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1 Related Works

1 – Introduction

In recent years, Virtual Reality (VR) and Mixed Reality (MR) has seen a growing use in the music industry typically tailored towards live events. These technologies take advantage of the immersion created by a virtual environment beyond a physical location to simulate the concert experience.

This shift towards more virtual alternatives can bypass the limitations of traditional live events, such as travel or pricing issues, allowing for a more global reach for artists and their fans. While other options have been explored, like livestreaming, has seen some success they ultimately fall short when it comes to immersion and user interaction.

In this report we will explore the role of VR and MR in live music events, providing critical analysis and high-level discussion of the design, benefits and challenges of its use.

2 – Literature Review

2.1 – Paper selection Summary

The papers analysed in this report have been chosen based on a variety of criteria such as: *Relevancy* – ensuring the paper focuses on VR/MR applications for concerts, *Recency* – ensure the research in the papers are relevant to current discussions/challenges, and *Credibility* – ensure research is coming from reputable and academic sources.

2.2 – Paper Analysis

Paper 1: "Research Trends in Virtual Reality Music Concert Technology: A Systematic Literature Review" (Park, Choi, & Lee, 2024)

- *Research Problem*: The use of VR in musical concert is in its infancy and thus is lacking in understanding of audience immersion/engagement and environment design.
- *Research Domain Challenges*: This is challenging as the solution needs to provide quality visual and audio experiences while still delivering an immersive level of interaction between audience and artist.
- *Importance*: identifying the trends that allow for audience immersion and usability/accessibility to make the experiences more engaging.
- *Proposed Solution*: There was no direct proposed solution as this paper was a literature review however there are some interesting things to consider. Virtual Reality in the context of concerts tend to have a bigger focus on the artist, more so than the social elements within real-life concerts. Additionally, there is discussion

about how music can be adjusted per person, so that it could either mimic what it would feel like in that spot within the audience or to tailor to preferences of the individual.

- *Immersive Impact*: the study investigates the concept of Flow State Scale, which is when users are totally immersed in an activity. As well as diving into FSS, the paper explores many techniques, such as haptic feedback suits and real-time motion tracking to increase the immersion felt by the user.
- *Key Takeaways for Our Project*: User avatars are a great way to increase immersion as it allows users to have more expression of self within the simulation. Additionally, having multiple positions where the user can "stand" might be good to include as it may change people's habits.

Paper 2: "The Sentiment of a Virtual Rock Concert" (Slater, M., Cabriera, C., Senel, G. et al., 2023)

- *Research Problem*: Understanding the response of participants in a virtual audience during a VR concert (more specifically a recreation of a 1983 Dire Straits concert), and how that the results and methodology could be used to improve similar scenarios, both in participant sentiments and concert reconstructions in general.
- *Research Domain Challenges*: The study found that participants experienced negative sentiments caused by the virtual audience, reporting feelings of harassment and the sensation of being stared at.
- *Importance*: This study highlights the importance of audience behaviour in the virtual experience to improve user comfort and immersion by addressing potential negative reactions.
- *Proposed Solution*: A co-design for VR scenarios, and the use of sentiment analysis in the process instead of solely relying on traditional methods such as questionnaires.
- *Immersive Impact*: Plausibility was enhanced with responsive events and spontaneous reactions when the virtual characters in the audience respond to the participant's actions, meeting their expectations of realism. Presence was enhanced using spatial audio and realistic animations, contributing to the increased presence of the participants.
- *Key Takeaways for Our Project*: Realistic audience behaviour and sentiment analysis should be used to make the experience more user-centred for enhanced immersion.

Paper 3: "Concert Experiences in Virtual Reality Environments" (Kelsey E. Onderdijk, Lies Bouckaert, Edith Van Dyck, Pieter-Jan Maes, 2023)

- *Research Problem*: The paper investigates the experiences and motivations of attendees in VR music concerts. It delves into how VR concerts compare to physical live concerts.
- *Research Domain Challenges*: Since VR concerts are considered a relatively invention, the problem lies with how VR can replicate or enhance the live concert experience in

comparison to physical concerts, particularly looking at social interaction and immersion and what is done to address said problems.

- *Importance*: Insights from this research can inform platforms that develop VR concerts on how to enhance user engagement and shape the future of virtual music events.

- *Proposed Solution:* The study uses numerous methods, combining qualitative and quantitative surveys, to analyse the attendees' motivations and experiences. The findings suggest that VR concerts are valued for their uniqueness, visual effects, and accessibility as they create an environment that is free for many and unique in customizability but falls short in comparison to physical concerts.

- *Immersive Impact:* MR is increasing immersion mainly through VR headsets, enhancing the sense of presence and making the attendees feel more connected to the concert environment and the artists. The study found that specifically highly immersive VR environments improve the social presence and emotional engagement of attendees by creating an experience unique to the artist whilst also maintaining the feeling of physical concert.

- *Key Takeaways for Our Problem:* The role of first-person perspectives and embodying that which makes users feel present, and a need to integrate interactive features that improve social engagement, such as real-time audience interactions or VFX design specific to the VR environment.

Paper 4: "Enhancing Participation Experience in VR Live Concerts by Improving Motions of Virtual Audience Avatars" (Hiromu Yakura, Masataka Goto, 2023)

- *Research Problem*: This paper covers the comparison of user participation and social engagement between real-life and virtual experiences. Where traditionally the physical crowd of a concert contributes towards the atmosphere/feel of an event, virtual experiences seem to fall short as users often watch alone or in small groups, limiting social interaction thus limiting overall immersion.

- *Research Domain Challenges*: A clear challenge is the complexity, both technically and conceptually, of achieving realistic social interactions. Additionally, network latency can disrupt synchronized movements, and simple mirroring of a user's own gestures can feel unnatural and inauthentic.

- *Importance***:** Since social interaction is such an integral part of live events, bridging that gap within a virtual experience is a challenge. Since virtual experiences rely on real-time user data to animate audience movements, a low attendance can lead to feelings of isolation for the user.

- *Proposed Solution:* Some methods explored in the paper include the mirroring of user movements onto the virtual audience, using past user data to simulate crowd movement, animating avatars in time with the beat of the song, and the use of AI or machine learning to synthesise avatar behaviour.

- *Immersive Impact:* With virtual audience members exhibiting realistic movements to the music, users will feel more immersed in the experience as part of a larger

engaged social group, enhancing emotional and sensory connection to the experience.

- *Key Takeaways:* Beat-Synchronous Animation - Incorporating movements that align with musical rhythms to make the environment feel more interactive. Avoiding Self-Replication - Users found it creepy when their movements were mirrored, so designing distinct, natural crowd behaviours is key.

Paper 5: "Bringing back the 'live' into the digital: Semiotics on the emergence of live VR in music concerts" (Jenske Verhamme, 2020-2021)

- *Research Problem*: Live music events have traditionally been defined by artists and the audience sharing the space at the same time to produce a unique experience. This paper tackles the problem of reconstructing the feeling of 'liveness' in a virtual/digital environment.
- *Research Domain Challenges*: The main challenge brought up in the study was deriving a definitive definition for the concept of 'liveness' in a virtual world. Since a VR experience cannot rely on the physical aspect of an artist's presence, the challenge is to create a convincing illusion of real-time interaction whilst still distinguishing itself from a prerecorded experience.
- *Importance*: Understanding the cultural impact of a VR concert is important as to replicate 'liveness', allowing these digital experiences to become a more legitimate alternative to traditional events. This will further the shift into the digital age and create more accessible experiences for a wider audience.
- *Proposed Solution:* The solutions explored in the paper are various semiotic frameworks. 'Structural Semiotics', this is the analysis of how the 'signs' within a virtual concert function and the construction of their meaning. 'Peircean Semiotics', this explores how the audience interpret/perceive the virtual space they are in. 'Lotman's Cultural Semiotics', this examines the role of virtual concerts within the culture and evolution of live music events.
- *Immersive Impact:* Immersion within these solutions is enhanced by spatio-temporal coherence, user interactivity, and more elaborate settings that subvert the audience's expectations and the laws of physics.
- *Key Takeaways:* Some concepts that we can take away from this include the importance of redefining 'liveness' to develop a unique and immersive experience, encouraging user interaction, and blending reality with the integration of MR.

Paper 6: "Methods and Techniques for Capturing Music Concerts for Virtual Reality Experiences" (Stephanie T. Benicek, 2018)

- *Research Problem*: Since traditional techniques for recording concerts often fail to capture the spatial and immersive aspect of true live music events, this paper investigates how 3D audio techniques and VR-compatible recording setups can improve concert immersion.

- *Research Domain Challenges*: The broad challenge presented by this paper is optimising live performance recordings for VR experiences. The smaller, more technical aspects of this challenge consist of playback optimisation, microphone placement, audio spatialisation, and mixing techniques.
- *Importance***:** The understanding of proper sound design is important in making performances feel less artificial and detached. This is needed to bypass the barriers of accessibility like cost and location.
- *Proposed Solution:* The techniques of audio capture explored in this paper consist of spatial mixing, technology that make use of ambisonics like Sennheiser AMBEO microphones or an Equal Segment Microphone Array (ESMA), and user testing.
- *Immersive Impact:* Realism of the experience is enhanced by the use of 3D audio rendering, head-tracked audio, and binaural processing (essentially surround-sound audio). Combining these techniques with high-quality visual elements can help the audience's feeling of presence in the experience.
- *Key Takeaways:* The most important concept to take away from this paper is the importance of an accurate atmosphere and ambience in a virtual environment. This is achieved through realistic sound capture, the balance of direct and indirect sound, and taking spatial awareness into account when processing the audio.

3- Comparative Analysis and Critical Discussion

Over the course of the studied papers, many key themes, encompassing the various dimensions of a collaborative space in a VR concert, became most prevalent, those themes include but are not limited to Immersive techniques, Social factors, Audience behaviour, The feeling of "liveness" and finally then the more technical aspects of solutions.

When it comes to Immersive techniques the recurring ideas were ides such as haptic feedback, motion tracking and spatial audio rendering to enhance the immersion of a virtual music event. While certain methods such as spatial audio, head tracking and having users being able to interact with their environment are generally agreed to further the immersive experiences of audiences, certain put forth ideas have come under scrutiny such as the idea of mirroring the user behaviours and movements onto virtual members of the audience, as they often made users feel uncomfortable, and often described as uncanny.

Widely thought of as one of the hardest barriers to overcome in VR concert space is the lacking social engagements which are foundational to traditional concert experiences. Virtual music events tend to leave users feeling a sense of isolation furthering the sense that virtual concerts are lesser than their physical counterparts. Most research solutions mention the use of interactive avatars for users to engage amongst themselves with, coupled with interactive audience reactions. This all contributes to co-presence and the feeling of attending a concert with others as opposed to just by themselves. There should be a variety of integrated social feature that allow for users to attend concerts with friends. As it

currently stands digital events still fall short in the social aspects but further additions of AI audience members who can interact in real time and improvements in user-to-user real time interactions may begin to bridge this gap between physical and virtual.

The audience is often regarded in most reports as one of the most quintessential elements of immersion and realism in the virtual music events. Most studies found that having lifeless audiences that were too rigid and obviously artificial led to dissatisfaction among users who felt it became distractingly unrealistic. Adaptive audience behaviour is essential, even with a low attendance of users the concert should still feel full and lively. One popular idea was to use previous user data to recreate their reactions to events that could be used in future concerts to make the audience feel more alive.

Some of the papers focussed on defining "liveness" in differing manners, many chose to focus on optimising real time audio processing and user interactions, but others chose to focus on semiotics and signals to measure and enhance "liveness". Overall, it seems most sensible to combine these ideas to produce the best outcomes to produce the illusion of having a real time presence in virtual events.

Whilst mostly focussing on higher level conceptual ideas it is still important to touch on the technical challenges faced by the industry. With realism in mind specialised equipment is required to make the music sound like an authentic concert, needing the use of 3D audio processing, ambisonics and microphone arrays. But these must be placed optimally around users and function in real time which proves more than simple to resolve. Most reports agree this is the area that likely requires the most research to breach these barriers.

Another lesser discussed point, that still warrants serious consideration is the idea of user customisation, being able to personalise their avatar and be able to express themselves during a virtual event, varying from allowing them to dress up their avatar and customise their own feature to look as they desire. But it should go beyond just cosmetic personalisation's, users should be able to adjust their position relative to the the stage, volume of the music and camera perspectives. This allows for more accessibility and inclusivity which are one of the best-selling points of virtual concerts to begin with, being able to attend a concert regardless of personal inabilities whether they be physical, financial or otherwise. As it currently stands there is a financial barrier to entry, many people do not own or have access to a VR headset which is the most used way to attend virtual events. Once this has been resolved the ability to allow those who would otherwise be unable to attend is crucial.

2 Project Brief

The music industry is always looking for ways to connect fans and artists together and innovating to bring more engaging experiences in live events. It is also always looking for ways to create different types of music that appeal to different audiences, such as virtual singers and idols. Recent innovations in AR, VR and mixed reality in general can be used to enhance and improve the live music experience, especially those not able to attend real life events, and creating new experiences to entice fans. The main aim of this project is to create a virtual environment for live music and concerts that is engaging and immersive to the viewer.

Our proposed solution is to build a virtual environment in VR that replicates a real-life concert hall. This environment would consist of a stage where the artist in question would perform, as well as seating on the floor for concertgoers and on a higher level using three separate platforms. As this is a virtual environment, we also have more flexibility and freedom over what and how lighting and special effects are used, as well as the option to change the size of the environment if needed. This allows us to put a twist on the traditional concert setting which are limited by what is possible in the real world compared to our solution which allows us to design environments that cannot be easily replicated, in turn, achieving our aim of creating an engaging and immersive experience for music fans.

3 User Experience

Our users will be between 16 and 50, as shown by a survey conducted in September 2024 (Statista, 2024).
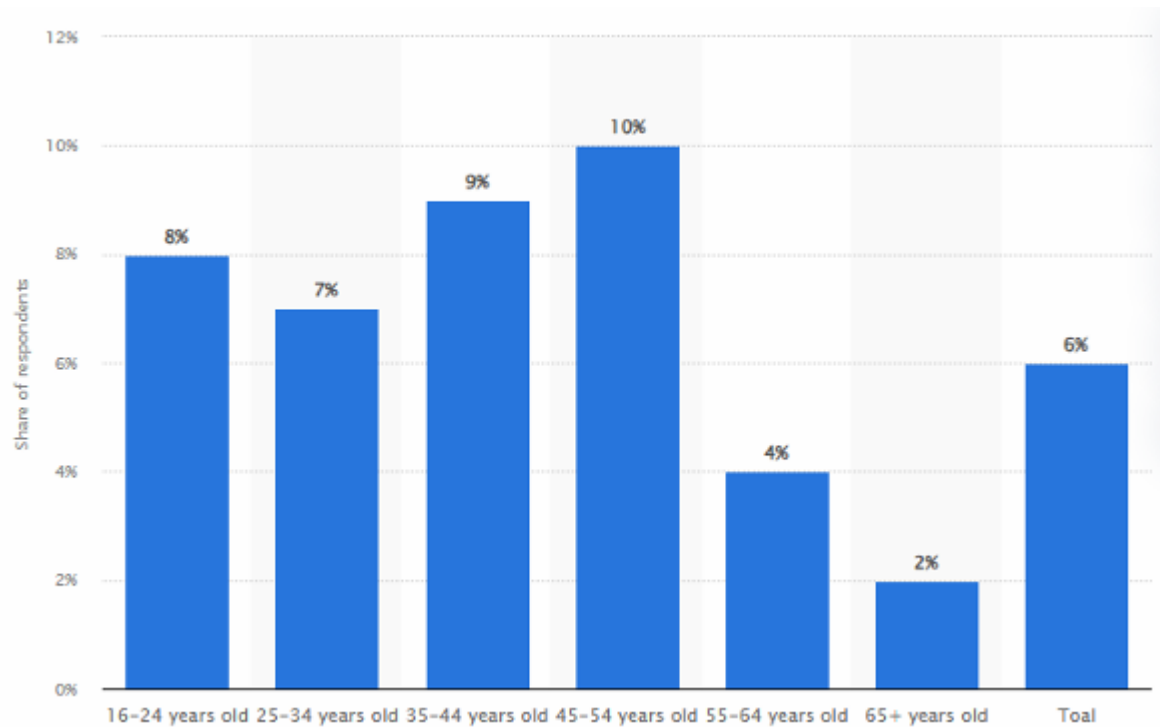
Figure 3.1 Survey of users of age.

Users look for an immersive and reactive virtual reality (VR) experience, with high-quality environments that replicate a sense of being in the virtual space and real-time feedback and interaction. These are standard requirements when using VR, demonstrated in real-world applications such as VR usage in healthcare, education, and entertainment (ResearchGate, 2024). The access requirements to get into VR are currently priced at around £300, with the Meta Quest 3 being one of the most accessible VR headsets available (Argos, 2024). The hardware required for VR includes a headset and controllers, with some setups including boundary boxes to define the physical space and prevent obstructions. While traditional VR setups are common, there are mobile VR applications that offer a cheaper alternative, requiring only a cheaper headset but have limitations such as motion blur and latency (ResearchGate, 2016).

VR also significantly impacts user behaviour, influencing how individuals interact within virtual environments. One notable effect is the Proteus Effect, where an individual's behaviour aligns with the characteristics of their virtual avatar (MIT Press, 2024). Our users should look to experience a VR concert like the Hatsune Miku VR concert in 2023, featuring high-fidelity sound, effects, and an immersive and reactive virtual space that mimics a real concert (Miku Expo, 2023).

4 Pipeline
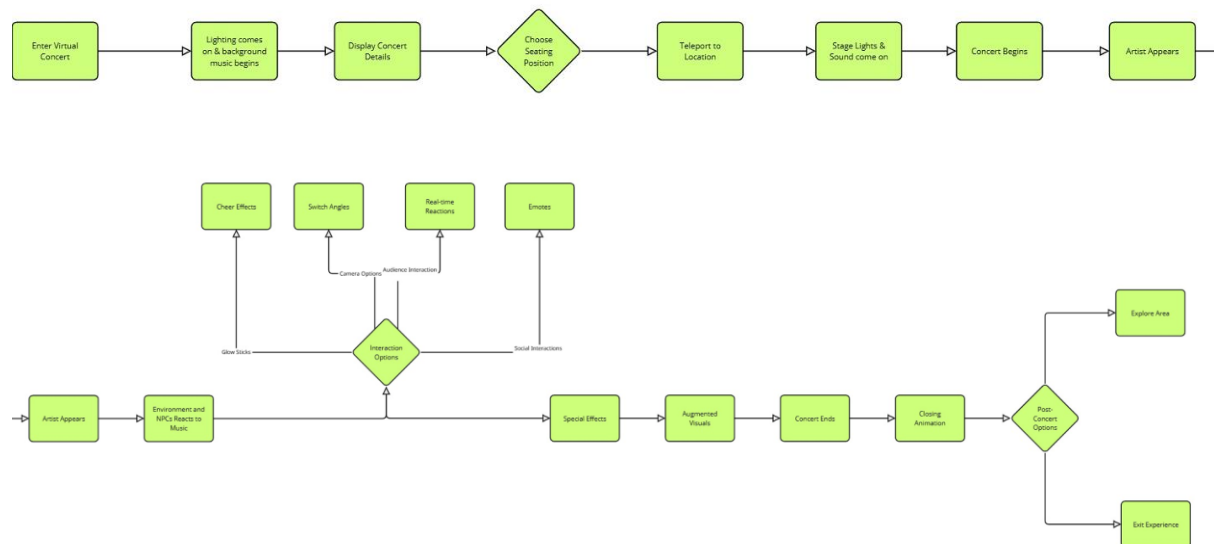
Figures 4.1a 4.1b Flowchart

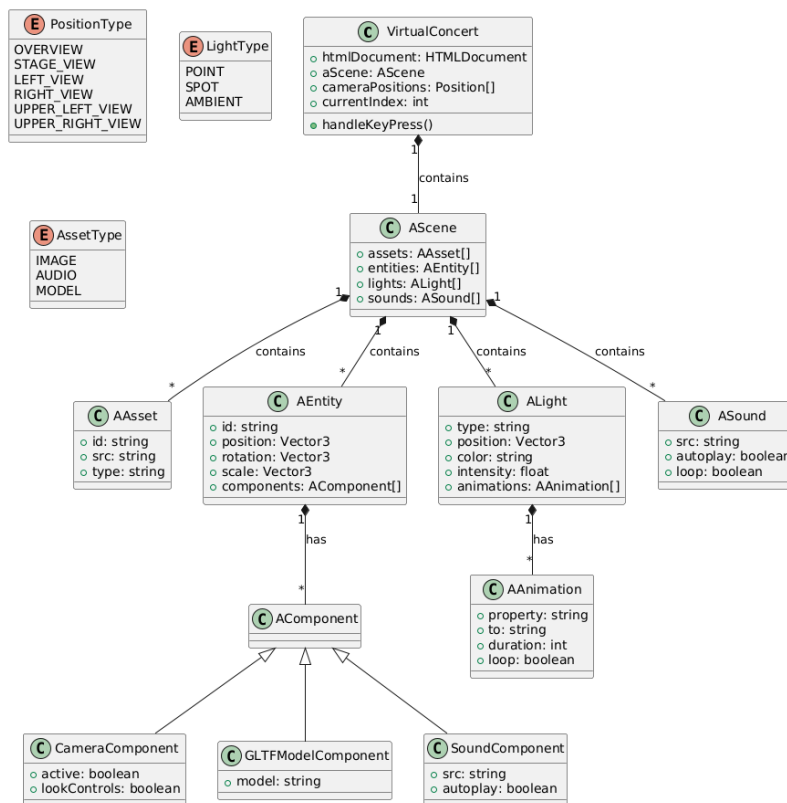Flow chart is split into half because it is difficult to read when all together.

Figure 4.2 Application Architecture

5 Mixed Reality Model

There are many different types of models we can use. We could lean into full virtual reality, where all stimulation is simulated or, alternatively, we could go for an augmented reality where users can interact with the world and have the concert take place in their homes.

Virtual Reality is when we use computer-generated simulations to define an environment that can be interacted with, using equipment such as controllers or headsets. Using VR allows users to be taken to a completely different environment that can be different from what is possible in the real world. Additionally, there are fewer physical constraints to worry about as since all of it is simulated, we can change what is shown easily as we do not need to build off an existing world. Additionally, since we don't have to use the real world, we can go for a higher stylistic approach to designing the stage and models as there won't be any unsettling contrasts between what is virtual and what is real. Less work is also required to make it immersive from a visual perspective as well, due to fewer constraints which allows us to invest more resources into controls and other senses.

However, there are some concerns regarding full use of Virtual Reality. Virtual Reality can be a cause for nausea and may make users uncomfortable after prolonged use. Additionally, more work will need to be done at the start of the project to build up a complete world, as it would be having to be worked on from the ground up, instead of using the existing world as the baseline. Embodiment could also present itself as a challenge as there are more physics and interactions to be considered, to allow to user to feel like they are in the world, instead of just observing it. Something else to consider is allowing the users to interact with each other. In a concert hall, it would be ideal for users to be able to interact with each other. This could be easily solved through an augmented reality angle where users can be in the same room and see the same thing but from different angles. However, allowing users to connect and interact with each other can be challenging to find a solution that isn't overbearing.

An alternative model is the use of Augmented Reality. Augmented Reality overlays imaging to the real world, meaning users interact with both physical and virtual spaces. Like VR, there are many benefits to using AR. For starters, AR is much more accessible, due to it being available on phones, tablets, etc. Additionally, since the physical world is still present, it causes less nausea and allows the user to be more aware of their surroundings. AR also allows the experience to be more personalised as their environment is adapted to fit the concert hall, so they could have a singer present on their sofas or tables. Furthermore, it is easier to connect with people who are physically nearby, allowing for better interactions. Just like VR, AR has some drawbacks we need to consider as well. Although it is easier to connect with people who are physically around, it is more difficult than with VR to connect with people who aren't nearby as it is much more difficult to have avatars walk around in

your environment that also suits theirs. Additionally, unless the application is very high quality, it is more difficult to be immersed, compared to VR, meaning for the scope of the project, VR may lead to more immersive experiences. Augmented Reality is also less developed than VR, leading to higher costs or lower quality experiences. Having the stage and characters be placed in a "normal" position might present another challenge as it would either require the user to place markers down, or for the application to have smart sensors which can place the virtual environment in an ideal spot.

After considering the two models, our group is leaning towards a fully virtual environment for our concert hall to take place in. Virtual Reality better suits our skillset and allows us to create an environment from the ground up, which means we can attempt to create a fully immersive concert hall. Additionally for our brief, it makes more sense to have it in virtual reality as the focus will be on the stage, which is a static object. People also tend to not walk around so much in concert halls so there are less health and safety concerns to worry about. Through VR, we can create a virtual environment which utilizes both sight as well as hearing to enhance the immersion experience. The fully virtual environment ensures that we can create a scene that feels like you are in a concert hall, and it allows us to control what can be seen and not, unlike dealing with the physical world constraints AR must solve. We could give each user an avatar that exists within the world and have NPCs roam around, mixed in with other avatars, to give life into the simulation.
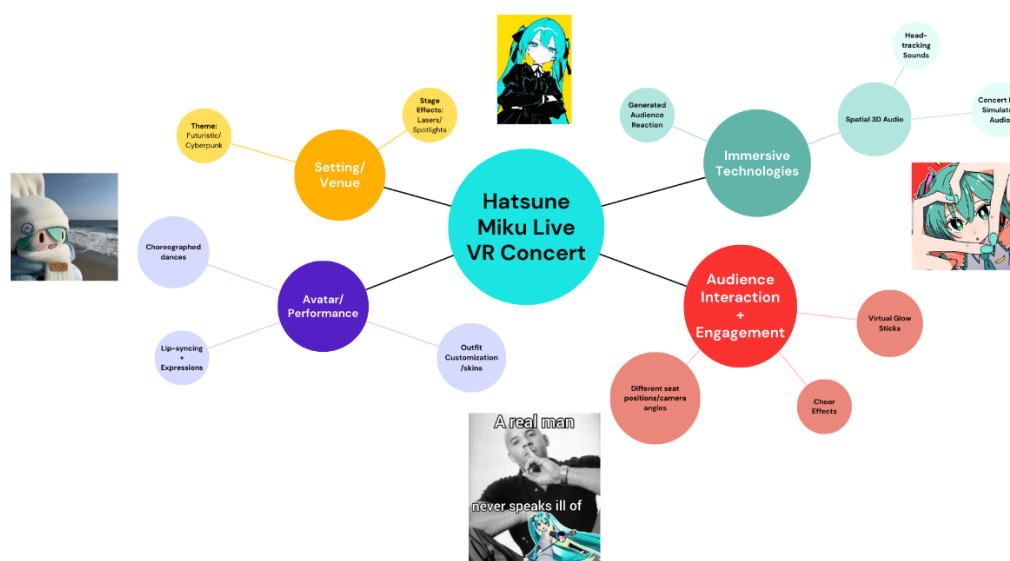
6 Conceptual Design

Mind map
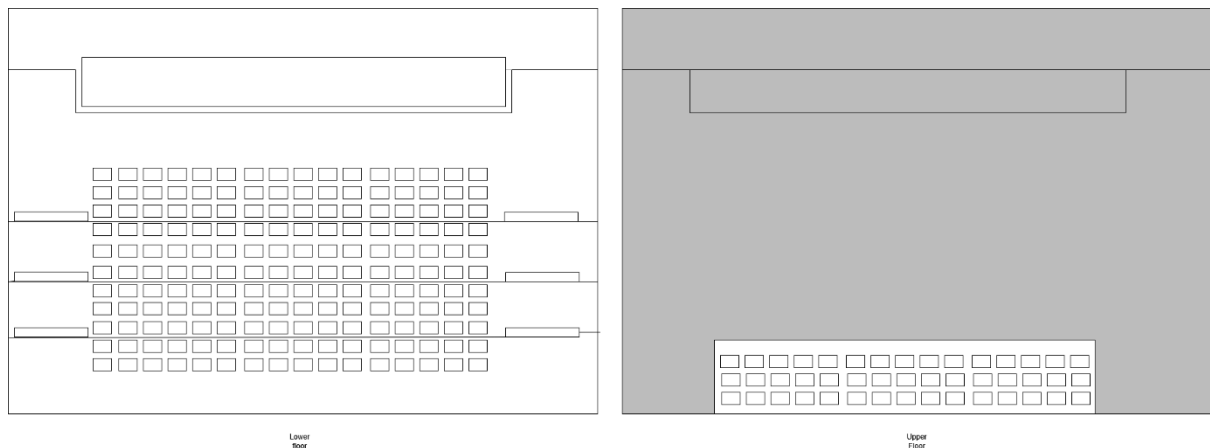

Figure 6.1 Hatsune Miku Mindmap

Spatial Map

Lower floor

Upper Floor

Figure 6.2 Concert Hall Spatial Map

Mood board
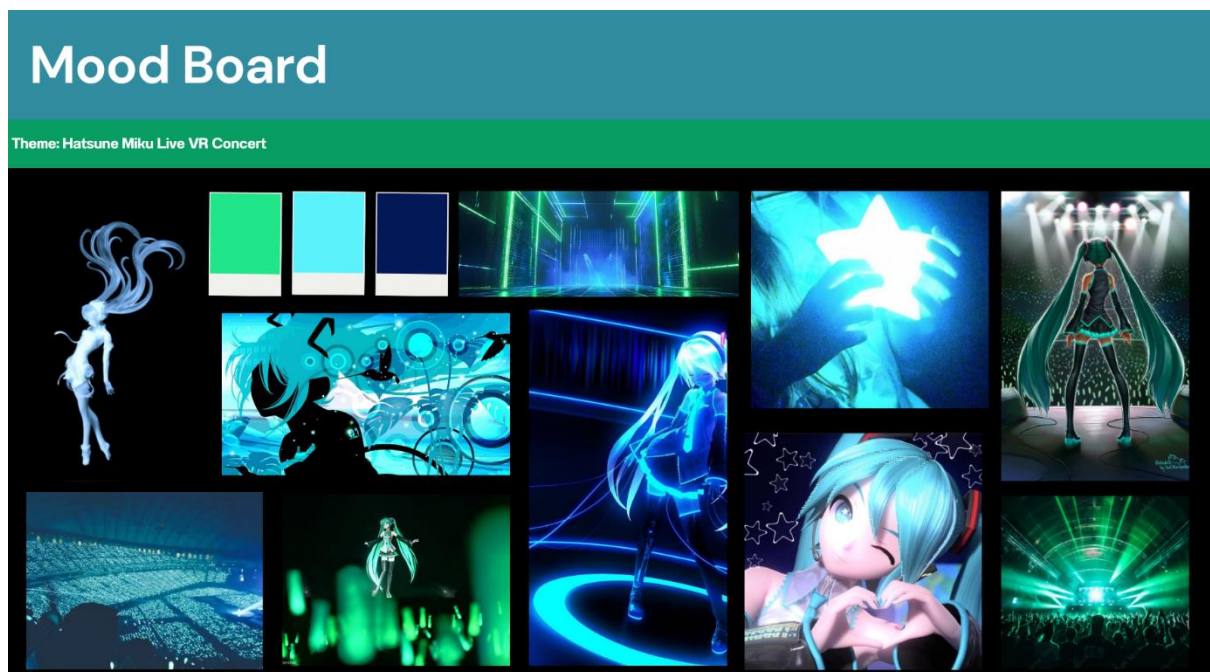
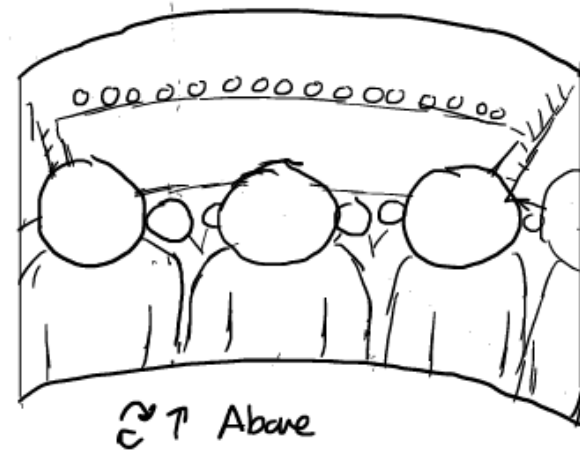*Figure 6.3 Hatsune Miku Mood board*

Storyboard

No audience

Front

℃↑ Above

Front

℃↑ Above
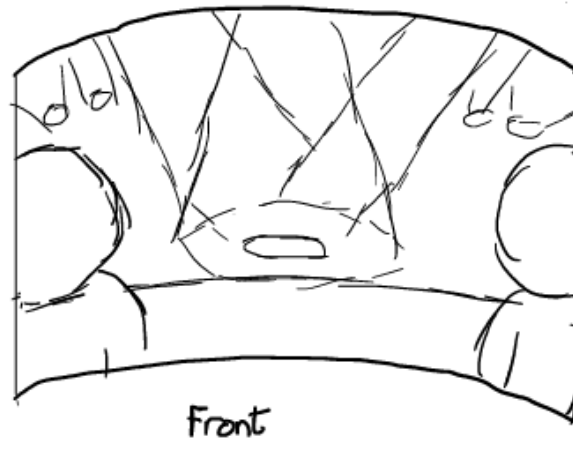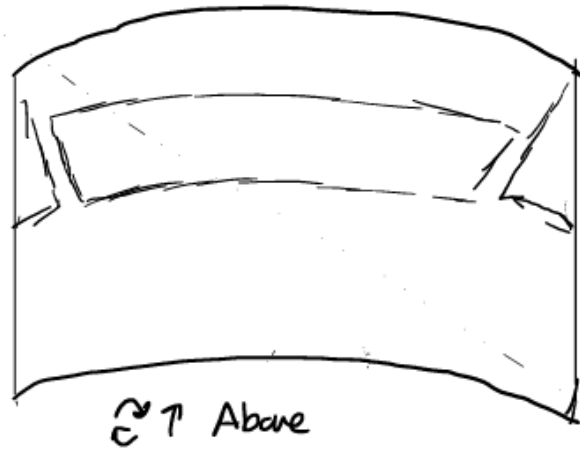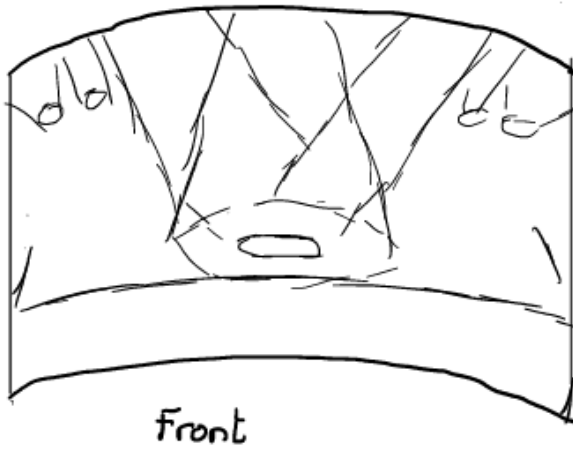
Action (waving light stick)

Parts of the stage omitted for visibility

Figure 6.4 Storyboard

Cognitive Walk-through

INTRODUCTION

User & Goal Definition

Target users:

- Concert Attendees
- Performers
- Event Organisers

User Goals:

- To navigate through the venue
- To interact with the visual elements
- To engage with other the NPC avatars
- To customize their avatar and outfits

This walkthrough focuses on core interactions that define the VR concert experience
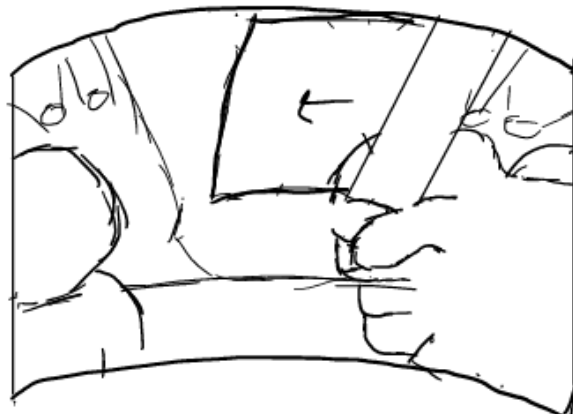
- Launching the Application
- Navigating the Venue
- Interacting with Virtual Objects
- Engage with NPCs through avatars.
- Participate in audience engagement activities (e.g., virtual glow sticks, cheering).
- Customize avatars and outfits
- Exiting and Returning

WALKTHROUGH

1. **Launching the Application**
    Action: User launches the app on their browser
    Expected response: App loads up and user can begin
    Potential issue: Users unfamiliar with WebXR may struggle to set up the app and VR on their device
    Recommendation: Provide a clear step by step instruction guide on setting up

2. **Navigating the Venue**
    Action: The user moves between different venue areas and camera angles
    Expected response: The user can move freely using teleportation or joystick controls
    Potential issue: Controls might not be intuitive for users unfamiliar with the platform
    Recommendation:

3. **Interacting with Virtual Objects**
    Action: The user attempts to select an object

Expected response: The object is selected correctly by the user and is shown to be selected by the user

Potential issue: Some users may not realise which objects are interactive

Recommendation: Visual indicators e.g. glowing objects or prompts can be used to indicate which objects are interactive

4. **Social & Audience Engagement**

Action: User uses the gestures, glowsticks or cheer effect

Expected response:

Potential issue: user may struggle with finding or using the engagement options

Recommendation:

5. **Exiting and Returning**

Action: User decides to leave the concert and rejoin later.

Expected response: Understands how to log out and come back later.

Potential issue: User might have a hard time figuring out who to exit the concert

Recommendation:

Issue	Impact	Proposed Solution
Unclear WebXR setup	High	Add step-by-step onboarding guide
Movement controls unintuitive	Medium	Provide an interactive tutorial
Interactive elements not obvious	Medium	Use glow/highlight effects
Social engagement options confusing	Low	Simplify UI and add preset reactions
Unclear exit/save system	Medium	Add confirmation prompts and clear signs
Unclear sound feedback	Medium	Provide an optional sound tutorial
Difficulty using audience tools	Medium	Add tooltips for glow sticks and cheering effects

Asset Sheets

Asset Sheet Hatsune Miku Avatar (Main Performer)

The main 3D asset will be a highly detailed, real-time-rendered avatar of Hatsune Miku. The avatar should include dynamic expressions, hair, and clothing that respond to the rhythm of the music, as well as lighting effects that sync with the music. Miku's design would incorporate futuristic elements, consistent with her virtual persona, with possible clothing changes and effects such as neon lighting.

By making her highly interactive and responsive to the concert environment, she becomes a central point for the audience, keeping them engaged. In VR, Miku's performance can respond to users' actions and movements, which enhances the overall immersion for the virtual concert attendees.

Link to 3D Asset: https://sketchfab.com/tags/miku

Virtual Stage and Environment

The stage design will feature a futuristic space that includes both digital and natural aesthetics. Like a transparent, holographic stage with floating platforms that change colours and morph in sync with the music. There will be neon and particle effects with lighting and visuals that shift according to the song's tempo and mood. This stage design ensures the stage does not feel static, enhancing the feeling of a live concert within virtual reality.

By combining elements from physical concert stages and virtual, abstract spaces, the environment gives users the sensation of being immersed in a game. The dynamic nature of the stage will make users feel like they are in a constantly evolving concert, keeping them engaged throughout the performance. The mixed reality aspect would benefit from physical gestures tracked and reflected on the virtual stage, creating an interactive experience that matches the crowd.

Link to 3D Asset: https://sketchfab.com/3d-models/concert-stage-e76209e5f0224c95b36a12fd5593ed7e

Audience Avatars

To improve the social aspect of the concert, the virtual crowd will have customizable avatars of the crowd, which will be highly reactive to the performance. These avatars can include animations such as clapping and cheering, or synchronized movements such as waving glowing sticks that respond to Miku's cues and the music. The avatars can also be programmed to react to user inputs such as hand gestures or voice commands, creating an engaging crowd experience.

Integrating interactive avatars allows the crowd to feel alive and connected to Miku. This creates a sense of social presence, improving the immersive experience by making the user

feel as if they are part of a live audience. By having the crowd react in real-time, they immerse the user, allowing for a greater VR experience.

Link to 3D Asset: https://sketchfab.com/apo11o/collections/crowd-4ed1c0ad5720496998b5a708aafddee9

7 Evaluation Plan

1 Introduction

1.1 Test Objectives

The purpose of this testing phase of the Mixed reality system should meet the requirements so that:

- The user can move around the stage.
- All music is fully functional and played correctly.
- Animations are running properly.
- The system is easy to use by the end-user.
- All points of interaction are functional.

1.2 System Overview

The Mixed Reality system is a virtual concert hall which has Hatsune Miku, a virtual singer, on stage and performing songs. Within the concert hall, the user can listen to her music as well as move around and participate as a member of the audience.

2 Approach

2.1 Assumptions and Constraints

2.1.1 Assumptions
- The build will be ready for testing by April 24th, 2025.

2.1.2 Constraints
- 9 weeks might not be enough time to fully test the system and then retest to find new bugs due to the implemented fixes.

2.2 Resources

2.2.1 Testing Tools
- Playback/Capture device

2.2.2 Test Environment

- Hardware
  - Asus
  - Intel Core i7-7700
  - 16GB RAM DDR3
  - RTX2080 Super
- Network
  - LAN
    - Internet connection required
- Software
  - Mixed Reality Build
  - Firefox
  - MS Windows 10 operating system

3 Features to be Tested

3.1 System Ease of Use

- Camera Control
- Spatial Audio

3.2 System Performance

- Time to load assets
- Average FPS during a song
- Time to move between camera positions

3.3 Non-player characters

- Miku's animations
- NPC movement

4 Features Not to be Tested

- Lighting
- Audio Controls

5 Testing Procedures

5.1 Evaluation Criteria

Feature	Definition	Testing	Success Criteria
Collaborative	Ability to support interactions between multiple users.	Perceived presence	Users feel environment is designed to socialize
Usefulness	Ability of the system to fulfil its intended purpose.	Conduct user surveys	Most users agree the application is useful
Usability	Level of ease of user navigation and interaction.	Users complete specific tasks	Most users' complete tasks successfully without help
Efficiency	Evaluating system performance such as loading times and responsiveness.	Measure loading time	App loads under 10s
Reliability	Ability to repeat an experience within the virtual environment.	Run the application multiple times	9/10 successful runs without errors
Accuracy	Evaluation of how similar it is to the intended experience.	User Survey	Most users agree that it the application is accurate.
Stability	The ability to remain operational and responsive, through different events.	Measure FPS between different actions	Frame rate to maintain with 15% of idle FPS

Interactivity	Efficacy of user interaction with the virtual environment.	User Survey	Most Users agree that it is interactive.
Robustness	Ability to remain operational through different types of errors during runtime.	Send unexpected inputs.	9/10 it doesn't crash

5.2 Experimental Protocol

To ensure that all participants are exposed to the same core features and their feedback can be compared consistently, each test participant will follow a standardized testing protocol.

Participants will interact with the following elements:

- The 'T' key – to move around the virtual space

- The mouse – the control the camera view and explore the environment

- The play button – To begin the concert performance

Ater interacting with the virtual application, participants will be asked to complete a short survey about their experience to provide insightful information on the functionality of the application features.

Each participant will complete one or more of the test cases below, depending on which aspects are being evaluated.

Test 1: Overall User Experience Evaluation

- Number of Participants: 4
- Background: Average university students
- Experience Level: Mixed
- Features Tested: Usability, Usefulness, Interactivity, Collaborative perception
- Test Method:
    - The users enter the virtual concert and are allowed to freely explore and experience the concert
    - They attend a performance and are told to imagine it as a public event
    - After the session, users complete a survey and answer:
        - How immersive or realistic did it feel (scale of 1-10)?
        - Did it feel like a shared or social environment?
        - Would you use this app instead of attending a real concert?
    - We recorded ease of navigation, interaction attempts, and moments of confusion
- Observations:
    - 3 out of 4 users explored the venue without asking for help
    - All participants were able to begin the concert.
    - 2 users rated the immersion as 6/10 or above
    - One user commented on a lack of social interactive elements
- Conclusion:
    - All users found the experience enjoyable
    - Feedback suggests the experience would feel more social with a more interactive crowd.
    - The design supports usability and interaction, but collaborative features are underdeveloped

Test 2: Performance and Functionality Test

- Number of Participants: 4
- Background: Technically proficient students
- Experience Level: Mixed
- Features Tested: Efficiency, Stability, Reliability, Robustness
- Test Method:
    - Users are asked to start up the application and the time taken to load is recorded.
    - Users are then asked to move to different locations and look around the venue while we observe for lag.
    - The framerate is recorded.
    - Light errors such as pressing random keys and rapid teleportation are executed
- Observations:
    - Average total loading time: 12.3s.
        - Average startup time:4.2s

- Average loading time for venue: 5.29s
- Average loading time for Artist: 6.0s
- Average start time for artist animation: 6.38s
- Average loading time for stage: 12.30s
  – On startup, the application lags when attempting to look around using the camera
  – No lag is noticed when key smashing and during rapid teleportation
  – No crashes during extended usage
- Conclusion:
  – The application is stable and performs efficiently across typical and edge case situations
  – The performance was mostly consistent with slight lag when looking around
  – The robustness of the application was confirmed as no test actions caused it to crash or behave unpredictably

Test 3: Navigation and Interaction trial.

- Number of Participants: 4
- Background: New VR user
- Experience Level: Beginner or no experience with VR
- Features Tested: Usability, Accuracy, Interactivity
- Test Method:
  – Users enter the virtual concert with no instructions
  – Users are prompted to explore the space and begin the concert all on their own
  – Users are observed for the difficulty level in figuring out and interacting with the elements
- Observations:
  – Two users found the camera controls unintuitive at first but claimed to get used to it
  – Three users commented on the lack of control on the teleportation location
- Conclusion:
  – Most users successfully navigated and interacted with the space after a brief adjustment period
  – The teleportation system requires clearer target locations
  – Overall, the application was approachable for first time users

6 Risks and Contingencies

This part of the document describes contingency plans, if the project experiences problems.

- Loading assets (or time) – Risk level moderate to high. Should a problem occur, code should be reviewed and number of assets used should be adjusted. Could have a large effect on user experience.
- Spatial Audio – Risk level low. Should a problem occur, push mono audio untill the problem can be fixed. Could impact user experience.

- NPCs movement – Risk level moderate to high. Should a problem occur, user experience could be affected. Fixing the issue could consume a large amount of time.

7 Conclusion

The application met most of its intended goals. Users found the experience immersive, functional, and mostly easy to navigate. There were minor usability issues such as teleportation targeting and camera handling which were identified but did not significantly affect the user engagement.

Key areas for improvement in the application include clearer teleportation logic and an increased social presence in the crowd reactions and interactions.

9 Citations

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10 Appendix

Survey Questions
Test 1: Overall User Experience Evaluation
- Please rate the following statements (1-10):

- I was able to explore the concert space without difficulty.
- I found it easy to start the concert performance.
- The controls (movement, camera, etc.) were intuitive.
- The experience felt immersive and engaging.
- I felt like I was part of a larger event (e.g., like being at a real concert).
- I would consider using this app again for a virtual concert.
- I was able to interact with the environment in a fun or meaningful way.
  - Do you have any comments to add about our system?

Test 2:Performance and Functionality Test
  - Please rate the following statements (1-10):
    - The app loaded quickly and without issues.
    - I experienced smooth performance while moving around the space.
    - There was little or no lag when interacting or changing views.
    - The system felt stable throughout the session.
    - I did not encounter any crashes or unexpected behaviour.
    - The application responded well to all my inputs, even unusual ones.
    - I would trust this system to run consistently in a longer session.
  - Do you have any comments to add about our system?

Test 3:Navigation and Interaction Trial
  - Please rate the following statements (1-10):
    - I could navigate the environment without help.
    - I was able to start the concert performance on my own.
    - The movement controls were easy to understand.
    - The camera control felt natural and responsive.
    - I understood how to use the interaction features (e.g., clapping).
    - I found the teleportation system clear and useful.
    - I felt confident using the application without guidance.
  - Do you have any comments to add about our system?

What test have you taken?	I was able to explore the concert space without difficulty	I found it easy to start the concert performance	The controls (movement, camera, etc.) were intuitive	The experience felt immersive and engaging	I felt like I was part of a larger event (e.g., like being at a real concert)	I would consider using this app again for a virtual concert	I was able to interact with the environment in a fun or meaningful way	Do you have any comments to add about our system?
What test have you taken?: Test 1: Overall User Experience Evaluation								
Test 1: Overall User Experience Evaluation	7	8	6	4	3	7	5	n/a
Test 1: Overall User Experience Evaluation	6	6	5	3	3	7	5	the camera movement tripped me out at first. needs more npc
Test 1: Overall User Experience Evaluation	5	8	7	4	2	7	4	
Test 1: Overall User Experience Evaluation	8	9	7	6	4	5	4	
Test 1: Overall User Experience Evaluation	8	8	7	7	3	6	4	

What test have you taken?	The app loaded quickly and without issues	I experienced smooth performance while moving around the space	There was little or no lag when interacting or changing views.	The system felt stable throughout the session.	I did not encounter any crashes or unexpected behaviour	The application responded well to all my inputs, even unusual ones.	I would trust this system to run consistently in a longer session.	Do you have any comments to add about our system?
What test have you taken?: Test 2: Performance and Functionality Test								
Test 2: Performance and Functionality Test	6	9	4	7	9	9	9	n/a
Test 2: Performance and Functionality Test	5	7	4	8	8	7	8	
Test 2: Performance and Functionality Test	5	6	4	8	8	8	8	
Test 2: Performance and Functionality Test	7	4	4	8	9	9	7	

What test have you taken?	I could navigate the environment without help	I was able to start the concert performance on my own	The movement controls were easy to understand	The camera control felt natural and responsive	I understood how to use the interactive features	I found the teleportation system clear and useful	I felt confident using the application without guidance.	Do you have any comments to add about our system?
What test have you taken?: Test 3: Navigation and Interaction Trial								
Test 3: Navigation and Interaction Trial	3	8	6	3	8	5	6	
Test 3: Navigation and Interaction Trial	3	9	3	3	7	8	6	
Test 3: Navigation and Interaction Trial	6	8	8	7	7	7	9	
Test 3: Navigation and Interaction Trial	4	8	2	2	3	3	4	