Nightports at Hull Minster: Physical, Hybrid and Virtualized Live Loudspeaker Array Spatialization of Electronic Music Performance

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***Abstract*–'Nightports at Hull Minster' is a musical project that harnesses spatialization techniques to present music composed of the sounds of Hull Minster, UK, in both the location itself and alternative performance spaces, whilst still expressing the spatiality of the location. The project involves a live electronic music performance by Nightports (The Leaf Label), using only sounds recorded in the Minster itself, spatialized in real-time by another performer across a 25-loudspeaker array. In total, three variant approaches are detailed: a physical acousmonium in-situ; a hybrid acousmonium and virtualmonium; and headphone-targeted virtualizations. To achieve virtualization, spatial room impulse response measurements were taken across the diffusion array to capture the characteristics of the loudspeaker arrangement implemented in the Minster. A scalable and adaptable spatialization system was devised to realize the different iterations and is detailed in this paper, alongside observations on the performative ramifications, compositional preoccupations, and potential developments of the project.**

Keywords—site-specific music, adaptive spatialization, heritage acoustics, virtual acoustics, live performance

I. Introduction

The initial concept and primary execution of this musical project involved a live electronic music performance within Hull Minster. The music is derived from sounds recorded in the bell tower, which were then diffused through a 'loudspeaker orchestra' array, utilizing amplitude-panning to exploit the distinct acoustic characteristics of the space, following the fundamental traditions of the acousmonium: the intention of 'diffusing' signals across loudspeakers distributed in a performance space [1]. The musical work is intimately entwined with the location: parts of the Minster date back to circa 1285 [2] and it features a rich, pronounced acoustic as to be expected of a large, stone church. The performance of the work requires three people – two triggering and manipulating sounds (referred to as Nightports), and one gathering the various categories of sound feeds and spatializing them in real-time (referred to as the diffusion performer). Subsequent, unanticipated iterations of the project have required reactive adaptations of the spatial presentation and virtualization of the acoustic properties of the Minster and the loudspeaker array that was implemented in the Minster in August 2022.

A. Origins

The origin of *Nightports at Hull Minster* was one of opportunity. Despite Hull Minster being a welcoming public space at the heart of the city, access to its bell tower is typically restricted and rarely granted. However, Nightports were granted the opportunity to ascend approximately 45-meters to the upper regions of the bell tower, where a complex arrangement of ropes and intersecting wooden beams converge to form the time-keeping apparatus of the structure. The project also emerged as a response to the symbolic and acoustic significance of Hull Minster (previously known as Holy Trinity Church until May 2017). For centuries, the building has marked time for the population of Hull, with its bells reverberating across the city and out across the Humber river. A preoccupation with matters of scale led to an appreciation of the dynamic presented: from the minutiae of the clock mechanism that has helped synchronize a city, to the miles-wide span of a sonic cityscape.

B. Materials

In September 2021, a stereo and ambisonic recording rig was setup in the bell tower. The day was dedicated to capturing a diverse range of sounds, which were subsequently categorized into five primary groups: 1) individual bell tolls; 2) peals occurring at quarter-hourly intervals; 3) clock mechanisms; 4) mechanical noises of ropes in movement during peals alongside sundry metallic objects forming the fabric of the apparatus; and 5) a sample set of the 25-bell/2-octave carillon. This extensive palette of audio then formed the basis for an 8-month creative process of curation, intervention, composition, and production. The outcome was a 30-minute ambient electronic composition designed for live performance, involving a mixture of pre-composed and improvised elements, distributed across 7 stereo busses for discrete spatialization via acousmonium-style diffusion.

C. Composition

From a compositional point of view, the idea of 'space' has two resonances here: architectural and acoustical. First, the space has significance in terms of what the intended function of the building means for the local population, and what opportunities the story of the building provides creatively: a factor that could be deemed a 'cultural' or 'dramaturgic' influence [3]. Although predominantly (or, at least, originally) intended for Christian worship, the use of the building has been expanded in recent years to embrace non-religious segments of the population in a kind of ethos of celebratory welcoming. This shifting use became reflected in the musical materials: there is acknowledgement and preservation of the character and therefore implied function of bell tolls (for example) versus contradictory interventions that invoke Berlin industrial music, completely at odds with the building and thus serving to recontextualize the space itself through sonic mediation. Compositionally, this can be considered a kind of functional or narrative counterpoint ('breaking expectations' [4]). The second resonance of space

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is just that – its acoustic properties (a 'physical' influence [3]). The original intention of the project was always to present this music as a live performance in the space – the music is thoroughly *in* and *of* that place – and this performance would exploit the expanse using live spatialization. There are two key conceptual points here. First, a space or a location is not simply a happenstance container for the musical performance and experience, it is a dynamic and integrated part of the approach. The performers do not just play *in* the acoustic, they play *with* it. In this instance, as Elblaus and Eckel would suggest, 'without a site, there is no piece' [5]. Second and leading on from the that, this sense that the acoustic would be an integral aspect of the sonic elements in performance exerted a natural limit on the textural or structural density of any one moment, or how rhythmically dense or intense these elements would be. The compositional and rehearsal processes, as a result, would often feel quite 'dry' as the completion of the sonic profile was deferred to the eventual live performance events situated in (and with) that specific acoustic. These processes consequently required a projection of an anticipated version of what the material would sound like in the space. This impacted compositional decisions particularly with regards to percussion onsets and how sound could become obscured by pronounced acoustic responses. Though this was often unrewarding during the creative process, this sense of incompleteness was, in retrospect, some indication that this dialogue with space was necessary and inherent.

II. The Spatialization System

The Hull Electroacoustic Resonance Orchestra (HEARO) is a collective focusing on spatialized presentation of electronic musical works based at the University of Hull, utilizing a loudspeaker orchestra. This is driven by the HEARO spatialization system, an implementation in a modular software environment developed to offer scalability and flexibility in presentation method and performative approach (from simple diffusion to ambisonics). The design takes cues from the fundamental diffusion approaches detailed by Harrison [6] and the 'BEASTMulch' software system developed for diffusion performance [7]. The system is composed of several functions: loudspeaker array definition and calibration; input routing from both fixed-media and real-time sources; virtual channel propagation and routing; mapping of physical controllers (such as an Open Sound Control (OSC) or MIDI (Musical Instrument Digital Interface) controllers) to virtual channel amplitudes; routing of virtual channels to loudspeaker channels; interpolation between physical controller state presets; virtual channel behaviors, including amplitude jitter and rotation around portions of a loudspeaker array. The system was extended to accommodate the needs of the *Nightports at Hull Minster* project, affording adequate flexibility for the spatialization of multiple incoming stereo feeds. Further to this specific need, opportunities to perform the work developed in unforeseen directions from the original intention and, subsequently, these differing contexts necessitated variations of the system to be designed. The spatialization system receives multiple audio inputs from Nightports, composed of 14 signals as 7 stereo pairs, each transmitting discrete components of the musical arrangement to afford both musical flexibility and sympathy in the spatialization approach (see Table 1). These inputs are subsequently propagated to 80 virtual channels, which are necessary to provide discrete routing of arrangement components. The propagation is a simple duplication preserving stereo relationships, to be mapped onto loudspeaker pairs, with certain arrangement components (e.g., 'Bells & Swells') requiring a greater number than others (e.g., 'Bass & Rumbles'), dependent upon their intended spatialization. These virtual channels are accordingly routed to certain portions of the loudspeaker array, with their amplitudes controlled via the diffusion performance interfaces. Therefore, some arrangement components could be sent to the full range of loudspeakers, whilst others to only a targeted portion.

A. The Primary Array

A loudspeaker array was installed for the project in Hull Minster in August 2022 for diffusion according to the acousmonium principle. The positioning of the array was partially altered for a performance that needed to accommodate a public audience in March 2023 (see Fig. 1). It was composed of 25 discrete channels, populating the ground-level of the building in a manner that afforded both envelopment around the performance area in the nave and extension along the length of the building: along the crossing, through to the chancel and beyond the high altar, having a 70-metre span at its longest point. The August 2022 array, referred to as the 'primary array' hereon in, is the basis for all subsequent iterations of the work. It is composed of: eight large loudspeakers forming a 'main ring' representing the perimeter of the nave performance area; six small loudspeakers in an oval around the nave performance area, oriented 180° azimuth from the nave performance area, and +45° elevation, producing a more diffuse response as a 'diffuse ring'; eight small loudspeakers arranged in close pairs, positioned approximately equidistant as a column from the crossing to behind the high altar, below the east window, with pairs given gradual azimuthal rotation from 0° at the front to +/-90° at the rear and an elevation increase from 0° up to +45° similarly along the column as a 'distant throw'; three discrete subwoofers distributed to provide adequate low-frequency coverage in the performance area and additional ones utilized as cross-over subwoofers with the small loudspeakers for improved low-frequency extension. Time-alignment was implemented only for the portions of the array that were within the nave, due to the pronounced delay compensation that would have resulted from including the remaining, more distant loudspeakers (~130-milliseconds), and how that would impact on the responsiveness of the spatialization control.

TABLE I. Arrangement components created by Nightports and the respective spatialization method.

Arrangement Component(s)	**Spatialization Method**
Bass & Rumbles	Fixed
Drums	Anchored with widening dynamic across front of 'main ring'
Percussion FX	Dynamic across full array
Bells & Swells	Dynamic across full array
Synths & Pads	Dynamic across full array
Performer 1 Return	Fixed in 'diffuse ring'
Performer 2 Return	Dynamic across 'main ring' and 'diffuse ring'

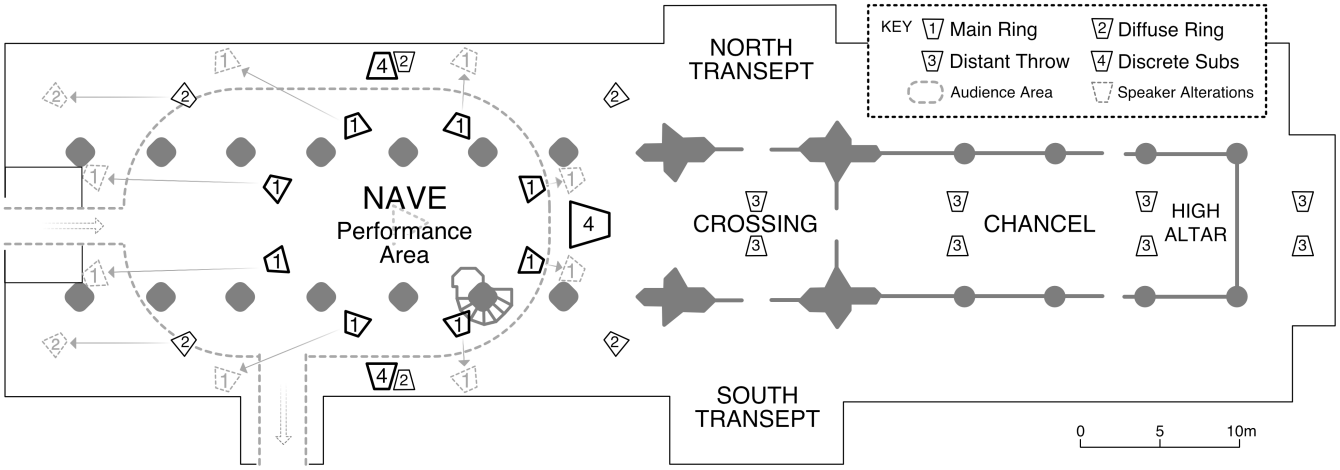

Fig. 1. The primary array as realised in Hull Minster in August 2022 for a filmed performance, with alterations required for a realisation in March 2023, accommodating a public audience.

B. Spatial Room Impulse Response Capture

For the initial presentation of the project (as part of Freedom Festival 2022 in Hull, UK) an audio-visual format was targeted for online dissemination. This performance involved extensive lighting, some of which was noisy, and the camerapersons needed to be able to move around, causing additional extraneous noise. It was determined that the presented audio of the performance would be a recording of the live performance produced by Nightports in-situ, but with a virtualization of the spatialization implemented in post-recording production to achieve a more controlled result.

To facilitate this aim, spatial room impulse responses (SRIRs) were captured across each component of the loudspeaker array, excluding the discrete subwoofer channels. A 1st-order ambisonic microphone was utilized to capture the responses using the sine-sweep method [8] each of which was characteristic of the response of each loudspeaker in-situ. The resulting SRIRs facilitated an ambisonic virtualization of the loudspeaker orchestra via multiple discrete convolution processes. All the convolution processing used in performance contexts was implemented with the non-equal partitioned convolution method, which is an efficient method for multichannel contexts, offering the possibility of near-zero latency processing [9].

III. Performance Interfaces & affordances

The performance interfaces were designed for immediacy, efficiency, and controlled flexibility. It was apparent that performance of the work could become unmanageable without a pragmatic approach to control design. Regarding the interfaces utilized by Nightports, performer 1 has responsibility for triggering the bulk of the pre-prepared sounds (which are organized into six blocks – roughly equating to six 5-minute tracks) along with some software and outboard signal processor sends to be applied in the moment; performer 2 has responsibility for live synthesizers and the application of a range of signal processors to the sounds triggered by performer 1. Outboard signal processors include reverbs and granulations, delays, noise and saturation. The performance is structured around the strict time-keeping function of the bell tower, beginning precisely on the hour, reaching the half-way point at exactly 15-minutes in, and culminating at half past. The structural flow within these main pillars allows for some degree of flexibility in how the performance unfolds. Other improvised freedoms in performance include addition and subtraction of audio elements within a texture, the intensity of send-return signals, and the combination of signal processing via pre- and post-fader configurations to further blur the source sounds. The spatialization of these live materials in all contexts was enacted by the diffusion performer and achieved utilizing a 32-fader OSC device and a MIDI device featuring XY controllers. The various fader and XY controllers are assigned to virtual channel amplitudes, providing varying resolution of spatial control, dependent upon the nature and range of spatial dynamic the diffusion performer intended. Three arrangement component controller assignments are detailed for illustration:

- The ‘Bass & Rumbles’ component, routed to various loudspeakers, is assigned to a single fader to afford overall dynamic amplitude control, without spatial movement.
- The ‘Drums’ component is assigned two faders to afford control over the amplitude level in an anchored position (front of the ‘main ring’) and an optional broadening of the image to occupy the front half of the ‘main ring’.
- The ‘Synths & Pads’ component is assigned eight faders to provide both a front/back dynamic across the ‘main ring’ and another along the ‘distant throw’. Additionally, an XY controller provides a dynamic between the ‘main ring’ and ‘diffuse ring’, affording a movement from direct to diffuse or varying amounts of each. Finally, another XY controller provides an intensity and speed control of an amplitude jitter across the virtual channel levels.

This model of arrangement component control is propagated in only slight variation across the remaining components (see Table 1 above), which provides adequate resolution of spatial control to enable and encourage curation of the space that is sympathetic to the musical materials and momentary performative variations. This curation of space with the arrangement components can be characterized along certain spatial qualities and dynamics: anchored/vectorial space; anchored/dynamic diffuseness; proximate/distal space; prospective/lateral space; and more variations [10]. The resolution of performance control over the arrangement components afforded a ‘polyphonic’ diffusion of elements. A method was developed that allowed the diffusion performer to

recall a snapshot of motorized fader positions that were devised for opportune moments between movements of the work. When recalled, an interpolation from the current fader position to the one predetermined is performed at a rate of 1-second. Any faders with active finger/thumb contact are excluded from the recall which enables dynamic spatialization to continue simultaneously. Adding this functionality created opportunity to choreograph some spatial movements that were unfeasible to realize with only performer input, including the staging of the clock mechanisms sounding at quarter-past the hour, featuring close-perspective capture of the mechanism spatially-counterpointed with a framed soundscape capture from the bell tower, accompanied by additional dynamic, processed layers of material and real-time signal processes.

IV. Spatialization Methods

The work has been realized in varying contexts, some of which were not anticipated when originally conceptualizing the technical approach to the project. The following is an outline of the technical implementations and inflections of each iteration realized. In each case, the arrangement components have been performed by Nightports and spatialized by the diffusion performer in the manner outlined, which has supported a coherence across the different performance contexts. Three variant approaches are detailed: a physical acousmonium in-situ (A); a hybrid acousmonium and ambisonic *virtualmonium* [11] (B); headphone-targeted ambisonic virtualizations (C1 and C2).

A. Acousmonium in-situ

A public performance was staged in March 2023 as part of the Awakening arts festival in Hull, UK. This iteration represents both the primary-intended context of the work and the most straightforward technological implementation, with a conventional, amplitude-panning approach to diffusion in real-time adopted in the acousmonium tradition. The spatialization relied on the physical loudspeaker positioning and the acoustic properties of the Minster in combination with the real-time routing of the arrangement components for the spatial dynamics of the work (as per Table 1). A substantial public audience was afforded movement around the nave performance area and, accordingly, the loudspeaker array was altered in certain aspects to accommodate that (see Fig. 1), resulting in a less precise response from the 'main ring' and a reliance upon elevated sound pressure levels.

B. Hybrid acousmonium and ambisonic virtualmonium

The HEARO loudspeaker orchestra was implemented in Middleton Hall, a concert venue situated on campus at the University of Hull, UK, as a 56-loudspeaker array utilizing mixed-loudspeaker models. The hall has raked seating and the array is subsequently arranged with particularly dense coverage in front and to the sides of the audience, some coverage above and only elevated rear coverage. The array is typically utilized for loudspeaker orchestra diffusion via amplitude-panning and, within that, higher-order ambisonic decoding via a 31-channel irregular array portion that resembles a distorted dome. The hall features a very short, subtle reverberation. The performance by Nightports as recorded in August 2022 was used as source for a concert of real-time spatialization in November 2022. The system was harnessed for a hybrid approach to spatialization involving an 'electroacoustic coupling' of the existing hall acoustic and a rendered simulation of the Minster's acoustic, akin to the 'active acoustic' method [12]. This was realized with amplitude-panning (as per the implementation in Hull Minster) in combination with real-time convolution of the SRIRs, upmixed to 3rd-order using the high angular resolution planewave expansion (HARPEX) method [13] for the reverberation layer which was decoded via the All-Round Ambisonic Decoder (AllRAD) method due to partial loudspeaker-coverage of the sphere [14]. Each SRIR convolution kernel is fed the corresponding loudspeaker signal feed, which is varied through the control of virtual channel amplitudes by the diffusion performer. The layout of the array established in the hall afforded an emulation of the primary array, with the most significant difference represented by the lack of equivalent area to the 'distant throw' portion of the primary array that occupied the chancel to beyond the high altar. As an alternative, the most immediate two pairs of the 'distant throw' were emulated at the far-stage area of the concert hall, with the remaining, more distant pairs instead emulated above the audience, utilizing a ceiling-mounted array. The SRIRs of each loudspeaker taken in Hull Minster were rotated to match the equivalent loudspeaker position in Middleton Hall due to the differences in array layout, which ranged from a 5-10° azimuth alteration, to a +90° elevation change, which was made to selected SRIRs to support the altered array structure. The resulting system afforded control over the direct and reverberant response of each loudspeaker, with the amplitude-panning approach contributing a less sizeable portion of the overall energy, and the loudspeaker sources intended to be more distant in character utilizing the decoded SRIR convolution feed exclusively. Sharing characteristics of other mixed-model loudspeaker arrays, the HEARO system imparts pronounced coloration and offers varying coverage for ambisonic decoding [15]. However, the approach outlined utilized anchored SRIR positions, mitigating for timbral changes that may emerge when sources are perceived to be in-motion. This approach is curious in that it hybridizes both a traditional loudspeaker orchestra acousmonium and an interpretation of Barrett's virtualmonium [11], a loudspeaker orchestra virtualized in ambisonics to produce an 'augmented' auditory reality [16].

C. Headphone-targeted virtualizations

Two iterations of the project have exploited ambisonic virtualization of the primary array for binaural stereo: a fixed-media audio-visual presentation of the work for Freedom Festival 2022 and a live performance for broadcast on BBC Radio 3. Given that the technical and musical nature of the project is enmeshed with Hull Minster and the loudspeaker orchestra, an alternative approach to the spatialization was devised to target headphone listening, whilst attempting to communicate the method, character and nature of the performance experienced in the Minster itself.

1) Fixed-media: The film produced for dissemination as part of Freedom Festival 2022 featured a version of the work realized in 3rd-order ambisonics [17]. A performance by Nightports staged for the filming was recorded and used as the basis of the iteration that had post-recording spatialization applied. To achieve this, a native ambisonic method was designed that afforded a virtual loudspeaker array to be implemented, akin to the virtualmonium, that was a direct emulation of the primary array. The signals that were otherwise routed to physical loudspeakers in other presentational contexts were instead routed to two processing destinations: 1) an array of convolution processors hosting

respective SRIRs to produce a reverberant response, upmixed to 3rd-order; 2) a room encoder that simulated the respective positions of the 'main ring' loudspeakers in the primary array, utilized to emulate a direct response in that portion of the virtual array. These encoded signals were time-aligned before being collected in a binaural decoder. The use of an emulated direct response of the loudspeakers and the emulated reverberant response was deemed creatively useful to be able to produce a response that was more akin to the listening experience of the work in the Minster, than just utilizing the SRIR representation of the 'main ring' alone. The production featured real-time 'performance' of the spatialization by the diffusion performer, using the same performance interfaces, with control data recorded as automation. Utilizing both a modular environment and a Digital Audio Workstation (DAW), this approach produced latency that would be problematic for a live performance.

2) Live performance for radio: A live (abridged and serialized) performance of the work was recorded for broadcast in stereo at the Trades Club in Hebden Bridge, UK, for the 'Northern Drift' program on BBC Radio 3 (recorded in November 2022, broadcast in January 2023). This involved live sources from Nightports and live spatialization by the diffusion performer. Primarily to support a real-time, more responsive approach for the live performance, the SRIRs and room-encoded loudspeaker positions (as previously detailed for the fixed-media presentation) were reduced in density (the 'main ring' was reduced from 8 to 4 loudspeaker positions and the 'diffuse ring' from 6 to 4). This reduction in emulated coverage contributed to a sparser virtual array, but one that suited the context (a non-head-tracked binaural feed) appropriately. It in turn made the channel counts more efficient and afforded a more responsive latency to be achieved, which was pertinent in this context given the live performance enacted by Nightports. Beyond this variation, there were a further two exceptions made in the treatment of arrangement components:

- The 'Drums' component was treated in parallel to the ambisonic encode and decode, being outputted in conventional stereo to maximize the translation of the image and transient profile. It was felt that the role and intended anchored spatialization of the element did not warrant processing through the room-encoded 'main ring' emulation, with a more successful result achieved without. It was convolved with the SRIRs of the two loudspeakers forming the front half of the reduced 'main ring' to impart the acoustic qualities of the Minster;
- The 'Bass & Rumbles' component was controlled only in amplitude at the spatialization stage and was sent to the output without spatial mediation.

The ambisonic signals were decoded to binaural-stereo and time-aligned with the non-ambisonic components. For this approach, the performers monitored via headphones and utilized the same model of performance interfaces as detailed previously, except a dynamic was implemented that afforded the diffusion performer azimuthal rotation of the ambisonic image.

V. Discussion

A. Performance Observations

In performance, there was a dynamic interplay and real-time exploration of several inter-related factors: distance/proximity, diffusion/localization, stasis/movement, clarity/noise, purity/distortion, focus/blur. These factors are the 'glue' between the immediate experience of the real-time spatialization (where sounds are located and how they behave in the acoustic) and the in-the-moment decisions about how to present sounds. In a sense, the real-time nature of the spatialization preserved and prompted an ethos of improvised exploration by Nightports, because the placement of sounds within the space never occurred the same way twice. As part of the Awakening arts festival in March 2023, four consecutive performances were given starting at 6, 7, 8 and 9pm. There was a sense of accumulating willingness for risk across this evening of performances as increased familiarity with the material and the space gave rise to an increased desire to explore how far (quite literally in the space) the performance could be taken, and how much noise the venue could withstand. The use of sends to pedals to distort and glitch sounds further became much more liberal in application and the whole effect was a form of sonic envelopment of and with the performance space. In short, the spatialization became more dynamic as did the degree of intervention and treatment of the source audio. In comparison to this, the performance for BBC Radio 3's 'Northern Drift' program took place in a building that was once a working men's club in Hebden Bridge, UK. This headphone-centric approach was a markedly distinct experience in a way that was unexpected, and which challenged the location-specific purity of the original concept: the headphone version felt sonically 'pure' whereas the acoustics of the in-situ live performance, in comparison, had a quality of 'interference'. Additionally, when the work is taken outside of the Minster itself, the opportunity to manage the direct and reverberant portion of the loudspeaker array responses (in this case by simply balancing the SRIR-convolved and non-convolved signals) was considered creatively essential, if not technically 'pure'. The project has produced caricatures of the space, rather than strict emulations. Each iteration outside of the Minster is accordingly a departure from the source situation, becoming an inflection of the work with qualitative contrasts, but also novel opportunities for spatialization. Given the origin of the project being in and of the building itself, this is a paradoxical effect that challenges the sense of integrity of the concept: this leads to the question of whether inhabiting the specific space being represented or interpreted is particularly important, or if it is instead a blueprint for emulation that can survive, supported by contemporary technological means, the process of being resituated. Then, the project's site-specificity becomes an evolving quality, just understood differently through mediation [5].

The choreography of the spatializations performed for each iteration was broadly similar, in part due to some compositional cues that necessitated certain staging approaches, but also because the virtualized loudspeaker arrays had good semblance to the physical one and the means of control was consistent. Due to a combination of practicalities and available means, the controllable spatial dynamic was primarily laterally planar in nature, but with some angling of loudspeakers and the reverberation propagation in the Minster providing extension into the upper sections of the space. The prominence of the reverberation

meant this was not considered a limitation, and instead gave focus to the spatial orchestration of the multiple arrangement components. The exception to this planar approach this was the layout variation that emerged for the implementation in Middleton Hall (spatialization method B) that provided exploration of height as a dynamic. This served to highlight not only the site- and context-specific aspects of the realizations, but also the portability of the work into different contexts and configurations, made coherent through exploitation of the emulated acoustic properties of the Minster.

Some key affordances emerged in the virtualization via ambisonics, namely through isotropic flexibility which provided the scope to rotate portions of (or the whole) array as part of the spatialization performance. This affordance produced more clearly recognizable movements across the 'main ring' in spatialization method C2, above those audible in C1, without rotational effects. Conversely, although the move into a virtualized and non-navigable perspective (i.e., non-head tracked) engendered a firmer grip upon the presented spatial experience, it also prevented the tendency to interrogate a sonic environment with head movements, useful for localization. This is the case for both the performers and the audience, who were otherwise able to reorient themselves in relation to the space. This is most pertinent (in this discussion) for the former and should not be overlooked as a factor in performance decision-making.

B. Technical Observations & Developments

The resolution of the SRIRs produced for each loudspeaker in the array was limited to 1st-order due to available inventory. Upmixed versions of the SRIRs were produced, but the methods outlined that utilize the SRIRs would also be improved with HOA (Higher Order Ambisonics) microphone capture, especially given the density of loudspeakers that formed the array. Additionally, the spatial impulse response rendering (SIRR) method [18] provides an alternative model for harnessing and improving on the qualities of SRIRs in performance contexts, potentially improving localization and employing convolution exclusively for spatialization, removing the ambisonic decoding layer. It should be noted that this method, if utilized for emulating the loudspeaker array utilized in the project in, for example, the Middleton Hall array as in spatialization method B, will require a considerable number of convolutions (682), but is more viable at the time of writing than previously observed of other convolution-intensive models [11]. For future headphone contexts, the SRIRs or SIRR-processed SRIRs could be decoded/transcoded to emulated binaural room impulse responses (BRIRs) before convolution as a 'virtual ambisonic' approach [19], also potentially harnessing ambisonic interaural level difference optimization (AIO) [20], reducing the number of convolutions drastically and increasing the chances of a more responsive latency being achieved. This would negate any ambisonics-related image transforms from being enacted, but some targeted dynamic movement along an array of BRIRs with differing perspectival qualities could provide some alternative affordances. For most iterations, the nature of the musical materials and performance methods harnessed did mean that the latency was not too obstructive to intentions, but for future variations of musical ideas it may become problematic, should a more responsive system be required. Finally, there is clear scope for head-tracked implementations in viable contexts, and otherwise, user-navigable dissemination methods can be harnessed.

VI. Summary

Although there is scope for refinements and extensions within each iterative version of *Nightports at Hull Minster*, the project highlights the potential that complementary technological approaches to spatialization can provide. Given the initial aim of presenting a performance through an acousmonium in the Minster itself, the emergent avenues of dissemination have compelled the creators to adjust the approaches to spatialized performance in a reactive manner. This situation has raised inquiries about the significance of the acoustic origins of the work, the viability of transferring a live, large-scale, site-specific piece, and how these factors have influenced the execution of the performances.

References

[1] F. Bayle, "Space, and more," *Organised Sound*, vol. 12, no. 3, 2007, doi: 10.1017/S1355771807001872.

[2] National Churches Trust, "Hull Minster," 2023. https://www.nationalchurchestrust.org/church/hull-minster-hull (accessed May 16, 2023).

[3] A. Knight-Hill, "Theatres of sounds: The role of context in the presentation of electroacoustic music," *Scene*, vol. 6, no. 2, pp. 165–175, Dec. 2018, doi: 10.1386/scene_00016_1.

[4] F. Macedo, "Investigating Sound in Space: Five meanings of space in music and sound art," *Organised Sound*, vol. 20, no. 2, pp. 241–248, Aug. 2015, doi: 10.1017/S1355771815000126.

[5] L. Elblaus and G. Eckel, "Acoustic modelling as a strategy for composing site-specific music," in *ACM International Conference Proceeding Series*, 2020. doi: 10.1145/3411109.3411141.

[6] J. Harrison, "Sound, space, sculpture: some thoughts on the 'what', 'how' and 'why' of sound diffusion," *Organised Sound*, vol. 3, no. 2, 1998, doi: 10.1017/s1355771898002040.

[7] S. Wilson and J. Harrison, "Rethinking the BEAST: Recent developments in multichannel composition at Birmingham ElectroAcoustic Sound Theatre," *Organised Sound*, vol. 15, no. 3, 2010, doi: 10.1017/S1355771810000312.

[8] A. Farina, "Advancements in impulse response measurements by sine sweeps," in *Audio Engineering Society - 122nd Audio Engineering Society Convention 2007*, 2007.

[9] L. Battisti, A. Farina, A. Bevilacqua, and L. Tronchin, "Implementation of non-equal partitioned multi-channel convolver," in *Internoise 2022 - 51st International Congress and Exposition on Noise Control Engineering*, 2022. doi: 10.3397/in_2022_0220.

[10] D. Smalley, "Space-form and the acousmatic image," *Organised Sound*, vol. 12, no. 1, pp. 35–58, Apr. 2007, doi: 10.1017/S1355771807001665.

[11] N. Barrett, "A Musical Journey towards Permanent High-Density Loudspeaker Arrays," *Computer Music Journal*, vol. 40, no. 4, 2016, doi: 10.1162/COMJ_a_00381.

[12] W. Woszczyk, "Active acoustics in concert halls - A new approach," *Archives of Acoustics*, vol. 36, no. 2, 2011, doi: 10.2478/v10168-011-0028-6.

[13] S. Berge and N. Barrett, "High Angular Resolution Planewave Expansion," in *Proc. of the Second of International Symposium on Ambisonics and Spherical Acoustics*, 2010.

[14] F. Zotter and M. Frank, "All-Round Ambisonic Panning and Decoding," *Journal of the Audio Engineering Society*, vol. 60, no. 10, pp. 807–820, Nov. 2012.

[15] J. A. Garavaglia, "Spatialisating the same acousmatic composition in different venues featuring high-density loudspeaker arrays," in *Proceedings of the 2019 International Computer Music Conference*, 2019.

[16] J. Blauert and R. Rabenstein, "Providing surround sound with loudspeakers: A synopsis of current methods," *Archives of Acoustics*, vol. 37, no. 1, 2012, doi: 10.2478/v10168-012-0002-y.

[17] Freedom Festival Arts Trust, "Nightports at Hull Minster," Aug. 2022. https://www.freedomfestival.co.uk/what-we-do/freedom-online/night-ports/ (accessed Jun. 14, 2023).

[18] L. McCormack, V. Pulkki, A. Politis, O. Scheuregger, and M. Marschall, “Higher-Order Spatial Impulse Response Rendering: Investigating the Perceived Effects of Spherical Order, Dedicated Diffuse Rendering, and Frequency Resolution,” *Journal of the Audio Engineering Society*, vol. 68, no. 5, pp. 338–354, Jun. 2020, doi: 10.17743/jaes.2020.0026

[19] M. Noisternig, T. Musil, A. Sontacchi, and R. Holdrich, “3D binaural sound reproduction using a virtual ambisonic approach,” in *IEEE International Symposium on Virtual Environments, Human-Computer Interfaces and Measurement Systems, 2003. VECIMS '03. 2003*, IEEE, 2003, pp. 174–178. doi: 10.1109/VECIMS.2003.1227050.

[20] T. McKenzie, D. Murphy, and G. Kearney, “Interaural Level Difference Optimization of Binaural Ambisonic Rendering,” *Applied Sciences*, vol. 9, no. 6, p. 1226, Mar. 2019, doi: 10.3390/app906122