Department of Electrical, Computer, and Software Engineering

Part IV Research Project

Final Research Report

Project Number: 62

Exploring Embodiment in Immersive XR

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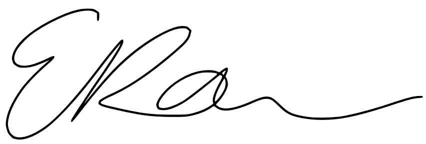
Declaration of Originality

This report is my own unaided work and was not copied from nor written in collaboration with any other person.



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Abstract

Virtual reality (VR) is a rapidly evolving technology that in 2021 is more widespread and accessible than ever. VR headsets are owned by an increasingly wide variety of people, not just gamers and tech enthusiasts. There exist many applications for extended reality (XR) technology and the arts, offering new digital mediums for art generation, education and consumption. Explorations into VR and dance are limited, as the field is fairly new, so there exist many potential design opportunities in the space. This project begins to explore this vast design space, investigating which types of VR experiences and virtual feedback are compelling in the context of dance, and rethinking effective movement feedback. Through qualitative data collected through workshops and discussions, several VR environments were developed in Unity using a Neuron motion capture system. These environments respond in different ways to the dancer's motion, utilising particle systems, audio, colour, and scale to convey movement qualities. These prototype environments show promise as generative tools for dancers, promoting creativity, spontaneity, and exploration of movement in embodied dance practises.

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1. Introduction

In 2021, extended reality (XR) technologies are more accessible than ever. Virtual reality (VR) headsets are becoming more common and affordable year by year, and are falling into the hands of not just gaming and technology enthusiasts, but artists, students, and everyday people. Advancements in XR technology have allowed for original and novel applications across many disciplines including the arts. However, the field of VR as a technology for dance is relatively new, so many potential design opportunities exist. There are some inherent challenges with integrating dance and VR as the feeling of embodiment during dance is so closely tied with the physical, often unencumbered, human body. Still, VR technology could offer a variety of generative, choreographic, collaborative, and educational applications for dancers and audiences.

1.1 Project Background

Dancing in/with the Digital is a research project led by Dr Rebecca Weber, a lecturer in dance studies at the University of Auckland. The project aims to understand the impact of XR spaces on choreographic creative practises. Project partners include people across the Design, Auckland Bioengineering Institute (ABI), and Computer Science departments at the university. In 2021, two software engineering undergraduates (myself and my research partner) were brought onto the project to support software development.

1.2 Related Work

1.2.1 Embodiment in VR

Embodied cognition theory suggests that human cognition is shaped by the ongoing interaction between our bodies and the environment [1]. This framework allows us to understand how XR can be used to affect our embodied cognitive experience by providing novel sensory input not present in typical body-environment interactions.

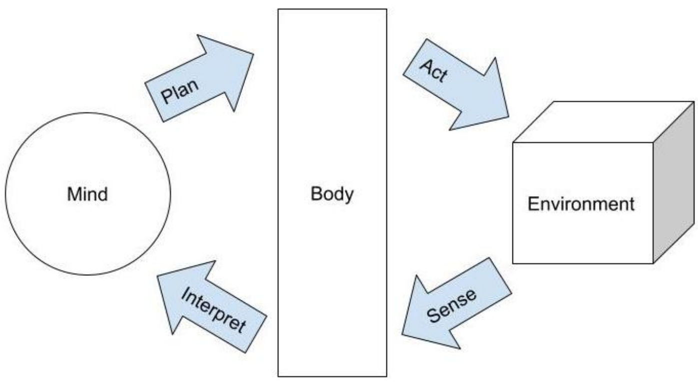


Fig 1: Diagram of mind-body-environment feedback loop

For example, for sighted people, there is an expectation that a movement of the body is reflected in our field of view. Much of VR embodiment research focuses on using avatars (virtual bodies) to mimic real bodies. The accuracy of the simulated body affects the plausibility of the virtual environment, as shown in [2]. The closer to reality, the more believable the scene; realistic lighting can enhance immersion as participants can see the effect that movement has on the environment (i.e. casting a dynamic shadow).

While mirroring real experiences can support embodiment, VR can be used to intercept and alter the mapping between action and environmental changes artificially as demonstrated in [3]. By mapping a participant's physical right hand to their virtual left hand, researchers altered how subjects felt towards their handedness. VR can also be used to add new elements to the mind-body mapping between real and virtual. As shown in [4], participants can feel agency over a virtual tail controlled by their hip movements. These studies demonstrate the power of VR to create links between the body and sensory input that do not exist in reality, and so can have significant effects on cognition and embodiment.

1.2.1 Feedback as a Generative Force for Dance

Embodied cognition theory tells us that to create a feeling of embodiment in XR, action in the physical world should have an effect in the digital (feedback). Dance is a discipline focused on the movement of the body, and there are many ways VR could provide feedback. VR controllers, headsets, and motion capture suits generate a stream of spatial coordinates that can be used to dynamically render a virtual environment.

As a natural consequence of translating an art form that from an audience perspective is reliant on viewing the human figure, much of the research into dance and VR is also focussed on avatars. Chan et al [6] show that VR avatars can be effective dance teaching tools, allowing students to pause, replay, and study the 3D movement of a teacher who appears as an avatar. There are opportunities in dance and VR to situate the dancer in contexts that would otherwise be impossible, e.g. having two people to overlap in digital space. Choreomorphy [7] shows that through changing characteristics such as blockiness or gender identifiers, dancers would alter their movement to reflect the modified avatar; “The different avatars created for the dance practitioners a creative, immersive experience which stimulated their movement improvisation”.

There have been some projects that use XR to map dancers’ movement onto novel sensory feedback without relying on avatars. Tsampounaris et. al [5] explore the use of particle and trail emitters in VR to create visualisations of movements over time. Bisig [8] uses a neural network to generate a figure that responds to a dancer's movements using motion capturing technology, for example by altering movements or generating extra limb extensions. Bisig notes that this approach “abstains from mimicking a human body and movement in favour of using more abstract systems”. In doing so, they create a relationship between the physical body and virtual object, without mimicry of the body. This feedback affected movement generation: “Because they all perceived the system as a response to them, they all played a game with it, responding to it, exploring all the possible responses to the different qualities they embodied, and even trying sometimes to find its limits”. Ackerly [9] showed that aural feedback can be an effective generative tool. Over time, participants could “tell through the sound how long they had been in stillness or in a repetitive cycle”, and this feedback prompted them to make “compositional choices to maintain, evolve, or dissolve an idea”. Similarly to [3], dancers can become accustomed to the relationship between movement and novel sensory feedback.

1.2.3 XR in Existing Dance Performances

There is unexplored potential for integrating the audience into an XR experience, an example given [10] is a hypothetical performance where the audience navigates a virtual space from the perspective of fireflies, illuminating performers. Whist [11] also blurs the line between audience and performer by placing audiences in the centre of an interactive story. In Farewell to Dawn [12] motion capture suits are used to project a live dance performance onto a virtual stage. Performers use augmented reality glasses (AR) to see what their avatars would see in the VR space, simultaneously occupying both the physical studio where the performance is taking place, but also the digital space where it is being watched. Farewell to Dawn also uses VR to create visual effects that would be impossible in reality, such as accelerating the passage of time.

Golz and Shaw [13] show how inexpensive techniques can enhance performances by using an augmented video stream viewed through an iPad camera. The audience is aware of both the unaltered dancer in front of them, and the parallel reality shown on the screen, where that dancer may change scale, teleport, or be affected by any number of virtual effects.

These performances show that XR technology can be used to enhance a choreographed performance from the audience's perspective, but do not address the influence of these spaces on dancers and their generative practises. While these environments/stages may be enhanced, they do not utilise feedback based on movement qualities, instead, the virtual environment is a separated backdrop.

1.3 Research Intent

This preliminary research shows that XR technology can be used to alter and enhance the experience of a dancer and affect their generative practises. It also shows the power that VR can have in mapping motion to novel visual environments, and how this feedback loop can enhance the sense of embodiment. The research intent of the project is to explore which aspects of VR feedback are meaningful for an embodied dance experience, as well as design opportunities within the space.

2. Methods

2.1 Research Approaches

We adopted an action research methodology [14] for the project where qualitative data was iteratively gathered, analysed, and used to inform the next data collection session. In action research, the steps of planning, action and results-analysis are repeated iteratively [15] to inform evolving theories and designs, and it is often used when studying social sciences. We took a research through design approach (RtD) [16] to the development of software prototypes, the subjective experiences and feelings of both workshop participants and the project team provided ongoing design feedback. This qualitative data collection approach was well suited to the subjective nature of dance and the open-ended research intent and allowed the team to use intuition around the design space to pursue directions we found compelling.

2.2 Technology Stack

Virtual reality scenes were developed using the Steam VR package in the Unity game engine. Prototypes were tested and developed using an HTC Vive headset. Axis Neuron was used to stream data from a Perception Neuron Pro motion capture system into Unity.

2.3 Division of Workload

Both Hazel and I worked closely together on many aspects of the project, such as creating workshop reports. Hazel is responsible for research into the VR sound system as well as the development of the particle scene and its control system. I developed the other scenes; colour changing scene, scale changing scene, terrain scene, ambient sound scene and trigger sound scene (including recording sound). Due to the Covid-19 lockdown, only one member was able to keep the VR equipment, so Hazel is also responsible for recording and editing videos that demonstrate the prototype scenes in VR.

2.4 Consultation

In late May the team consulted over Zoom with Lucie Sykes, a PhD candidate whose research [17] explores how dance embodiment can be empowered through digital environments. Her work around trace making and artifacts aligned closely with findings from our first workshop, further discussed in section 3.1.

2.5 Workshops

Through a series of workshops, participants were exposed to a range of extended reality experiences. Insights gained from one workshop inform the structure of and design prototypes presented in the next. Discussions and note-taking were conducted both during and after the workshop activity. Observations and qualitative results from each workshop were summarised in reports and kept alongside images and recordings.

2.5.1 Workshop 1 (March):

Setup: Workshop one probed existing VR technologies to explore which aspects of VR showed potential when viewed through the lens of a dancer/choreographer/audience member. The technologies investigated were Beat Saber (Demo), Google Tiltbrush, 360 video and OhShape. Google Tiltbrush was chosen as it is an open-ended creative tool, and we hypothesised that trails created through movement could be compelling in a dance context. Beat Saber and OhShape were chosen as they require the player to be highly aware of the virtual environment relative to the position of their body. Finally, 360 live video is a technology being developed by a project partner from ABI which could provide novel visual perspectives. Participants were a mixture of dance undergraduates, postgraduates, and engineering undergraduates.

Event Structure: Participants rotated between stations facilitated by the project team who encouraged ongoing conversation and took notes on the discussion. After trying the various stations, the group reconvened for a somatic awareness exercise led by Dr Weber. Participants were then tasked with generating a short (one minute) performance incorporating a technology of their choice. Finally, the group reconvened for an open discussion about the workshop.

2.5.2 Workshop 2 (May)

Setup: The workshop was held in a lab in the Auckland Bioengineering Institute (ABI) building. Participants were a mixture of dance undergraduates and postgraduates. Participants used a VR headset to view the 360 video feed from cameras mounted in the centre of the ceiling. A modded multiplayer version of Google

Tiltbrush created by a project partner from the ABI was used to explore creative potential when multiple artists occupy the same digital space.

Event Structure: Participants took turns wearing the VR headset to see the 360 video feed, giving a novel 3rd person perspective of their bodies. Other dancers were asked to enter/leave the space. After exploring the view, the headset user was prompted to choreograph another dancer using the VR perspective. Two participants then tried a modded multiplayer version of Google Tiltbrush where they could see each other's drawings.

2.5.3 Workshop 3 (June)

Setup: The workshop was an extension of workshop two (2.5.2) used to further explore emerging ideas around the importance of perspective and was held in the same lab in the ABI building. Participants used the same 360 video feed set up as described in workshop two.

Event Structure: As in workshop two, participants took turns wearing the VR headset to navigate with the 360 camera view, and other dancers would enter/leave the space. Physical contact between dancers was investigated as a technique for grounding the perspective. Participants were then asked to try to choreograph other dancers using the VR view.

2.5.4 Workshop 4 (July)

Setup: The workshop was held in a lab in the ABI building. Participants were a mixture of dance undergraduates and postgraduates. Due to Covid-19 lockdowns, this was the last workshop held in a physical space. The workshop demonstrated 360 3D point cloud software developed by a project partner from ABI. Live footage of the room captured by cameras and depth sensors mounted in the centre of the ceiling was converted into a three-dimensional virtual environment that can be navigated using a VR headset. Three prototype scenes developed in Unity by Hazel and myself were also demonstrated:

The interest in 3rd person perspectives shown by 360 video experiments as well as interest in the effects of movement over time shown by Tiltbrush experiments lead to the development of a prototype particle scene. Particle emitters are attached to the joints of a skeleton rig viewed in third person in VR. The rate of particle emission has a linear relationship to velocity, such that fast movements are emphasised and the body mostly disappears when stationary. For more about this scene, please refer to the report written by my project partner, Hazel Williams [18].

To escape the focus on avatars we wanted to investigate types of VR feedback that were not literally representative of the body, so developed two prototype scenes exploring colour and scale as potential types of feedback. The scale changing scene linked the velocity of joints linearly to the height of objects in a VR landscape. Similarly, the colour changing scene linked velocity to the colour of static, floating spheres.

Event Structure: First, participants tried the 360 point cloud software to explore how this affected navigation and perception of others in the space. Then, participants rotated through the three prototype scenes and were encouraged to give feedback. These scenes would evolve into the final prototype scenes discussed in section 3.2. Finally, a short motion capture recording was taken of a dancer to be used as replayable footage in the development of final prototypes.

Fig 2 (left): Short performance in workshop one   *Fig 3 (right): Exploring touch in workshop two*

2.5 Final Workshop/Feedback Session (October)

The 5th and final workshop, held in October over zoom, was used to showcase and gather feedback on final versions of design prototypes developed over the year. Participants included dancers who had previously participated in workshops, as well as dance researchers and computer science faculty. The group was shown a video of each prototype, alongside footage of the dancer used to generate the scene. The particle scene was demonstrated with three different settings: low gravity/long decay, high gravity/short decay, and a scene that demonstrated the control panel to move between settings. Participants were asked to give feedback through an anonymous Google survey after each scene, before opening up to a group discussion. The chance to give anonymous feedback first was important to ensure that respondents' genuine first impressions were captured. Finally, participants responded to several questions in the Google survey ranging from concrete to hypothetical. These responses were collated in a workshop report, and the Zoom discussion was recorded.

3. Results

3.1 Workshop Findings

3.1.1 Limitations of Avatars

The first workshop probed existing VR technologies to explore which aspects of these were compelling in the context of dance. It was quickly made apparent through OhShape that users whose stature did not match the avatar's struggled to play the game successfully. The incongruence between the height of one's limbs in reality and the game made it difficult to position the virtual body. As discussed in section 1.2, most research into embodiment in VR focuses on realistic avatars. However, this experience demonstrated the fragility of systems that use avatars when users of different body types aren't considered. This experience also promoted some negative self-judgement as users became highly aware of their body shape, which could be avoided in software with more abstract feedback.

3.1.2 Generative Potential and Tracemaking

Participants experimenting with Google Tiltbrush had strong reactions to how the space evolved over time as they filled it with drawings; one participant felt compelled to fill in any empty spaces. This shows that by keeping a record of movement over time, dancers can feel compelled to cover new ground. This extra temporal dimension afforded by VR technology has the potential to alter how dancers understand the space they're in. In traditional performances, the history of movement in space is not easily perceived by the audience or performer. However, props such as ribbons or flowing costumes can serve as short traces of movement through space and time. These props emphasise the path of the current movement but do not capture relationships between present and past. Furthermore, trace making can be used to generate an artifact that is left behind after the conclusion of a performance; a static representation of a dynamic piece of art that may capture more dimensions of the performance than a photograph, for instance. Choreographers using trace making software might compose a performance to generate a particular artifact, such as an image produced by dancer's movements in Tiltbrush. This artifact generation process is something considered in the research of project consultant Lucie Sykes [19] where the path traced by a performers hand is captured and 3D printed to create a sculpture. This sculpture represents the “process of ‘immersion’ and embodiment through a solid form, and echoing the moving memories of the ‘live’ moving body in the space”. This aspect of XR technology is clearly compelling in the context of dance and warrants further exploration.

Both groups composing a short performance in workshop one chose Google Tiltbrush but used the technology in very different ways. The first group situated a non-dancer with a headset in Tiltbrush who created a drawing in VR. A dancer then followed the movement of the drawer, translating motion into a dance performance while holding a piece of fabric that moved to mimic the virtual trail. The second group used Tiltbrush in a way closer to a choreographic tool. The dancer created a virtual landscape with words and images. These acted as prompts or a score for the dancer during the performance. This showed that a technology can be used generatively in both an exploratory way and a more methodical choreographic way. It also highlighted the importance of distinguishing between the perspectives of dancers, choreographers and audience members, as each can view software differently. This observation informed the structure of workshop two wherein dancers were asked to use the 360 video software in both an exploratory and choreographic way.

Participants in workshop four responded positively to the three prototype scenes, with each scene promoting different types of movement. When using the particle scene, participants experimented with contrasting complete stillness with large, fast movement, creating a visual effect wherein a human figure would emerge suddenly from empty space. There were many requests to experiment with simulation variables such as the lifetime of the particles, or the strength of simulated gravity. Changing these variables can lead to drastically different appearances, and participants were eager to tweak them.

In the colour and scale changing prototypes, participants created large movements to see reactions from the environment. Participants expressed a desire to move through and further explore the landscapes. The different types of movement generated by the three prototype scenes showed that different types of VR feedback could be compelling in different ways.

3.1.3 Grounding and Orientation

One participant noted that sound was important to ground him in reality when using Tiltbrush; inhibiting a fully immersive experience as he felt a sense of simultaneously occupying two worlds. Rather than an annoyance, this sensation enhanced his confidence and supported orientation when using the software. Participants also commented on how the stationary traces left behind in Tiltbrush were important in orienting them in an otherwise uniform void-like landscape, giving them a sense of where they'd been.

3.1.4 Disorientation and Challenging Perspectives

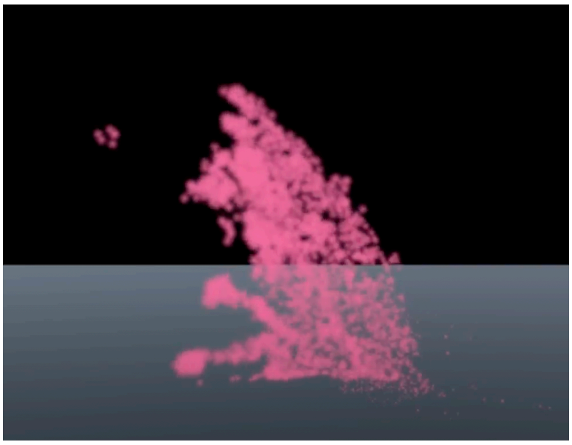
Experiences with the 360 video setup in workshops two and three seemed to be discordant with sensations of embodiment. Participants noted that their movement became informed by the 3rd person "God's eye" view streamed from the camera in the ceiling rather than their own spatial awareness. Participants noted that it was easier to navigate the room with their eyes shut than to use the headset video feed. This lead to a sense of detachment between body and mind; without any prompting, participants began to refer to the image of themselves in the video feed as their "avatar". One participant described the experience as "untraining the trust of self". Misalignment between reality and the headset led to further disorientation. Interestingly, rather than finding the strange perspective offputting, dancers found that the difficult nature of the headset perspective was a compelling challenge; when the misalignment was explained as a mistake, participants insisted that they preferred it. By being placed in a very alien situation, dancers described the feeling of heightened awareness of connections between body and mind as they had to work much harder to navigate physical space. This forced a level of introspection and showed that while some aspects of XR may not be conducive to embodied sensations, they can pose interesting challenges that promote different ways of thinking about movement. For many dancers, unexpected results can serve as creative catalysts.

3.2 Final Scenes

This section will outline the five scenes that were developed and presented in the final October workshop, presenting a variety of feedback types as an exploration into the design space. In these scenes the live or recorded motion of a dancer is streamed to Unity, controlling an invisible, virtual skeleton rig, which has velocity/acceleration trackers at each joint. Information from these trackers is used to control the virtual environment. Some effects are tied to one joint only, e.g. a sound plays when a foot undergoes rapid deceleration to emphasise footsteps. Other effects may be tied to average values across multiple joints, e.g. terrain grows according to the average height of every joint in the rig.

3.2.1 Particle scene

This scene extended the particle prototype scene demonstrated in workshop four (section 2.5.4). A control station was added (fig. 5) which could be used in VR to tweak various variables affecting particle emission, such as lifetime and gravity. This control system was added to investigate how dancers/choreographers may use a scene when they have finer controls of its behaviour and appearance, as well as for convenience by removing the need to restart the program to make changes. This scene was developed by my project partner Hazel Williams, so please refer to their report for more detail.



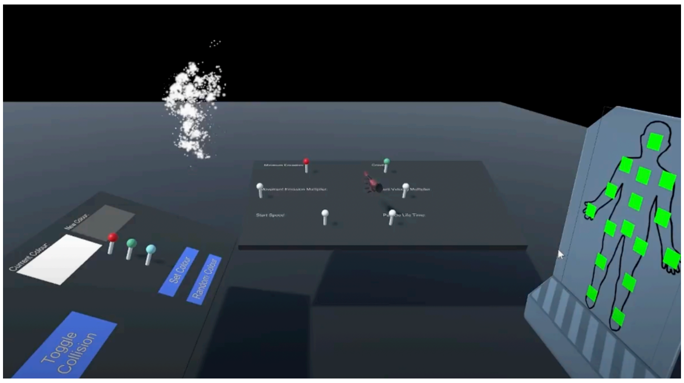
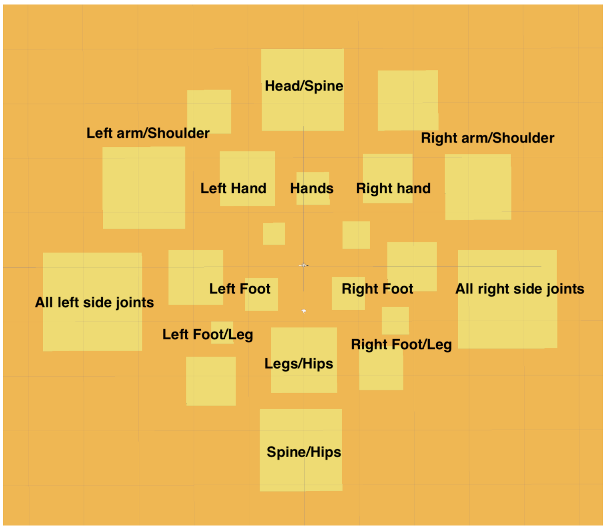


Fig 4 (left): Quick movement in particle scene. *Fig 5 (right): VR controls in particle scene.*

3.2.2 Scale changing scene

This scene extended the scale-changing prototype scene demonstrated in workshop four (section 2.5.4) and was developed to investigate how movement might be linked in a simple way to changes in the environment, providing a unique type of feedback. More blocks were added so that the dancer was in the centre of the landscape. Each block changes height according to the average speed of a group of joints. Trackers corresponding to neighbouring body parts control geographically grouped blocks (fig. 6). This layout was designed to give dancers a greater sense of control over the environment as they may better predict the effect their movements will have. For example, a rolling motion from the left to the right side of the body might create a wave-like pattern in the environment. The result from an inverse linear interpolation is squared before being applied to calculate height, deemphasising very small movements and highlighting larger, more intentional movements. Changes in height between frames are clamped to reduce jitter.



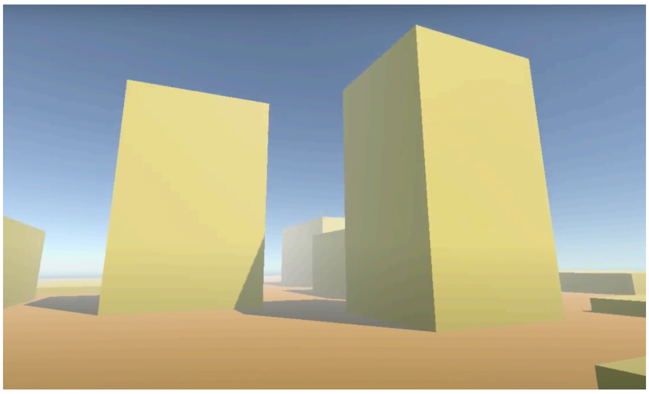


Fig 6 (left): Layout of blocks and joint relationships.   *Fig 7 (right): In-game view of scale scene.*

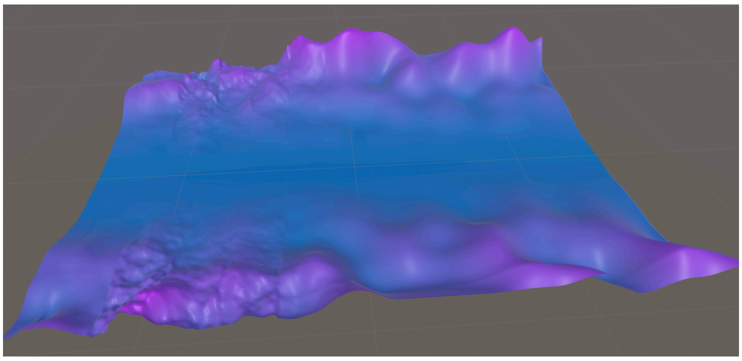
3.2.3 Terrain Scene

This scene was designed to address both the desire to have a record of movement over time and also the ability to shape one’s environment through movement. Terrain is procedurally generated using four octaves of Perlin noise. The persistence (diminishing influence of smaller octaves) and lacunarity (diminishing scale of smaller octaves) are controlled by the movement of the dancer. Specifically, persistence is controlled by the average acceleration of the trackers and lacunarity is controlled by the average speed. This results in fast/sudden movements being expressed as gritty, spiky landscapes, and slow/gentle movements expressed in smoother, flowing landscapes.

The maximum height of the map is limited by the average height of the trackers, such that the dancer can control the height of the peaks by stretching upwards or focussing on low floor-work. A colour gradient is applied to the terrain mesh according to the height at each point. This colour gradient is chosen randomly on each playthrough, to encourage exploration. A maximum delta variable is used to clamp how much the height, lacunarity, and persistence can change over a single frame to reduce jitter.

At each frame, the sampling coordinates for the Perlin noise are offset, creating the illusion of drifting forwards through the landscape. The scale, lacunarity, and persistence values are gradually frozen behind the midpoint of the terrain map, such that a user in VR can turn around to see their movement reflected the frozen terrain generated 5, 10, 15 seconds ago etc (fig. 8). The terrain in front of the dancer is constantly evolving with their live movements. This generated terrain map is an artifact produced by the dancer's performance and could be saved as an abstract summary of the performance over time.

A square-curve dampening effect is applied in the centre of the landscape, providing a flat area of clearance within which to move, as well as an improved view of the terrain. Fog is applied to obscure the sharp edges of the map.



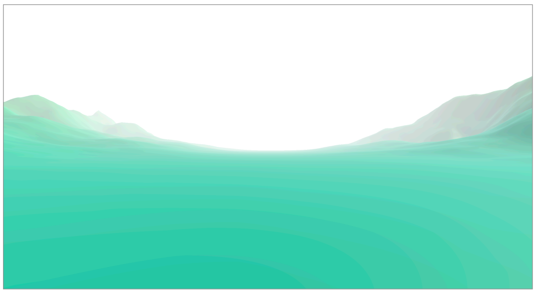


Fig 8 (left): Developer view. Frozen terrain generated by high activity seen on left. *Fig 9 (right): In-game view of terrain scene.*

3.2.4: Trigger Sound Scene

This scene was created to investigate aural feedback in VR (as had been suggested by dancers throughout the workshops), as well as provide a sense of feedback over time. Thresholds are configured to trigger once a body part (hand, foot, etc) has undergone a rapid deceleration. On passing the threshold, a tone is played and one of the floating spheres flashes to provide both aural and visual modes of feedback. The note/pitch of the tone is randomly selected each time the threshold is crossed. The notes selected are not all in the same key (B, C, D, E), sometimes yeilding dissonance, and sometimes yielding musicality. Different tones are used for hands and feet, so one may identify which body parts are related to which sounds.

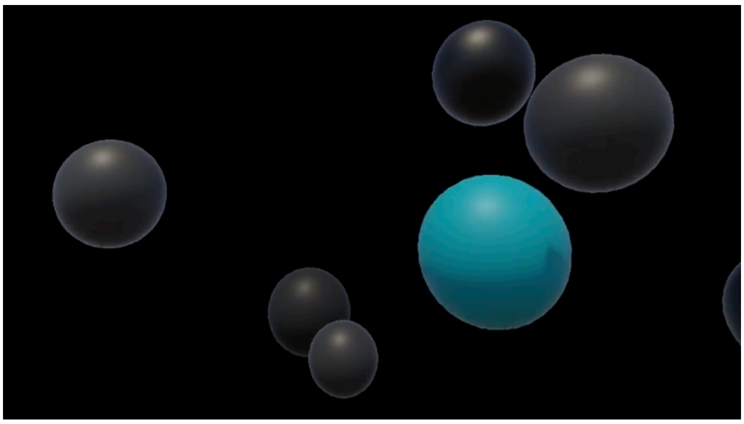


Fig 10: Trigger sound scene with one threshold activated

The goal of the setup is to allow for intentional control of the system through fast extensions of the limbs (e.g. punching the air), and also through the sudden deceleration undergone by feet contacting the ground when walking/running. In addition, ambient background noise is used to indicate changes in movement qualities over time. The track glides between two synth loops depending on whether acceleration has been increasing or decreasing over the last 30 seconds. With decreasing acceleration, the track favours a loop heavy in bass frequencies with a slow rhythm. With increasing acceleration, a mid-frequency rhythmic track is favoured. This effect reflects trends in movement activity throughout a performance.

3.2.5 Ambient Sound Scene

The ambient sound scene explores several linear relationships between movement and visual/aural feedback. The scene extends the colour-changing prototype presented in workshop four (section 2.5.4); floating spheres change colour from white to blue according to the average velocity of joints in the body. Similarly to the scale scene, these spheres are grouped such that neighbouring body parts correspond to geographically neighbouring spheres. The floor oscillates in a gentle, radial sine-wave pattern, at an amplitude that linearly increases with fast movement, and decreases with slow movement.

The sound of rushing air reflects the overall speed of the dancer in a linear relationship to volume. An ambient musical track [20] plays at constant volume in the background to enhance immersion. This scene contrasts the sharp, sudden feedback given in the trigger sound scene, with feedback that has more fluid and airy qualities, combining feedback in the form of audio, shape, and colour.

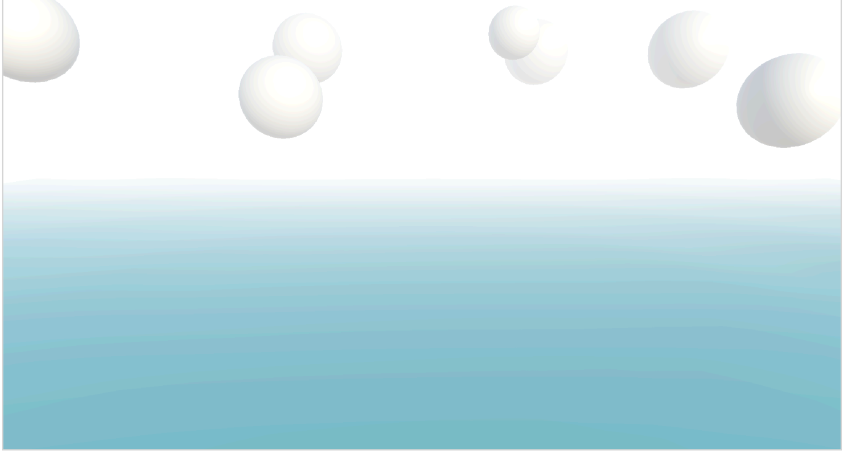


Fig 11: Ambient sound scene with low movement activity

3.3 Final Workshop Findings

Responses to the particle scenes were positive; some participants reported a sense of kinesthetic empathy as a desire to mimic/embody the recorded form. This effect was not as present in the other scenes, demonstrating that a representation (even abstract) of the human body is a compelling part of performance from an audience perspective. When asked through the survey which scenes were their favourite, all respondents mentioned the particle scene, with some also being drawn to those with aural feedback. Participants were able to ascribe their own abstract qualities to the scenes, using terms such as "energy", "power", and "strength".

While respondents showed a preference for the particle scene, the scenes which gave feedback through the changing environment showed potential for exploration and play. When asked whether an abstract or direct correlation between movement and the given feedback was preferred, we got a mixture of responses. A non-dancer noted that as an audience member, more clear links were preferred as they "made the visuals feel like they related to the dance, rather than being something separate to the dance that just happened to be occurring simultaneously". This idea of feedback feeling incidental was echoed in responses around the terrain scene. My lack of access to equipment for testing resulted in effects that were visible when rendering through a static camera being lost in the VR recording. Changes in the lacunarity and persistence were hardly noticeable. Survey respondents showed a clear desire for some form of visible feedback through the environment, and indicated that they would like to further explore the environment to better understand its mechanics: "The slight morphing of the surface detailed by some light and shadow contrasts was intriguing, would love to know what specific movements lead to these textural changes to push the boundaries". One participant noted that it was difficult to distinguish features in the monochrome terrain, and suggested that more realistic terrain (e.g. grassy/mountainous) could be rendered that changes depending on "what the movement is doing". The problem with this scene seemed not to be that the correlation between movement and feedback was too abstract, but that it was not clear that qualities of the terrain were changing at all, and that after viewing the previous scenes, a level of control/malleability may have been expected.

Participants noted that the scale-changing scene was difficult to understand in correlation to the dancer's movements. The jerky, quick movements of the blocks shooting up and down contrasted to the more fluid movement of the dancer, creating a sense of dissonance. While watching the video demonstration, participants spent time trying to figure out the correlation between movement and changes in the environment, describing the scene as a "puzzle". One participant suggested that using position might be a better way to encapsulate movement; "It may be harder for the viewer to associate acceleration and deceleration with animations happening in the environment as opposed to motion". Through the lens of an audience member, qualities such as acceleration can be difficult to understand. The disconnect between dancers and the feedback showed a need for further testing with live dancers in VR, and also the need to reflect on qualities of movements that might not be encapsulated by quantitative measurements of distance, velocity, and acceleration. Feedback in VR for dancers should be linked more qualitatively to movement to foster a harmonious cognitive feedback loop that feels intuitive and controlled. The particle scene was successful in this regard as visual feedback is very tightly related to movement positionally, as particles are emitted at joints that move with the dancer. Because the particles also inherit the velocity of their parent joints, the direction in which they fly off matches the direction of the body's motion. This results in imagery that is relatively predictable and easy to understand from both a dancer and the audience's perspective.

Respondents showed excitement around the scenes that used aural feedback. Of the sound trigger scene, one participant noted "seeing this space is super exciting", and expressed disappointment that the motion used to demonstrate the scene didn't make full use of the effects. They also expressed the desire to try the scene in VR. Through the ambient sound scene video, the participant whose movement was used as a demonstration was able to reflect on the qualities of her movement through aural feedback in the scene. The participant noticed a rhythmic, repeating volume swell, and then realised that this rhythm was due to a natural rhythm in her recorded performance: "I noticed that the sound was really soothing and it had a particular rhythm, and then I realised that I was the one making these really bland, boring rhythms, (…) as a dancer I was like oh, that's my rhythm, thank you for pointing that out through the music, that's something I would do differently next time". This result mirrors those found by Ackerly [9], who showed that audio feedback can be an effective tool in self-reflection, increasing awareness of movement and encouraging new types of movement.

Before being shown the scenes which utilised audio, one participant suggested that they would like to experience the particle scene with audio. While different feedback types were seperated intentionally to better test them individually, this shows an intuitive desire for aural feedback to accompany visual feedback. Historically the art of dance is closely tied to music. Often qualities of motion reflect the accompanying score of a dance performance, so dancers are already familiar with qualitative links between motion and audio. This suggests that the design space could be explored further by recombining the modes of feedback we have investigated in our prototype scenes.

Participants indicated the desire to try the scenes as generative tools. Of the particle scenes, one participant noted that in their first impressions they were considering “the capacity for the programme as a device to stimulate and challenge movers with a responsive practice” and that “there are potentials in the programme to be used as a device that could instigate processes of translation”. When prompted to identify which scenes might have the least generative potential, participants stated that each scene had potential in different ways. This shows that many different and successful combinations of feedback types may exist in the design space. The prospect of exploration was exciting to respondents, one stated: “The most compelling aspect of these spaces to me was how they might inform the dancers' movement, motivate different choices and (create) 'urges to just move around and explore the worlds’”.

4. Future Work

Results from the final workshop made it clear that further work must be done in ensuring feedback more closely aligns with qualities of movement. Testing with live dancers in VR will allow for better variable configuration to support this, and will also show how different scenes in the design space are used after sustained immersion as users become more familiar with the feedback systems. Tests with users in VR will reveal whether the links between virtual environments and movement support an embodied dance experience.

Further research into identifying movement qualities through quantitative measurements such as position, velocity, and acceleration should be conducted to create more expressive virtual feedback. For example, grouping movement qualities and feedback types using a Laban movement characterisation system [21]. Successful elements from the different prototype scenes should be combined to experiment with more holistic experiences in the design space.

Finally, further exploration should be done into how these scenes work in the context of a dance performance to better understand how the technology might be situated for an audience perspective (e.g. audiences immersed in VR, or the environment being projected behind a live dancer etc.).

5. Conclusion

In this project, several VR environments were developed that occupy different points in the VR/dance design space. These environments offer a range of feedback types, abstract, visual, and aural to reflect the movement of a dancer in VR. These environments show that VR movement feedback in dance does not have to take the form of avatar representations, and can exist in a myriad of forms. Positive feedback from dancers shows that these environments could promote creativity, spontaneity, and exploration of movement in embodied dance practises. This project has highlighted factors affecting the success of VR feedback, such as viewing movement over time and having a cohesive link between movement and changes in the environment. The design opportunities in this space are huge and may be further explored through combining types of feedback or providing control to dancers to customise their own experiences.

6. References

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