stirling, Robert Carver’s *Mass Dum sacrum mysterium*, and James IV’s colossal warship The Great Michael which was built at roughly the same date); St James, James IV’s namesake; and St Margaret, that of his wife.

If the user looks down, they will see clay floor tiles. By 1996, some 500 fragments of these had been found in archaeological digs from

across the site.¹¹ One contains an intertwined ‘I’ and ‘M’, and therefore must date from the years immediately following the 1503 marriage of James IV and Margaret Tudor,¹² making them appropriate for the flooring of the chapel, completed shortly thereafter. The masons responsible for the “paythment” of the chapel were paid in February and April 1507 (Paul 1900, 297-8); on James IV’s visit to Linlithgow in August of the same year, the masons were paid 42 shillings “in drinksilver” (Paul 1901, 411).

Perhaps the most challenging aspect of the reconstruction was the positioning of choir stalls. The archaeological survey suggested that they would have been placed in the traditional position, along the north and south walls, though there is no surviving physical evidence of this (Linlithgow Palace: Archaeological Survey 2015, 189). However, this positioning blocks much of the light through the windows. Attempting to ameliorate this by positioning these closer to the altar blocks access to the ambulatory and also causes issues with positioning singers around a lectern. No matter where the stalls were placed, they left very little space between them due to the narrowness of the chapel.

We know that the roughly contemporary early chapel at Stirling Castle featured wooden choir stalls with canopies, as these were used as the model for the stalls in Glasgow Cathedral in 1506 (Dunbar 1999, 126). We might therefore have expected that Linlithgow would also have had stalls since the personnel of the Chapel Royal served both. Nonetheless, Linlithgow Palace chapel was significantly smaller than the space at Stirling; even the latter’s earlier 15th-century chapel, closest in age to Linlithgow, still measured upwards of 9m x 29m (a footprint of 261m², versus only 120m² for Linlithgow). It is possible that James was attended by less than a full complement of the Chapel Royal when in Linlithgow: Robert Lindsay of Pitscottie notes that half of the Chapel Royal would travel with the older James III (Mackay 1899, 200). Certainly, there is documentary evidence for the transporting of the “chapele geir, organis and eucharist” to Linlithgow (Paul 1902, 347), suggesting a somewhat less permanent installation, at least until the later installation of an in-built organ.¹³

11 For a full account, see Caldwell, Lewis 1997.

12 See Caldwell, Lewis 1997, 837 for an image.

13 Organs were, in the meantime, frequently transported between Stirling, Linlithgow, and Edinburgh. As noted in Paul 1902, 347, David Trail, the Sacristan of the Chapel Royal, organized the transport of the “chapele geir, organis and eucharist of Linlithgow”. The permanent Organ was installed in April 1513. A French organ builder, named Gilyem, was paid 10 “licht Franche crounis” 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 1902, 523.

The problem of situating the choir stalls is exacerbated by the positioning of seating for the Royal couple. After the period of our reconstruction, a wooden loft was added, which sat above the west Wall of the chapel, which has been described as either an organ loft, or a box for the Royal Family. The first of these suggestions is unlikely, since there is insufficient material in the 1513 accounts of the organ's attachment to the wall for the loft to have been constructed - and the organ does not appear to have been relocated later. In either case, it is clear that there was nowhere separate to seat the monarchs at the date of our reconstruction. In the end, we followed the Historic Environment Scotland interpretative reconstruction and set seating for the Royal couple on the North and South wall, making placement of the choir stalls essentially impossible.

5 Acoustic Reconstruction

As well as our visual reconstruction, we sought to reconstruct the acoustics of the chapel. This relied on a detailed understanding of the acoustic properties of the materials we believed were used to construct the building. Materials reflect and absorb sound by different amounts at different frequencies; rough surfaces will also scatter the reflected sound more than smooth surfaces.¹⁴ Having investigated the proposed materiality of all surfaces within our reconstruction, we tagged them with coefficients relating to absorbency over the range of audible frequencies, and a scatter coefficient, so that we were able to model how sounds would have interacted with the reconstructed space.

Once all the surfaces in the model had the required coefficients, 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, which can be saved as a .wav file that can be loaded into a convolution reverb plugin, allowing one to apply this room-sound to any 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 on our recorded music.

In order to test the efficacy of this approach, we ran a test that compared an impulse response derived from a Sine sweep in a real building with one in a virtual reconstruction (with both the sound

¹⁴ See, for instance, Rindel 2000.

source and the receiver identically positioned),¹⁵ which enabled us to judge how effective our reconstruction process had been, and enabled us to test the efficacy of various plugins for reconstructing acoustics in VR.¹⁶

5.1 Recording Process

Given the importance of acoustic reconstruction to the process, we chose to record in an anechoic chamber, a space which had close to no natural acoustic (fig. 9). This 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. However, this does invite various performance problems: the environment is claustrophobic, bears no resemblance to the reconstructed acoustic, and offers very little in the way of feedback to the performer.¹⁷ It is therefore also important to ensure that performance decisions are taken which reflect the intended reconstructed acoustic, rather than the acoustic as is found in the chamber. The difficulty is how to arrive at performance decisions, such as tempo, phrasing, diction, and blend, for an environment which is entirely virtual. We experimented with different approaches, initially recording with headphones that fed back a real-time rendering of the singers with the acoustic overlaid, but we eventually continued with no artificially supplied acoustic. Instead, performance decisions were discussed in advance, short sections were recorded and then listened to within the control room with the overlaid acoustic, and then confirmed. We regularly listened back to the recordings with the overlaid acoustic between takes to ensure that we were still approaching the reconstructed acoustic in a musically appropriate manner. You can hear an example of some of the music recorded in our reconstructed acoustic on Historic Environment Scotland's website.¹⁸

15 A Sine sweep involves using a tone derived from a Sine wave which moves across all audible frequencies, in this case starting low pitched and ending high pitched.

16 For a full discussion of this experiment and its results, see Selfridge, Cook, Kenny McAlpine, Newton 2019. This experimentation took place for another heritage site which was explored during the project: St Cecilia's Hall. A similar process could have been undertaken with the Linlithgow model. However, this was complicated by Linlithgow Palace's status as a tourist site and the fact that it has no roof or windows. This made obtaining sufficiently clean recordings exceptionally difficult. The presence of a colony of bats in the ruin was also problematic for the use of high frequencies within the Sine sweep.

17 For a full investigation of the process of recording and the production of the associated commercial CD recording, see Cook et al. forthcoming.

18 <https://hes-scotland.sharefile.eu/share/view/s713d48dc20af4e-c7aae385e3bdc0e2cf>.



Figure 9 The Binchois Consort with Andrew Kirkman in rehearsal in an Anechoic chamber, York University

6 Interactivity and the User Experience

An important aspect of the development of our VR output, for the impact and engagement follow-on, was that it was designed to be used by visitors on site, within Linlithgow Palace. This necessitated various important changes to both the hardware and software design. The first version of the application ran on an HTC Vive. This wired headset makes use of infrared sensors deployed on two poles for the derivation of positional information. Combining this detailed positional information with the high processing power inherent to wired headsets, it was possible to give an extremely interactive experience. The user could walk freely in real life as a method for navigating the virtual space, mapped to a 1-to-1 scale. Acoustic data could be ‘baked-in’ at various points with cross-fading as the user moved between them, so that real-time acoustical computation was not required but the acoustics still accurately reflected the spatial characteristics of the exact location of the user.

Nonetheless, the practical realities for having a VR experience onsite cannot be overlooked. The wires of the Vive proved to be a tripping hazard, whilst any occlusion of the sensors – say, for instance, by another visitor walking past – would lead to application-breaking glitches (and extreme nausea on the part of the user). It was also clear that it was not possible for HES staff to be on-hand at all times to watch the expensive laptop and prevent theft, or indeed simply to run the application at source. This model of use also only provided for one user at a time – something which was liable to cause bottlenecks on site. More generally, the combination of phys-

ical movement and the wearing of VR headsets – problematic at the best of times – is especially fraught in a historical building with uneven floors. Though it was attractive to imagine walking around the real space of the chapel, mapped perfectly in the virtual world, and experiencing the reconstruction, this was clearly impossible in reality – other visitors would provide collision hazard and uneven floors would cause tripping (not to mention the potentially fatal glass-less second-floor windows!).

The model was therefore substantially redeveloped with optimization for use as an onsite visitor attraction at the heart. This version was developed instead for the Oculus Quest, a wireless headset which required no positioning poles, and which was substantially cheaper. This removed any danger of occlusion, and allowed for us to supply 5 headsets for simultaneous use. The flip side of this was a huge reduction in processing power, as well as the necessity to run the experience as an ‘at seat’ application. These two aspects posed questions around the accuracy of the acoustic model, the graphical spectacle (i.e. resolution and rendering), and the degree of interactivity available. Perhaps the most obvious answer to the last of these points is the use of the joystick controllers to control avatar movement on each handset of the Quest. However, given that these are very small and liable to be lost or stolen, we instead sought to use a mode of control which would not require the handsets. The application instead immediately starts (and restarts) when placed upon the head of a user – meaning that no prior knowledge of how to work a VR headset is required. All other functions are selected by using an eye reticule. The user simply looks at an object and, by holding their gaze upon it, can select options. Movement of the player avatar was changed to take place essentially as a ‘fly-by-rail’ track, where the user is taken automatically around the space. In order to give a degree of agency – and indeed to maintain the ludic aspect which was at the heart of the initial project – the headset tracks the movement of the user’s head as they look around, and they can seamlessly transition between the past and present, watching and listening as both the visuals and the acoustics change. Whilst this lost a degree of the desired interactivity, the savings in deployment of processing power allowed us to be far more accurate with our acoustic model. When allowing for unlimited free movement in the space, we had to rely on the Steam VR audio plugin, which was not fully accurate, but did allow calculation of the acoustic as the user moved around the space. Having switched to movement following a set path, we were instead able to make use of Odeon to apply our acoustic, and therefore reach far greater levels of accuracy.¹⁹

¹⁹ For a discussion of the pros and cons of these various plugins, see Selfridge et al. 2019.

The experience was set to be implemented onsite for early 2020, and was thus ultimately postponed in the face of the pandemic. Indeed, as of the writing of this article, the Palace is still closed to the public due to high-level masonry precautions, with the full public release of the VR application delayed until re-opening. With that being said, directly outside the chapel there is currently an interpretation board on the fence that wraps around the palace with a QR code that, when scanned, plays a short version of the experience [fig. 10]. According to HES staff, the resulting music playing openly from visitors' phones is rather poignant: the low-level ambient sound playing on personal devices for others nearby to hear is almost as if you are standing in the outer courtyard in 1512, listening to the music drift out of the chapel windows. Though it was never an intended output of the project, it is perhaps significant that currently the only way that a visitor can visit any part of the interior of Linlithgow Palace, is through a version of the VR reconstruction.



Figure 10 A visitor to Linlithgow Palace in 2022, scanning the QR code to experience a condensed version of the project, Historic Environment Scotland

Virtual representations will never fully replace the experience of actually visiting an historic site. It can instead add layers of interpretation and access otherwise difficult to achieve in the physical world. Indeed, until Linlithgow is reopened to the public, this virtual representation is the only way to explore beyond the Palace walls.

7 Final Thoughts

This essay has aimed to outline the context, methodology, and potential of the AHRC-funded research project, *Space, Place, Sound, and Memory: Immersive Experiences of the Past*. Building from a highly accurate digital representation of the site as it stands today, teams across organisations and disciplines were able to reproduce a hypothetical and historically informed musical performance at the Palace chapel for the Easter of 1512.

Digital documentation and the creation of a 3D model should act as a foundation from which to explore facets of our heritage in unique and meaningful ways. As we have discussed above, the *Space, Place, Sound, and Memory* project not only utilises this virtual stage to explore visually the lost realities of experiencing Linlithgow Palace chapel in the 16th-century, but vividly brings it to life through the use of historical music and acoustics. For the teams at HES, this project has showcased how a carefully researched repatriation of historical experience through visual and audio reconstruction opens up new methods of storytelling and meaning-making in the heritage sector at large.

For musicologists, this project can be situated within the context of a number of others seeking to situate historical performance within reconstructed spaces and acoustics, such as Cappella Pratensis' recording of Obrecht's *Missa de Sancto Donatiane*, recorded as a virtual reconstruction within the Church of St James in Bruges,²⁰ and the *ReviSMartin* virtually reconstructed acoustic of the Abbey of St Martin in Tours, which used an excerpt from Okeghem's Requiem.²¹ More broadly, scholars are exploring the importance of soundscapes and acoustic reconstruction to understand performance across a number of disciplines, such as the British-Academy-funded research project *The Soundscapes of the York Mystery Plays*,²² which takes a similar approach to medieval drama. A refreshing aspect of this project, however, has been the focus on its realisation within the specific context of a heritage environment, with a focus on curation of the site, and user-experience at the heart of its development. The degree to which this allows the musicologist to centre historical sound and music within the visitor experience has been really powerful.

The chapel of the past was not bare-stoned and silent as visitors experience it today, but rich with colour, movement, and sound. The use of cutting-edge digital technology combined with a collaboration of minds throughout the historical, archaeological, musical, and

²⁰ <https://sites.williams.edu/obrechtmass/>.

²¹ <https://renaissance-transmedia-lab.fr/rtl4/revismartin/>.

²² <http://soundscapesyorkmysteryplays.com/hearing-the-mystery-plays/>.

digital heritage spheres results in a dynamic interpretation of a moment in our past. This is what digital heritage is capable of: never to replace our built heritage, but to fill in the gaps, virtually bridging the distance between the past and present by reconstructing sight, sound, and exploration.

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