

Deconstructing an Accessible Virtual Reality Musical Environment

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Abstract - This paper presents an Accessible Virtual Reality Musical Environment (AVRME) collaboratively created using an ability-led design approach. Grounded in the creative practice of a musician with cerebral palsy being facilitated in play by the author, acting as researcher, designer, and access music tutor, it offers a design case study and situated experiential account of how ability-led design exposed the affordances and constraints of immersive music technologies in accessible music-making contexts. Through the deconstruction of an AVRME, a set of design goals can be examined, centred on where agency lies and where musical expression can be expanded. These goals are informed by an iterative design history incorporating hand-based interaction and head-oriented selection techniques (HOST), including ray-casting methods, across multiple technological systems. An entangled XR music ecosystem fosters broader discourse on facilitation in a multiplayer XR music ecosystem that supports cross-pollination of methods, ideas, and virtual musical artefacts, presenting an opportunity to expand accessible XR music practice for disabled musicians and accessible music facilitators.

Keywords - accessibility, ability-led, virtual reality musical instruments, VR, XR, co-design, ray casting, disability, facilitation.

I. INTRODUCTION (VR AS AN ADMI)

Musical XR is a well-developed field of audio-centric and multi-sensory research [1], now being examined for its potential as an accessible digital musical instrument (ADMI) for use in inclusive music practice [2], [3]. Immersive technology has been broadly adopted for music-making, prompting this research into its potential as a platform for ADMIs. Inclusive music design on immersive technology must factor in that accessibility tends to be considered only after broader advances in usability and interaction design [4], and, as Kathrin Gerling and Katta Spiel note, virtual reality technology “is a body-centric technology that poses barriers for disabled users,” where minority bodies are routinely considered an afterthought in what is becoming a mainstream activity [5]. This paper builds upon the thesis that immersive technology and its ecosystems of artefacts and toolsets, when sensitively and collaboratively researched and applied, can be utilised as a bedrock for inclusive music research [6].

We can consider the accessible virtual reality musical environment (AVRME) as the ecological context that encompasses the accessibility of a technological system and affords the design of accessible virtual reality musical instruments (AVRMIs), a term used to describe ADMIs built in virtual reality (VR). AVRMI to date have been

created for individual musicians or small ensembles [7], [8], [9] and use design specifications informed by the individual access needs of participating musicians to forge new design paradigms. VR hardware, as an intimate technology designed to be placed on the face and in the hands, contains many disabling attributes that not only displace local sensory information with crafted digital content designed for immersion, but may also exacerbate disability through inaccessible hardware, which constitutes a primary access barrier to entry, while software may be unsuitable for atypical users [10].

An AVRME reflects the ecological perspectives of ADMI accessibility, with its affordances and constraints, enablers and barriers to activities that are external to the individual [11]. Accessible music-making considers independent action within an inherently interdependent process, a shared phenomenon that applies not only to a disabled musician navigating immersive technology positioned as an ADMI, but also to the facilitator, who acts as a mediator between the access needs of a musician and the accessible affordances of a technology. Over the course of eight years, the author and participant musician have negotiated and wrangled diverse, rapidly evolving ecosystems of immersive technologies towards enabling musical play, constrained by costs, resources and time [12] required for thorough explorations of a technology as an accessible music technology, with concerns rooted in any given system’s potential for musical adoption and sustained longevity of use.

II. A BRIEF HISTORY OF VR FACILITATIONS

A. Origins of practice

Our AVRMI designs started in 2018, using the HTC Vive¹ PC VR headset and the programme ‘Exa: The Infinite Instrument’² (Exa) and was performed within an inclusive ensemble employing community music approaches with the author acting as an accessible music tutor [13] and Mary Louise McCord trialling immersive technology for the first time as an assistive music technology. By attaching the hand-held controller to Mary Louise’s hand using a passive, atypical grip, she could action MIDI triggers or ‘musical widgets’ [14] placed around her according to her preference. The design process involved the author observing gesture ranges, then drawing triggers around those gestures, alternating who wore the head-mounted display (HMD) to adjust and add triggers [15]. Iterations were rapidly actioned through co-design, as instruments made within a cohesive software package and created using light are made of a very malleable and manipulatable material. The resulting

¹ <https://www.vive.com/us/support/vive/>

² <https://steamcommunity.com/app/606920>

experimentations performed in an inclusive music ensemble, a performance which effectively established a base-line for applying critical disability studies to musical XR and the start of our immersive music collaborations. Musician feedback of the process and performance was very positive in terms of orchestral inclusion, musical agency and platform potential.

B. Doctoral Research

Further research integrating technology probes and co-design methodologies to inform the prototyping, evaluation, and performance of AVRMI [6] was conducted using the Unity [1] game engine. Musician agency was prioritised through an ability-led approach where prototype AVRMI were introduced and evaluated by two participant groups. A graduated model of knowledge exchange was adopted to support a co-design team new to XR and co-design practices, scaffolding the implementation and signification of affordances through iterative development cycles. Musicians trialled hand recognition [16] and ray-casting methods for selecting virtual objects at a distance originating from the head-mounted display [17] for both musical instrument control and performance. The author has dubbed this method *head orientated selection techniques* (HOST). Musician agency and accessibility were further enhanced through the co-location of virtual musical artefacts on physical surfaces, aiding gesture and fatigue control and additionally providing passive haptics that gave a physical attribute to VR musical widgets. Co-design practices reinforced participant perspectives that this research was intrinsically motivating and rewarding, providing a case study of creative practice with reciprocal benefits within applied, third-wave human-computer interaction research.

C. Current Directions

The issue of longevity in design became pertinent. Musicians found AVRMI difficult to access independently. We considered systems in terms of their potential longevity of adoption; a sustainable approach to technology is desirable for technology adopters [20], [21]. Resource costs inform what technology is considered worth adopting and reflect improvisational research strategies, allowing for the opportunistic integration of emerging technologies. We cannot discard the fact that some musicians require facilitation in their music-making. This approach evolved from earlier gesture-driven models of human-computer musical interactions towards an ecological perspective where accessibility is understood as a situated condition emerging across embodied, technological, performance, and social contexts, and where agency is a continually negotiated variable. Ecological approaches to accessibility prompted research and development focusing on translating hand gestures and ray-casting methods to two networked systems.

The first approach involved using WebXR technology as an XR music interface that adopted low-cost web-browser based resources (Musical1y.net)³.

The second approach, and the focus of this paper, was the adaptation of the immersive music application PatchWorld [2] as a potential AVRME, a software

application positioned as a dedicated XR music laboratory and self-contained digital audio workstation with networked multiplayer access. The advanced PatchWorld socio-technical system offered an opportunity to examine how a networked, entangled ecosystem of people and VRMI artefacts could affect not just the translation of accessible affordances from doctoral research, but also the facilitation process itself, mediated by networked hardware and software infrastructures.

D. Introducing the AVRME to be deconstructed

This iteration of the AVRME was created in Patchworld in June 2026 (*figure 1*). PatchXR are the team behind Patchworld, a multiplayer audiovisual creation platform for XR. PatchWorld is a toolkit that modularises the variables used in programming three-dimensional audio-visual interfaces, establishing it as a platform for XR music research for embodied and spatial learning [22], where multi-user scenarios positively affect social presence and flow [23]. The author migrated to studying accessibility in Patchworld after recognising its advanced ecosystem for building virtual reality musical instruments (VRMI), adopting a socially entangled world-building application alongside other VRMI luthiers (patchers) who use its modular, three-dimensional, visual scripting style, where code is written in scenes by routing data and audio signals between blocks to create ‘devices’. The building-block modular approach to design presents opportunities for diverse customisations and cross-pollination, its active development promising longevity of use, both of which are desired principles for implementing bespoke interfaces [24]. Embedding research onto an existing platform can prevent wasting energy on solutions already established [25].

Deconstruction of musical artefacts within the PatchWorld ecosystem was both a research method and creative act in itself. Deconstructing the AVRME uncovers a history of design choices where musical possibilities emerged from specificities of embodied capacity within shifting, context-determined workshop and performance spaces. Musical interfaces are called devices, a nomenclature suggesting a multimodal application beyond sonification. Devices are made up of blocks, the fundamental visual programming units that represent a specific function, such as visual elements like shapes, logic functions, mathematical functions, connectors for routing signals, motion and physics blocks, and system interfaces such as buttons and sliders. Devices were created by combining tags (signifying spatial relationships), jolts (sending discrete data), and streams (sending continuous data such as audio). The image (*Figure 1*) shows the latest iteration of an accessible interface consisting of multiple devices and blocks, created with Mary Louise, trialled and iterated over time, that considered options for virtual environmental control and musical expression. We can unpack the elements of this image (*Figure 2*) into their component parts and, in doing so, unravel eight years of iterative research and development translated into PatchWorld, a phenomenological approach that starts with analysis of PatchWorld and its practical application within a socially situated collaborative music practice [26].



Figure 1: AVRME prototype (Mills, 2026)

III. FACILITATED HUMAN COMPUTER MUSIC ENTANGLEMENT

A. Methodology

This research adopts a framework integrating a longitudinal, practice-based, participatory co-design study of ability-led design. It is applied research, guided by ethnographic observation, improvisational bricolage, and ecological analysis to investigate accessibility as a situated and negotiated relationship between musician, facilitator, and technological systems. Accessibility is positioned as both a design lens and an evaluative framework, informing the facilitator's multiple roles as researcher, designer, and access music tutor, shaping the development of immersive musical systems that, in turn, support Mary Louise's own music practice as musician, researcher, student, and co-designer. Embodied, embedded, and extended behaviour informed the ergonomic and cognitive parameters of instrument and affordance design. Physical ability was reflected in gesture that guided interface design and iteration. Usability was a core design value; a participant who experiences usable instruments that deliver pleasant musical interactions relatively quickly is more likely to be motivated to continue research and development. Knowledge sharing is an integral part of co-design, characterised as cognition of the music environment and defined in musician agency in play.

The author spent one year learning and playing in PatchWorld, developing a collection of prototype devices and engaging in community activities. Inclusive yet goal-oriented research required a balance between human-computer interaction-led affordance research, useful for prototype device design and control-method design and refinement, and community music methods leading towards the performance of co-designs. This socially situated,

flexible method provided a means of examining both natural and directed behaviour. In this research, the author applied verbal prompts, probes, mapping games, structured and free improvisations, and dialogical knowledge sharing in workshops to collaboratively scaffold play and opportunities for system evaluation.

The co-design team met in the first half of 2026, once a week during academic term time, providing a structure for AVRME evaluation and iteration cycles. Weekly iterations allowed the author to experiment with his own understanding of the PatchWorld system alongside consultations with the wider PatchWorld community. As facilitator and technologist, the author had greater agency in prototyping and system manipulation, while the rapid development ecosystem of music-focused resources allowed for the collation of a digital resource of accessible virtual music possibilities. As an ally to accessibility, the author was prepared to incorporate or discard technological affordances according to participant need and performance contexts. There is asymmetrical yet negotiated agency within the co-design team, where the author has greater technical and prototyping agency, while Mary Louise has agency through trialling, evaluation, personalisation, and determining what should be retained or removed, ranging from discrete device personalisation through to a complete rollback of affordances within the AVRME.

B. Data Collection

Over the course of the eight years of collaboration, as various iterations of the VRMIs and new ideas for instrument interfaces were imagined, realised, trialled, adopted, and performed, the author had to consider how to capture musical interactions and how methods of observing digital interactions developed over time, migrating from the audience perspective of external observation (Exa), through observation via telepresence using a personal computer

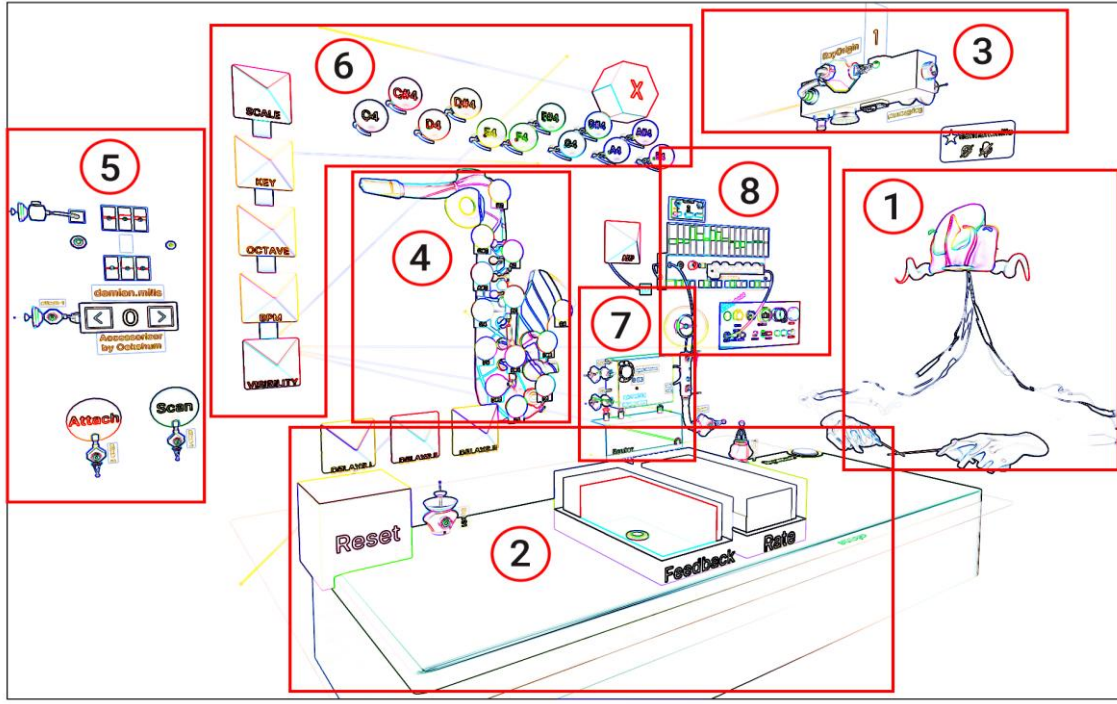


Figure 2: Our AVRME prototype mapped

(Unity), to shared embodiment using two HMDs sharing a multiplayer space (PatchWorld). Our current system uses the Meta Quest⁴ ecosystem. Three Meta accounts were required for shared embodiment capture, one for Mary Louise’s device, one for the author’s device, and one for a PatchWorld desktop using a Laptop PC for audio and video capture, and also used as third party reference from an audience perspective. The author has historically used qualitative data capture methods for data on musician HCI. Video analysis of performers’ avatar interactions were influenced by Laban movement analysis⁵. Audio recordings of structured, semi-structured, and ad-hoc interviews were transcribed and thematically analysed. Questionnaires were designed for screening community musicians, with consideration given to safety, comfort, independence, quality of facilitation, and digital representation, hand tracking, instrument placement, control satisfaction, and participant motivation. Further detail of data collection methods is accessible on the ReShare UK Data Service⁶. These understandings scaffolded facilitator-led dialogical approaches informed by observations and experiences of shared embodiment in PatchWorld’s multiplayer spaces.

C. The Performer

Mary Louise is a multi-disciplinary artist collaborating in dance, music composition, and visual arts. She is an Arts Council of Northern Ireland artist award recipient, awarded to further her music and dance practice, prioritising collaborative practice. Collaboration is central to her artistic practice, as Mary Louise has quadriplegic cerebral palsy. Through her involvement in facilitated music-making programmes within VR and subsequently XR, Mary Louise has emerged as both an advocate and representative for communities engaged with accessibility in immersive

technologies. Her role extends beyond participation, contributing to the articulation of musician-centred design priorities and highlighting the broader socio-technical implications of accessibility within XR-situated musical practice. She enjoys XR music-making because, as she explains: “I find it difficult to use traditional instruments as cerebral palsy affects my hands and arms, I cannot hold a traditional instrument”.

Mary Louise operates from a predominantly static perspective, where locomotion presents a significant accessibility challenge [10]. She sits in a motorised wheelchair at home, with a height-adjustable table positioned in front of her. Her static position determines the dimensions of her accessibility, where interaction in virtual space is often conditioned by physical ability in the real world. She is embedded in both the physical world of her living room and the virtual world, operating simultaneously within physical and virtual environments.

D. AVRME Elements

1. Facilitating musician’s avatar.
2. Hand instrument co-located.
3. Ray-cast device.
4. Saxophone VR ray-cast instrument.
5. *Accessorizer* for attaching ray cast to musician’s head.
6. Scaler interface.
7. Router transmitting data between 3, 4 and 6.
8. Arpeggiator device.

⁴ <https://meta.com>

⁵ <https://labaninternational.org/>

⁶ <https://reshare.ukdataservice.ac.uk/857811>

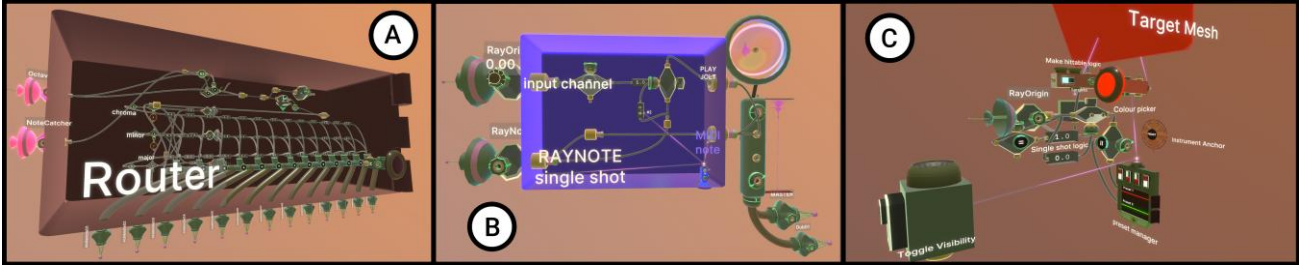


Figure 3: Visual Scripting of (A) Router Device, (B) Single Shot Logic Device, & (C) Visibility Device

E. Musician Workflow

A typical session involved the author visiting Mary Louise at her home. Mary Louise, whose avatar is not present in this scene, needed facilitation in a number of ways that online facilitation could not assist with, namely placing the HMD hardware on her head, navigating the operating system to load PatchWorld, assistance in situating herself at the height-adjustable table, assistance in monitoring comfort levels during play, and, when finished, assistance in taking off the headset.

A typical facilitated immersion consisted of:

- The facilitator starts the scene and co-locates the table in the scene using Mary Louise's headset (element 2).
- The facilitator broadcasts the scene as multiplayer over the PatchWorld servers and sets to 'private'.
- The facilitator joins the scene on headset, and optionally on computer-based client.
- The facilitator positions Mary Louise in front of her physical table and immerses her using HMD
- The facilitator sets Mary Louise's avatar to anchor a pre-set static object to avoid involuntary environment navigation due to clenched hand pose.
- The musician, using HOST, selects Hexagon X (Figure 1, element 6) to toggle visibility of scaler interface.
- The musician using HOST, selects Root Note, Octave or Scale widgets to make relevant control arrays visible.
- The musician using HOST selects desired root note, octave and scale, Saxophone inherits chosen notes, note colours, and transfers root note to arpeggiator.
- The musician can dismiss (make invisible) scaler arrays in part, or in whole as needed.
- The musician using HOST, toggles visibility of hand control elements (element 2). Hand gestures are guided by desk top control sound effectors.
- The musician dialogically directs facilitator, or responds to facilitator prompts for future design iteration improvements or sonification preferences.

Mary Louise often directed design dialogically, with carer assistance. Conversations were often one-sided due to the constraints on speech indicative of someone with cerebral palsy, and required a method of querying designed to elicit evaluations of design efficacy and value. Topics for post-immersion discussion were, by necessity, mostly facilitator-led. Prompts included confirmation of design priorities, confirmation of cognition, queries on placement

and sonification preferences, and ideation for future iterations. Likert scale-like evaluations applied during discussions helped rate experiences, priorities and design proposals. For longer answers as quoted in this paper, pre-prepared questions allowed Mary Louise to programme her text to speech device in order to answer in more detail.

IV. COMPONENTS DECONSTRUCTED

In deconstructing the AVRME in (figure 2) we introduce the function of each element alongside a design history where appropriate.

1. Avatar & Navigation

This is the avatar of the facilitator in PatchWorld within the networked multiplayer space, where musicians can collaborate within the same virtual instance, a format that enables socialising, musical artefact sharing, virtual world building, and ensemble play. The avatar displays the relative head and hand positions of the facilitator. This default avatar mesh takes up little visual space and was considered visually accessible to a static musician, where a larger avatar could obscure visual information.

While the musician occupies a static perspective, the facilitator is mobile and can navigate both physical and virtual spaces. Navigation in PatchWorld is supported by the metaphor of grabbing, pulling, pushing, and rotating the world using a grip gesture. Coincidentally, Mary Louise's hands have a tendency to hand-clench, which can involuntarily action avatar navigation and consequently cause her displacement in relation to virtual artefacts, interrupting any play state. This displacement required external manual resetting through a facilitated button push on the hand-held controller. We trialled turning off virtual movement in PatchWorld. With avatar movement turned off, movement in virtual space is reflected by movement in physical space. The author physically moved around Mary Louise and navigated desks, chairs, and other people, while virtual artefacts were afforded limited virtual real estate; otherwise, as we found, we would need to access the next-door neighbour's house to retrieve virtual artefacts. After community consultations, a software block was introduced as a local anchor to inhibit involuntary avatar movement. This anchor became the centred control point that must first be established, as it dictated the positioning of all other virtual artefacts and afforded accurate referencing of physical artefacts in the play space.

2. Tabletop Co-location & Hand Control

Element 2 is a musical device created primarily for hand interactions, designed for co-located table top interactions.



Figure 4: Mary Louise Operating a Head Mounted Paintbrush

Surface co-location is a control mechanism Mary Louise found useful in early doctoral research. This interface was designed to be positioned according to Mary Louise's own height-adjustable table. The use of hand gestures in both instrument excitation and positional control is a desired option for enactment, even if hand gestures vary in intentionality and accuracy, reflecting both ability and disability. Robust hand recognition requires constant HMD camera contact. Hand recognition is easily disrupted during play when performing a range of musical gestures, and hand spasticity compounds accurate representation. We noticed that Mary Louise's hand shapes rarely matched the hand avatar's displayed poses.

We have historically found that table surfaces guided musical gestures along the X and Y axes, provided support for the musician's armature during play, and that surface friction assisted gesture accuracy [7]. Different hand shapes and poses while performing VRMI negatively affected hand recognition. A tabletop surface can re-enforce camera-to-hand recognition by assisting finger splaying, a technique that the author has observed as a universal gestural prompt for establishing hand recognition. In previous iterations created in the Unity game engine, we used a HOST for ray-cast selection of a "To-Me" command to translate an instrument to the current hand position, a method translated to PatchWorld using the *Accessorizer*. The "To-Me" translation method was found to have variance due to inaccurate camera perceptions of hand position, positioning an interface below or above the table and influencing instrument designs that elongated notes along the Y axis to accommodate inaccurate height placement. This hardware and operating system issue translates to PatchWorld, and, though animation re-enforces interaction feedback, it was substituted by a more flexible method in which widgets align to the tabletop avatar, remain invisible (and non-reactive), and use HOST to make widgets visible (and reactive) instead.

The size of interface elements used for hand manipulation was determined by Mary Louise. Prototype designs started larger and were reduced as we considered gesture ranges, accuracy, and the constrained virtual real estate. Element 2 features a co-located slider designed to reduce spatial interactions to a potential two axes of movement to accommodate neuromuscular gesture impairment. The first movement is along the Z axis, guided

by co-located tabletop resistance; the second is an exit gesture on the Y axis. Improvements to Mary Louise's accuracy and intention when using sliders on co-located surfaces were made possible by an update to PatchWorld in January 2026. A slider block was developed that afforded parameter adjustment without using a pinch motion. A pinch gesture is a useful action where a person's forefinger and thumb can define an intention with a discrete movement, an action that is unlikely to be unintentionally repeated. In creating a slider that was actionable without a pinch gesture, we accommodated Mary Louise's hand movement, but we also inherited a *Midas touch* problem that increased the potential for non-intentional interaction, where a system interprets any movement within the boundaries of a spatially located slider as an active command. We found the slider block can be customised in several ways that facilitate intention in artefact behaviour. A *drag* interaction on a slider ignores hand positions outside of a narrow band of space in proximity to the slider's current state. This discretion of control actioning facilitates some avoidance of the Midas touch effect. This method has been applied in trials of sound-effects control, including delays and reverbs, and in synthesiser sound design.

3. Ray Casting and HOST

Ray-casting is an interaction technique where a laser-like ray extends traditionally from an immersed person's controller or hand. When using ray-casting, "Users with motor impairments might struggle with environments where fine details and exact positioning are crucial" [9]. It was through observing a photograph of Mary Louise painting with a head-mounted paintbrush (Figure 4) that the idea for a head-mounted ray-cast was formed. She adopted the device immediately. Previous iterations of research trials determined that head-oriented selection techniques provided Mary Louise with a good level of accuracy for summoning and dismissing virtual elements [6], due to the relatively steady kinematic chain operated by neck muscles on a steady corpus the same head movements that Mary Louise uses to control her paintbrush become performative gestures for AVRMI instrument excitation and for interface navigation and selection techniques. Ray-casting was not a feature of PatchWorld; however, discourse with the PatchXR team led to a ray cast function being introduced in

January 2026. Modifications for usability were required. The ray cast device continually triggered a target object once per frame with an option for attaching logic for a button press to confirm action, as you would with a hand-held controller. Discrete interactions required additional logic for single-shot sample actioning (*Figure 3, Image B*). Community discourse and contributions led to a single-shot logic gate being implemented. In addition, to enable single-note actioning, each note on the saxophone had code logic attached that registered a ray-cast ‘is being hit’ state that cannot reactivate until an ‘is not being hit’ state has been established.

Ray casting from a static position using head movements transforms three-dimensional space into, in effect, a two-dimensional interaction space, with the ray cast acting as a cursor. In addition, ray-casting methods have to consider Midas-touch-like properties: a ray can action any object in its path. Musical interface design had to accommodate accuracy and intent; widget arrays require enough space between constituent elements to navigate a ray between them, and designs also considered the number of discrete head movements needed to action (or avoid) virtual objects within an array of widgets. This determined the design of *Figure 2, element 6*.

4. The Saxophone VR

The *Saxophone VR* instrument (*Figure 2, Element 4*) was imported from a previous XR inclusive music performance. Mary Louise had used Saxophone VR to play as part of a duet. She used HOST to action the VR Sax, with the spacing and size of note widgets directed by Mary Louise. The Saxophone VR can also be actioned by hand, a useful feature for a digital luthier, where wearing a HOST ray cast can interfere with development. The saxophone’s 3D mesh was imported into the scene via the PatchWorld online portal [1]. Instrument sonification is actioned by ray-castable widgets that inherit MIDI values from the Scaler Interface in the scene (*Figure 2, element 6*) via the data Router (*Figure 2, element 7*) and are sent to a sound player device (*Figure 2, element 8*).

5. Accessorizer

The *Accessorizer* (*Figure 2, element 5*) was created by PatchWorld community participant ‘Oekshum’ and freely shared with the author as a solution to the design requirement of attaching a ray-cast to the forehead of a musician. When activated, the device scans the room, identifies participants, and selected blocks and devices can be snapped to a musician’s avatar, mirroring their movements. Creating devices such as the *Accessorizer* can be a complex task requiring deep knowledge of the building blocks, so cross-pollination within an online community provides opportunities for sharing specialist knowledge with less advanced patchers. Options are provided in this scene for Mary Louise to scan and attach the ray-cast to her head herself, but these have not yet been tested.

6. Scaler

In May 2022, Mary Louise requested agency to choose and select the scale, octave, and root note of a digital musical instrument. The native Scaler feature in PatchWorld was not compatible with HOST ray-casting. In response, the Scaler device was created. Iterations of designs trialled by

Mary Louise found that the options needed to select the root note, scale, and octave of an instrument would require significant virtual real estate; as the number of control options increases, scene complexity increases. Additionally, iterations had to negotiate the “Midas touch” constraint inherent to ray-casting. Densely populated control widgets led to issues such as accidental ray activation, disrupted lines of sight, interference with real-world awareness, and increased cognitive load, all of which detracted from focused interaction. Earlier approaches to managing this included blocking devices to intercept ray-casts and the use of hover-duration selection methods [7]. Previous prototypes that animated interfaces into and out of the user’s motor space reinforced interaction feedback and consequence recognition. We trialled the animation of widgets in and out of control space in PatchWorld, but this proved difficult to implement and iterate, as the positions of movement rails were relative to the world space rather than relative to parent devices. In later designs, animations were replaced by a visibility device (*Figure 3, Image C*) that responded to single ray-cast or hand inputs, controlled the visibility of linked devices and interface elements, signalled state changes through colour variation, and provided a more manageable and scalable solution to scene complexity. Visibility was used to construct contextual menu hierarchies that reflected existing menu hierarchies Mary Louise has used in assistive digital technologies.

Placement of widgets must negotiate spatial constraints with neighbouring widgets and instruments, and be accessible using the least amount of head movement possible. In *Figure 2, Element 6*, a hexagonal icon sets the visibility of device elements positioned below it on the X axis. The hexagon is always visible in the scene; its role is to toggle the visibility of sub-menus on the Y axis. Sub-menus display sound parameter widgets (root note, scale, octave, etc.). In a performance, a movement sequence to action a note change using HOST contains the following movements: head up to action menu visibility, head down to exit the widget, head left to action a sub-menu, head right to exit the widget, head up to select a sound attribute, and head down towards the musical instrument. The menu elements are programmed to toggle colour when active (red meaning active, yellow or green meaning clear to play). Menu items appear on the Y axis; sub-menus appear on the X axis.

7. Router

The router (*figure 2, element 7*) contains a networking module for integrating HOST with the Scaler array. It contains workarounds for PatchWorld’s default *Scaler* device (which does not as yet accept ray-casting), and contains the logic blocks (*figure 3, image A*) for affording ray cast control of octave, root note and scale attributes of Element 6.

8. Arpeggiator

The Arpeggiator (*Figure 2, Element 8*) is a device created by Patchworld community contributor ‘Actiondyne’ that contains methods of controlling an arpeggiator function popular in ADMIs, where infrequent interactions by a musician can produce complex musical output. When purchased using ‘Vibes’, the in-application currency, interfaces can be deconstructed and re-imagined.

This device was edited to integrate hand control and a ray cast toggle to turn it on and off.

V. REFLECTIONS

When we adopt a platform for accessible music development, we adopt a new ecosystem of potentials and constraints.

1. *Evaluating this Iteration*

This environment deconstructed was created to afford Mary Louise control of multiple interfaces within one scene. While useful in an academic paper for discussing a range of accessible affordances translated within PatchWorld, the collective placement of these elements within the scene has been found to be difficult for Mary Louise to manage. Yet a complex environment is a personal design and performance goal. When asked by the PatchXR team, “If you could imagine your ideal future creative setup with no technical limitations, what would it look like?” she responded: “Inclusive design to me would mean I could completely independently choose, play, compose, and save music in the VR”.

During doctoral research, each component of our AVRME was built in response to an interaction need, given time to understand, and the signifiers of each affordance collaboratively negotiated. Independently, over the course of our time designing and playing in PatchWorld, Mary Louise has trialled and evaluated each component as an effective control or performance device. She has requested and used the Scaler device to choose her root notes, octaves, and scales; played the XR Saxophone live with HOST; toggled the arpeggiator on and off and affected it with the Saxophone device; and changed the sonification of the arpeggiator using delay effects placed with table surface co-location. In combination, this environment becomes a collective artefact that needs to be learned. PatchWorld is a rapid prototyping environment; many changes to the environment can be made from week to week, and each device or block whose spatial position is re-mapped presents a signifier or affordance to be re-learned. Navigating complexity requires a form of virtual housekeeping, for example, remembering to close a device before opening another one that will spawn in the same location, the one location that may be ergonomically suitable. Our method of toggling device visibility addressed the Midas touch problem of a crowded virtual real estate, but instead a cognition-of-current-state-of-play problem was introduced, where the play state of multiple devices, some of them not currently visible, had to be remembered.

Shared embodiment became an important part of Mary Louise’s musical agency, where if cognition of the digital fails, the human can be called to intervene. As Mary Louise stated, “I should always have control of my choices. Whether it is by the VR or by directing Damian”.

2. *Development First, Music Later*

It is to Mary Louise’s credit that the act of deconstructing PatchWorld for accessibility has been a process that has often demanded perseverance and attention in examining control methods rather than the actual goal of music performance. Working within a novel, visually engaging, shared musical environment mitigates the trial-

and-error process somewhat, with Mary Louise excited to be at the vanguard of representation of a community of interest. She stated: “I play the instruments on VR using the eye gaze technology. I also have the option of using my hands but sometimes they would not behave. I can see the real world while I am in VR. I love the options and freedom the VR allows me to experience any instrument I want. It gives me opportunities I otherwise would not have.”

Sessions always started with trialling iterations of the AVRME, focusing initially on cognition and control, followed by musicality through improvisation and exploration, often with additional musical accompaniment as the facilitator summons additional devices and joins in the music-making. Finally, a wish list of improvements, expansions, contractions, or dismissals of AVRMEs, informing future iterations, is created. As Mary Louise said, “I don’t have any frustrations at present because I am still in explorative mode and I like to give Damian a to do list to work on after each session.”

Agency is thus collaboratively imagined, directed, and earned. It is to be noted that, even after eight years of collaborative design and developing understandings of Mary Louise’s virtual reality embodiment, the author still makes mistakes in prototype design. A facilitator acts as an ally (a numeronym denoting an accessibility ally), a role that requires humility and patience, acquiring knowledge that informs prototypes of devices, or combinations of devices, that may subsequently be abandoned. Adopting PatchWorld brought a great leap forward in design potential, with more artefacts available with less onboarding time and more control options. Whereas in doctoral research many negotiations in design waited upon the upskilling of the author to implement affordances, the reverse can be stated when working in PatchWorld: the burden of learning combinations of actions was transferred to Mary Louise. This process itself needed deconstructing. Dialogical planning and strategising around design themes contributed to scaffolded learning; however, when device introduction was prolific, potentially useful affordances and interfaces became discarded due to cognitive overload.

This experience demonstrated that complexity must be negotiated differently between the relaxed design space of exploration and the more constrained requirements of public performance. Many of the affordances embedded in the iteration examined in this paper will therefore be hidden or deactivated for public performance. When music performance does occur, we have found that a simply designed system specific to the needs of a particular performance worked best. An example would be in choosing a predetermined choice of scales for a particular performance and making invisible the rest. A similar process was used in the performance Zoom Time Over and Out⁷ where redundant options for operating instrument positioning were removed from a performance scene in favour of devices pre-set on scene launch.

Complexity in design can be constrained in PatchWorld through the use of the *pre-set block*, where values can be saved and combined to display a range of desirable states for included devices within an AVRME. Presets are negotiated *a priori* and constrain musical choices to predetermined sound and effect parameters. The next

⁷ <https://zoomtime.net/>

iterations will concentrate on how and when presets are visually presented, including the incorporation of colour and shape into asset. To date, we have used structured improvisations in our performances, conducted by the author using physical gestures and verbal prompts. AVRMEs can also be designed to reflect conductor gestures and prompts. The next step is to collaboratively constrain choice to a meaningful, usable, adaptive, and expressive range of sonification in performances.

3. *Embedded Facilitations*

We have found that a co-located, multiplayer XR approach involving shared virtual embodiment between musicians provided a more rapid workflow than in previous systems. Sharing virtual spaces during facilitation supports immediate feedback, collaborative exploration, and faster, more accurate iterative refinement. This affords system cognition and enables rapid, immediate adjustment without the more time-consuming build and deploy cycles, supporting responsive, in-situ prototyping. We become more aware of musician body postures, states of comfort and fatigue, physical gestures where system hand recognition is not robust, and disparities between physical and virtual embodiments. Shared embodied interactions accelerate mutual understanding of performance possibilities and interface design, enabling rapid iterative cycles in which interaction is directly observable and informs design decisions in real time. Co-design in a three-dimensional visual coding environment is more intuitive than previously experienced with Exa and Unity, and more engaging for Mary Louise, who can perceive a visualised signal flow as extant within PatchWorld.

VR and XR are excellent mediums for sharing perspectives of each other. Multiplayer representation of position and action is an actively developing technology. In XR, we can see the gap between the embodied musician and the discrepancies in avatar dependencies and co-location, some resulting from the inherent network latencies and audio synchronisation within PatchWorld, and other discrepancies due to local camera hand recognition. XR design balances local-area camera projection against an infinite space of virtual musical widgets. A musician negotiates both in directing designs. Without an external camera feed, VR offers less visual clutter. A neutral background constrains attention for both musicians, assists in identifying the orientation and position of HOST ray casting, and provides a neutral background for deconstructing virtual music artefacts.

4. *An Ecosystem of Human Entanglements*

The co-design team's adoption of PatchWorld as an accessible ecosystem involved developing an understanding of the nuanced complexities of instrument design that emerge through sustained practice. Extending accessibility research into a social space has seen a leap in perceptions of possible musical interactions. Community members invested in the production of VRMIs contribute to the number of potential devices that influence or can be deconstructed for accessibility. These understandings are further extended through engagement with a broader community of practice that sees accessibility as a collective interest, an ecosystem further augmented by social media engagement through the official Discord and YouTube channels. The shared XR music space has opened up perceptions of disability and access needs in XR to a wider

audience of XR luthiers. PatchWorld's modular building-block approach means that quite often there are multiple solutions to design problems. Multiple networked actors bring diverse approaches and understandings of how to implement solutions to specific design problems. Community members have offered musical artefacts freely or for in-game currency, which has provided a wide range of interfaces. Devices were systematically disassembled to identify their core interactive components, which were then reconfigured or even simply re-oriented to become usable for hand-based, surface co-located, and HOST-directed interaction methods.

Networked communities support access music tutors by providing a resource of pre-made digital artefacts that may seed further peer-led, ability-led explorations. This evolving ecology extends the reach of AVRMEs towards supporting diverse ways of conducting remote and distributed modes of engagement for a broader community of musicians. Concurrently, declining barriers to entry, driven by lower system costs and increased cross-platform accessibility of digital content previously constrained within siloed ecosystems and environments, indicate a near-future expansion in access to XR music practices.

Entanglement informs instrument designs. As development continues, and XR luthiers continue to share perspectives and methods, the tools themselves will evolve. It is likely that the ray-cast feature will iterate, changing the logic systems to include single-shot mechanism options, as used in this paper. The interfaces and instruments built here reflect the methods required to adapt PatchWorld to our access needs, established in previous research and translated across immersive music ecosystems. As the tools become more accessible, the role of the facilitator itself becomes more accessible, widening ecological access and broader adoption. Accessibility within entangled facilitated music relationships requires ability-led design to orientate towards the facilitator also, where the establishment of pre-prepared accessible building blocks, devices, and scenes promotes a plug-and-play approach that may potentially broaden the adoption of XR in music facilitation.

VI. CONCLUSIONS

The AVRME design deconstructed here is situated in the current ecology of music development within the music metaverse, where disparate communities of music makers work with tools that offer tremendous potential in virtual spaces, while the providers of those tools operate with tight constraints on their own developmental potential. Our approach of ability-led design, participatory co-design, and practice-based inquiry worked towards the thesis that VRMIs can further inform processes of research adapted to assistive technology. Even with a cohort of one, sustained ability-led design has forged novel instrument performance paradigms, demonstrating how the specific access needs of one musician can generate design knowledge with relevance beyond the individual. The resulting interfaces and control mechanisms provide examples of how bespoke accessibility requirements can contribute to the development of musical tools and methods of interaction that may be adopted by others. We made use of the tools we had access to, adapting them through sustained practice with Mary Louise. Hand interactions are prized for their unique gestural contributions to expressive performance, while HOST brings a more accurate approach to environmental and

musical instrument control. The range of accessible interfacing that Mary Louise has adopted foreground the agency inherent in instrument design and sonification processes even if some unintentional gestures generated a more relaxed correspondence between intended musical outcome and realised sound. Disability, therefore, is considered integral to the musical act and is performed through it, contributing to a unique dimension of a musician's expressive identity and the music produced. Mary Louise's embodied knowledge shaped development and application. These approaches are of interest to XR luthiers beyond accessibility goals. Combined with other musical artefacts, these resources may enable someone, at some time, to make what was once an inaccessible music space perhaps a little more accommodating.

The relationship between facilitator, disabled musician and technology is an inherent aspect of this research, the capabilities of actors determined by the changing iterations of the PatchWorld ecosystem, yet we are not passive consumers but active progenitors of possibility. To their credit, the PatchXR team are actively pursuing collaboration and knowledge of how diversity can be accommodated in PatchWorld. Understanding Mary Louise's perspective offering an opportunity for ability-led designs to influence the coding and mechanics behind the ray-casting and hand gesture blocks in turn making future facilitations simpler to implement for diverse community participants. Making ray-casting a more integrated and therefore ecologically accessible device will in turn present an inquisitive community with tools for forging unique XR instruments and interfaces. Integrating QR code or image recognition may assist in facilitating collocation of virtual and physical objects. This research echoes a core tenet of inclusive design, that the highly specific access requirement of one person can become a source of general interaction innovation.

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