SONIC SCULPTURAL STAIRCASE

AN INVESTIGATION OF HIGHLY IMMERSIVE AND WORLD AWARE AUGMENTED REALITY IN AUGMENTED SCULPTURAL STAIRCASE EXPERIENCE

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Except where otherwise indicated, this thesis is my own original work.

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ABSTRACT

Modern head-mounted augmented reality technology has now advanced to the level that it can be said to enable a Highly Immersive and World Aware Augmented Reality (HIWAAR) experience. Critical to providing such an experience is the ability of some modern systems, like the Microsoft HoloLens (HLs), to capture video information of the surrounding physical environment in real time and to build models of that environment which enable a user to be "world aware" in the augmented world. At the same time, such systems can provide graphical images and audio that surround and augment the user experience in a highly immersive manner. Works that utilise such HIWAAR technology for the creation of augmented art experience have been claimed to be effective in activating users' engagement and enhancing art appreciation. However, few works have specifically considered how augmented art experiences should be designed and fewer have provided rigorous evaluations of the effectiveness of such experiences.

This thesis presents the Sonic Sculptural Staircase (SSS), a HIWAAR installation that explores the use of visual overlays, sound and interaction using Microsoft HoloLens Gen 2nd (HL-2) in providing an augmented sculptural staircase appreciation experience.

The thesis commences using interviews with art professionals seeking for design inspirations for the HIWAAR augmented sculpture (or sculptural elements) experience. Drawing on results from these interviews, the SSS was designed and developed. Two different experience conditions, the *informational* experience and the *experiential* experience, are introduced to reflect on the use of visual overlays, sound and interaction in providing an augmented sculptural staircase appreciation experience. User evaluations are then described to quantitatively and qualitatively evaluate the functionality and effectiveness of SSS in providing such rewarding experience. Results from user evaluation show that the SSS presented a pleasant augmented sculptural staircase appreciation experience along with enhanced awareness of the physical piece, on both experience conditions over time. However, whether there is a distinctness between the *informational* and the *experiential* experience with aspects of visual overlays, sound and interaction in such rewarding experience requires further investigation. Furthermore, preliminary evidence from follow-up studies appear to show that the experiential experience has a more lasting impact than the informational experience on the way that participants view the sculptural staircase in their daily lives.

Overall, this work has illustrated a novel use of HIWAAR system with aspects of visual overlays, sound and interaction in realising highly immersive and rewarding augmented sculptural staircase appreciation experience. Positive results revealed from user evaluations preliminarily support the effectiveness of utilising such technology for the design of other augmented art experiences for relevant communities.

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ACRONYMS

3D three dimension. 18, 19

ANU The Australian National University. 18, 25, 26

AR Augmented Reality. 1, 5

CH Cultural Heritage. 11

HIWAAR Highly Immersive and World Aware Augmented Reality. ix, 1, 5, 9, 17, 18, 23, 26, 49, 67

HL-1 Microsoft HoloLens Gen 1st. 1, 2, 9, 11

HL-2 Microsoft HoloLens Gen 2nd. ix, 2–5, 9, 25, 28, 32

HLs Microsoft HoloLens. ix, 6, 9, 25, 45

HMDs head-mounted displays. 1, 6

HN building Hanna Neumann building. 3, 25, 26

MX Mixed Reality. 8

SLAM Simultaneous Localisation and Mapping. 9

SSS Sonic Sculptural Staircase. ix, 1–5, 11, 17, 19, 23, 25, 33, 45, 47, 50, 53, 55, 63–65, 67, 70

1 INTRODUCTION

With recent innovations in wearable computing devices and head-mounted displays, modern head-mounted augmented reality technology has evolved sufficiently to be able to deliver a Highly Immersive and World Aware Augmented Reality (HIWAAR) experience. Applications of such technology have revealed various benefits, ranging from education, entertainment, tourism, and many others industries. In particular, works that rest on the creation of HIWAAR experiences to complement artwork or cultural sites have presented a novel way to enhance users' art engagement and exploration.

This thesis describes the design and development of the Sonic Sculptural Staircase (SSS), an installation that delivers interactive experiences to enhance the appreciation of a sculptural staircase and its surroundings using a HIWAAR system. Specifically, this work explores different ways to integrate visual overlays, sound and/or interaction in providing augmented art experiences on top of real world feature. The goal of this project was to study the potential and effectiveness of such HIWAAR system in the creation of such experience for enhancing people's appreciation of artworks.

1.1 AUGMENTED REALITY, ART ENGAGEMENT AND EXPLORATION

Augmented Reality (AR) has been widely used to deliver an augmented art experience in cultural computing and other artistic communities. Originally identified as a technique that combines real and virtual content in a real environment, AR has been beneficial in providing visual or audio augmentation such as visual overlays or information to support an art or art-appreciation experience [18]. Applications in this area range from education tools that enhance users' historical or culture heritage learning [3], museum or heritage tour guidance that enhance users' visiting experience [9, 41, 18], or creative artworks that seek new art expressions for interpreting and reflecting the physical world [1].

With the recent advancement of head-mounted displays (HMDs) and mobile devices in AR technology, augmented art experiences can be realised in the Highly Immersive and World Aware Augmented Reality (HIWAAR) system, that integrates portable see-through HMDs and heavily spatial-aware algorithm for real-time virtual-real content mapping and interaction. That being said, the HIWAAR system can enable an highly immersive, engaging and personalised user experience in understanding art content. As an example, the "Listening to Listening" installation [22], augmented a sculpture with sonic information and visual overlays using the Microsoft HoloLens Gen 1st (HL-1). By embedding sound sources in AR holograms (that model the physical environment), one can directly access the augmented virtual information as well as appreciate and engage with the physical sculpture in their own way. Such installation can prompt user's active engagement, and can encourage a more playful and novel experience in sculpture appreciation. Other applications in HIWAAR such as Strickland's project explored eye gaze and voice input by

Microsoft HoloLens Gen 1st (HL-1) as a way of control to obtain information of a portrait and art experience [41].

Recent progress in the so-called "instinctual interaction" offered by Microsoft HoloLens Gen 2nd (HL-2) has deepened the flexibility of interaction in HIWAAR system, allowing the touch, grasp, and movement of virtual objects as well as interactive aural sensations and feedback [24]. Such new HIWAAR system affordances present new possibilities for users to access related information and to experience interacting with artworks on top of visuals and sound. Motivated by the above, this project further investigated the potential of using HIWAAR system in the creation of augmented art experiences. In particular, the project investigates the integration of "instinctual interaction", visuals and sound together in creating an augmented sculpture experience, which was inspired by the work "Listening to Listening".

1.2 RESEARCH QUESTION

The general research questions in this project are:

RQ1 : Can an interactive HIWAAR installation enhance the understanding of a sculpture element or architectural space?

RQ2 : How can HIWAAR contribute to the creation of such an experience by integrating interaction, visual overlays and sound?

RQ3 : Can HIWAAR installations change a person's daily experience which relates to the environment?

1.3 RESEARCH METHODOLOGY

The research questions in this project are addressed through the design and development of HIWAAR installations with the aim of augmenting a physical sculpture (or sculptural) element, as well as user evaluation in response to the effectiveness of the experience developed. Our work follows the typical research methodology in HCI research field that consists of three distinct phases of designing a desired system: collecting system requirements, designing and developing the system as well as user evaluation [40]. It can be seen from this process that there are two user studies involved: one before the implementation of the system, and one after to evaluate the implemented system. The whole system design and development process are normally conducted in several iterations to refine the work. Given the time limit of this project, our work only completed one major iteration.

In our work, a Grounded Theory approach [6] was adopted with art professionals as the first user study to collect background information and design requirements for the later construction of our work. This phase also attempted to address RQ1 in research questions. The results from this user study were then used to shape the design, development and user evaluation of the Sonic Sculptural Staircase in this project.

Overall, the study was composed of three distinct stages:

Interview with Art Professionals

The main aim of this interview study was to survey artists to answer research question RQ1. We were particular interested in the background knowledge of sculpture and sculpture experience, as well as the potentials of HIWAAR in augmenting sculpture experience. Semi-structured interviews were conducted with four art professionals (experts in sculpture) under COVID-safe conditions. The interview data were further processed using thematic analysis to identify important patterns in response to research question RQ1. Notably, the interview results presented two distinct directions for the design of augmented HIWAAR sculpture experience. The details and outcome of this study will be mainly discussed in Chapter 3.

Design and Development

Based on findings from interviews with art professionals, we ideated the design of HIWAAR sculpture experiences for this project. We selected an interesting sculptural staircase situated in the Hanna Neumann building (HN building) at ANU and developed Sonic Sculptural Staircase (SSS). SSS is designed as interactive HIWAAR experiences incorporating real and digital information with the aim of enhancing users' appreciation of the sculptural staircase and its surroundings. In particular, it includes two experience conditions: "informational" and "experiential" between levels 2 and 3 of the HN building using the Microsoft HoloLens Gen 2nd (HL-2). During these experiences, there are different interactive features with sound and visual overlays that allow the user to explore and obtain related information. Design details of this work with aspects of visual, sound and interaction are described in Chapter 4 Section 4.1.

The implementation of SSS was realised in Unity [42] with the 3D staircase model crafted in Cinema4D [43]. Additional engines and other HIWAAR toolkits were used to support its development. These will be further described in in Chapter 4 Section 4.2.

User Study

We recruited 10 participants to evaluate two HIWAAR experiences. Five participants were asked to evaluate the "informational" experience, the other five were allocated to "experiential" experience. The user study included post-study evaluation (including post-study questionnaire and immediate-after interviews), and follow-up studies. The follow-up studies were conducted one week and four weeks after the experience evaluation. Both quantitative and qualitative data were further processed and produced useful insights to address research questions RQ1-RQ3. Details of the user study are described in Chapter 5 and the results of this study and discussion are presented in Chapter 6.

1.4 ETHICS AND SAFETY CONCERN

Throughout this project, there are several major risks or concerns identified:

- In person interview study during the COVID-19 pandemic
- Participants' safety concerns when using the real world staircase while wearing a HIWAAR equipment
- Hygiene-related issues while wearing the Microsoft HoloLens as well as together with the real world staircase

All the possible hazards have been considered, assessed and approved by ANU Work Health and Safety (WHS) group in addition to regular ethics approval by ANU Ethics and Research Committee. The researcher needed to complete ANU WHS management training to ensure any potential risks were considered properly to the formal study. Related documents of WHS and ethics approval can be found at Appendix 7.2.

1.5 THESIS OUTLINE

Chapter 2 provides a general background of AR and describes the specific technology HIWAAR used in this project. It additionally discusses how the dimension of "immersivity" contributes to such immersive AR experiences and related works that investigate AR for the creation of art experiences.

Chapter 3 discusses the interviews details with art professionals, seeking artistic input for the SSS installation. Drawing on the interview results, high-level design requirements were defined which contribute to the later design and development of our work.

Chapter 4 provides details regrading the design and implementation of SSS. In particular, the design uses visual overlays, sound and interaction augmentations of the real world to a sculptural staircase located at HN Building at ANU. The system architecture of the work SSS is described, with details on how the design was technically achieved in HIWAAR system with HL-2.

Chapter 5 describes the user study to evaluate the two experiences in SSS. It discusses details of its approach, process, and feasibility as well as data collection set-up.

Chapter 6 discusses the quantitative and qualitative results obtained from the user study. It will explain in depth how each type of data was processed and what kinds of metrics were selected to illustrate our findings. It then discusses patterns and significant results that were found from the data analysis.

Chapter 7 provides a conclusion to our research questions through the exploration of SSS in this project. It also discusses opportunities for future work based on this thesis.

2 BACKGROUND AND RELATED WORK

This chapter presents the background and related work of Augmented Reality (AR) technology used for the development of Sonic Sculptural Staircase (SSS) in this project.

Section 2.1 provides a general overview of AR and specific discussions on how dimensions of *immersivity*, including *world awareness* and *information awareness* in AR, contribute to a rewarding augmented user experience. In Subsection 2.1.1, a specific discussion of the equipment Microsoft HoloLens Gen 2nd (HL-2) used in this project is presented, which is considered as Highly Immersive and World Aware Augmented Reality (HIWAAR) system.

Section 2.2 presents the current state of art and notable HIWAAR applications related to our work. It mainly discusses works that use HIWAAR system in providing immersive sculpture or art appreciation experience.

In addition, Section 2.3 discusses some works related to the augmentation of sculpture or art appreciation experience in a broader digital (non-AR) technology context.

2.1 AUGMENTED REALITY

Augmented Reality (AR) involves combining "virtual" elements (computer graphics and audio) with physical worlds, although current definitions vary in the consideration of its implementation technologies and aspects of reality [39]. The traditional definition of AR rests on the Reality-Virtuality Continuum as proposed by Milgram et. al. [32]. As illustrated in the Figure 2.1, it can be seen that AR is positioned between the extremes of real and virtual environments, while being a closer distance to the real. This means that AR should be a primarily "real environment" augmented with some virtual parts, rather than offering primarily virtual environment(VR). An example demonstrating the difference between AR and VR is : a typical VR device is the VR headset which has been popular for game applications, providing a whole immersive virtual game experiences for users (Figure 2.3). In contrast, a typical AR device is the game Pokémon Go on the smartphone, which has the virtual Pokémon presented on top of the live camera feed as if they were in the real environment (Figure 2.2). In this example, AR is considered as adding virtual things on top of real world, instead of providing a fully virtual world.

Modern AR systems vary based on their implementation technologies and aspects of reality [39, 5]. According to Coppens's analysis of the state of art of AR technology, AR systems can be mainly categorised as monitor-based AR, see-through AR, spatial AR, etc, based on the nature of displays used [11]:

(i) The monitor-based AR is recognised as the simplest type of AR where users view augmentations on top of camera feeds on a "distant" screen. A typical example of such system would be a TV broadcasts of sports matches with computer graphics rendered over the field of play (Figure 2.4). Another example is the the Pokémon Go game on the smartphone, which we have discussed above. Monitor-based AR systems are also formally refereed to

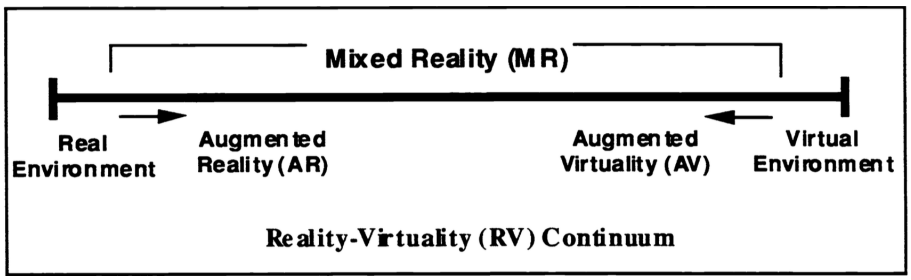

Figure 2.1: Reality-Virtually Continuum

Figure 2.2: The Pokémon Go game on the smartphone in which the virtual Pokémon is presented in the camera feed as if it was there in the reality

Figure 2.3: A user is playing VR boxing game using a VR headset. The TV display shows the VR environment the user actually sees.
Image Source

as a "Window-on-the-World" by Milgram et. al. [33], and are mostly used for TV lives or video games. In these systems, the monitor display is treated as the window to the augmented world. The user is able to see additional virtual content on top of the reality broadcast on the screen. Given such, the "immersivity" of Monitor-based AR systems vary based on the size of screens and whether or not the camera feed is of the immediate environment.

(ii) The see-through AR refers to a system that presents users with an augmented environment by letting them directly see through from their own perspective. This means that the user is able to have a highly immersive AR experience as the field of view is fully surrounded, as opposed to the monitor-based which see virtual augmented elements from a distance. This kind of AR systems is normally realised with head-mounted displays (HMDs) devices. Such AR experience is realised by projecting virtual elements on a transparent surface on top of the physical world in front of the user. Furthermore, such HMDs AR systems can be furthered categorised based on where such transparent surface is located in relation to the user: spatial see-through, or optical see-through. An example of the later one is Microsoft HoloLens (HLs), which will be discussed in detail in the following Subsection 2.1.1.

(iii) Spatial AR, which is also referred to as project or protective AR,

Figure 2.4: Virtual visual arrows indicating soccer players running direction in a match on TV displays

presents an augmented environment by directly projecting images onto real objects. Such AR systems are often used by projecting images onto surfaces (i.e. Light show installed/projected on certain real-world features such as *Vivid Sydney Festival* [1]).

As an alternative taxonomy of augmented reality systems, Bimber and Raskar's Eye-to-World spectrum additionally provided a systematic summary based on the user's relationship to the AR display. As illustrated in Figure 2.5 in their taxonomy, AR systems can be mainly categorised into three different types: head-attended, hand-held and spatial see-through display. Both Coppen's review and the spectrum posed useful perspectives of describing the experience presented by AR, that is the "immersivity" that a user can perceive by AR devices, and the "world awareness" which the AR device can detect in response to how virtual content can be presented and interacted in an augmented world.

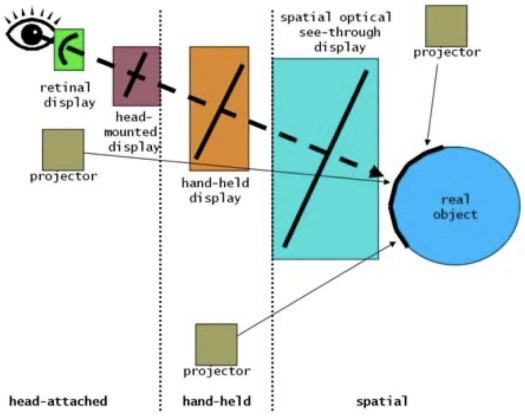

Figure 2.5: Eye-to-World Spectrum

1 https://www.vividsydney.com/

Immersivity and World Awareness

In the Mixed Reality (MX) context, the term "immersivity" was originally discussed in VR devices, and refers to the degree of situational awareness and effectiveness that information can be presented in performing certain tasks in a virtual environment[13] . Later the term has also been applied to describe certain aspects of AR systems, given that AR is considered as a complementary to immersive VR with a focus on enhancing the experience of "reality" [5]. Given such, "immersivity" can be understood as how much a user is enveloped by the augmented world that they see and interact. Based on AR system examples discussed above we can see that the TV broadcast and Pokémon game on the smartphone examples are not very immersive as the user only sees an augmented world from a distanced display window, and rare interactions can be performed with the virtual information. On the other hand, an HMD is highly immersive given the AR view fully surrounds the user, and the user is able to flexibly interact with virtual content while seeing through the augmented world either using physical controllers or free hand gestures that can be understood by HMDs [5].

The differences of such AR systems in realising "immersivity" can be further categorised as two aspects: *world awareness* and *information* awareness. Both aspects have contributions to the creation of an immersive AR experience. *World awareness* refers to how an AR system can understand and anchor virtual content in the physical environment. One of the key aspects in achieving is *tracking*, which has been one of crucial fields in AR research. As show in the AR survey of [5], different tracking techniques can result in different AR experiences. For example, GPS tracking is widely used in AR game applications such as Pokémon Go, although certain limitations haven been reported due to the low accuracy of location detection as well as sole two dimensional positional tracking, which largely restrict the AR experience [5]. What's more, existing literature has shown that computer vision techniques are the most common used approach in realising real-time AR experiences, yet the robustness and accuracy of such systems remain questionable [5].

Information awareness refers to how additional virtual elements can be presented and manipulated in the augmented world. This aspect is related to the choice of AR interfaces and is highly related to design goals for certain applications. Different interaction schemes can enable different ways for engaging with the virtual content, and thus have different impact on the AR experiences that can be obtained.

Organising all the examples discussed based on these dimensions, in Table 2.1, it can be seen that different AR systems have different levels of immersivity based on AR displays and implementation technologies.

In summary, modern AR systems vary based on different technologies being used, and the choice of AR systems can entail different degrees of AR experiences one can obtain. Analysis of existing literature has revealed the dimension "immersivity", including "world awareness" and "information awareness" have an implication on various modern AR systems created, as well as restrictions revealed in applications development. In particular, HMDs are effective in providing a highly immersive experience with flexible free hand gestures in interaction in comparison to other works. Yet further work is required to critically examine all such dimensions in AR systems.

Examples	Immersivity		AR Immersivity Level
	World Awareness	Information Awareness	
TV sports broadcasts	Low	Low	Low
Pokémon Go game on smartphone	Medium	Medium	Medium
Lighting Show	Low	Medium	Medium
HMDs AR device (i.e Microsoft HoloLens)	High	High	High
Immersive VR games in Oculus headsets	Not applicable	High	Not applicable

Table 2.1: Analysis of Various AR Systems in Relation to Immersivity: World Awareness refers to the extent that the information is presented in the system; Information Awareness refers to the extent that the system can understand the reality i.e 2D or 3D

2.1.1 *Highly Immersive and World Aware Augmented Reality: Microsoft HoloLens*

HLs is a family of mixed reality headsets (Microsoft HoloLens Gen 1st (HL-1) and Microsoft HoloLens Gen 2nd (HL-2)) powered by 3D holograms to realise a mixed reality experience. It is mainly composed of a pair of see-through AR lenses and cameras designed and developed by Microsoft. The HLs are advertised as "the world's first head-attached holographic computer" and enables a heavily spatial-aware experience. The development of AR experiences in HLs can not only be able to access video and audio streams, but also obtain real-time motion of the device (i.e location) as well as perform a 3D environment detection.

In particular, Simultaneous Localisation and Mapping (SLAM) and spatial-mapping algorithms are used to maintain an accurate physical **world awareness** while the HL is running in real-time [36]. That being said, the HL can achieve a HIWAAR experience with the use of the see-through HMDs and on-board computer to analyse the world in real time (although the quality of the HIWAAR experience can deteriorate due to lighting [25]).

Hardware

The HL-2 [24] devices used in this thesis are equipped with an advanced HPU (holographic processing unit), Qualcomm Snapdragon 850 ComputePlatform, 4-GB LPDDR4x system DRAM and 64GM total memory. In addition, the HoloLens uses four head-tracking cameras with an IMU (Inertial Measurement Unit) to achieve 6 DoF (Six Degrees of Freedom) real-world environment scanning and understanding. What's more, the HPU is exclusively manufactured to process sensor data and camera feeds to handle 3D virtual holograms and physical world to enable HIWAAR experience.

HIWAAR - "Mixed reality" experience

Although existing resources have described HLs as a *mixed reality* device, the above discussion has shown that HL should still be recognised as an AR experience with great potentials of it in use. Potential ideas range from AEC (architecture, engineering and construction) industry that use holograms as 3D models for on-site real-world facilities design and construction [11], to artistic applications that provide enhanced audio or visual experiences to the physical world. In particular, the latest HL-2 headset has realised the so-called "instinctual interation" which has enabled more flexible interaction options

Figure 2.6: Microsoft HoloLens (gen 2nd)

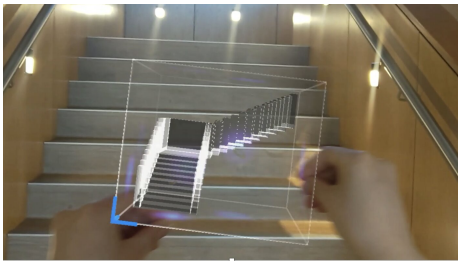

Figure 2.7: Interacting with Virtual Staircase Model using HL2
Video Demo

[24], in addition to basic interaction such as voice, eye gaze or simple hand air-tap from HL-1 [26]. Such functional capabilities allow a convenient and hands-free AR experience that increases both the productivity as well as how information can be manipulated for performing certain tasks. For example, as illustrated in Figure 2.7, the user is not only able interact with a virtual staircase hologram like one would manipulate with a real 3D micro staircase model, but also makes a straightforward measurement of the staircase while being immersed in the real world.

In this project, we aimed to specifically explore the use of such a HIWAAR system in providing immersive AR experiences for art-related applications, which will be discussed in the following sections.

2.2 IMMERSIVE AUGMENTED REALITY ART EXPERIENCE AND ENGAGEMENT

Nowadays, more and more AR applications have been applied to the art-related fields. A number of surveys [3, 5, 17, 21, 16] have reported different AR applications ranging from tourism platforms to enrich tourist experience for cultural sites, novel interfaces for museums content, to alternate representation or augmentation of artworks and paintings to expand viewer's experience. As addressed by Kljun et. al., AR's advantage of blending digital and real information allows users to explore and engage with the augmented content as an active participant, and thus obtain a personalised art appreciation experience [18]. Yet few works specifically focus on the AR applications that enhance art experience exploration and engagement.

In particular, Bekele et. al.'s survey [3] of immersive technologies for Cultural Heritage (CH) applications presented a detailed classification of applications in use: i) education exhibition, ii) enhancement, iii) exploration, iv) reconstruction, and v) virtual museums. Notably, the survey showed a large proportion of *exhibition* and *reconstruction* applications for CH using immersive technologies (with 33% and 31% respectively), but with only 9% for applications related to *exploration*. According to Bekele et. al., *exploration* refers to applications designed to let users discover, interpret, and acquire new insight and knowledge from the content presented in an immersive technology system. In other words, this type of application aims to let users actively engage with the content and obtain an enhanced art appreciation experience. As further explained in the survey, reasons for such rare *exploration* applications are mainly due to the high requirements of mixed reality technologies. Not only do *exploration* applications require an integration of complementary displays and accurate hybrid tracking to perform accurate spatial-mapping for realising additional virtual features, but flexible interaction and immersive environments are also desired to achieve an engaging user experience while viewing and exploring CHs. That being said, a suitable HMD device with interaction relying on interface-related tracking would be ideal for the development of such applications [3]. However, challenges such as locating a suitable hardware, a design of platform that can be effective in CH exploration as well as maintaining a virtual and real-world mapping during the enhanced CH experience can not be easily resolved, although MX and AR are considered as the best choices for achieving this. Furthermore, weighing on above challenges, CH-related AR applications are usually only simply classified as indoor or outdoor systems, with mobile devices or tangible interaction interfaces reported as the most commonly used platforms [3].

There are only a few works that attempt to use HMDs (or HIWAAR) with the integration of other advanced techniques to provide an augmented art appreciation experience, and thus a thorough review of related field is yet to be presented in existing literature. Drawing on this context, in Subsection 2.2.1, we mainly discuss several noted works that incorporate the idea of HIWAAR system to provide an immersive art appreciation or exploration experience. These works either provide specific technical background, or aesthetic insights for the design of the Sonic Sculptural Staircase in this thesis.

2.2.1 *Visual and Sonic Experience in Highly Immersive and World Aware Augmented Reality*

Visual overlays, and sound, along with interactions in the HIWAAR system have been exploited to accompany visitors for sculpture appreciation or museum experiences with various benefits in enhancing the overall visiting experience as well as improvements. Here, we discuss two notable works: *Listening To Listening* and *Envisioning the Museum Voice* which use the HL-1 to deliver an augmented visiting experience.

Listening To Listening In this work, Martin et al. designed additional sonic layers which incorporates a real-world sculpture to enhance user's awareness as well as engagement in understanding the original physical piece using HL-1

(Figure 2.10) [22]. The work specifically used audio field recordings which are related to the physical sculpture's aesthetic context in the environment, along with simple interfaces as the control to let the user be actively engaged with the physical sculpture. In particular, two interaction schemes: UI Mixer and Locative Audio Sources were designed to explore ways that the user is able to engage with the sculpture in HIWAAR system. As illustrated in Figure 2.8, the UI Mixer was achieved by providing an additional virtual control panel in front of the sculpture. The user is able to mix three layers of sound and listen to the mixed sound layers for obtaining a different sculpture appreciation experience. As for Locative Audio Sources, it can be seen from the Figure 2.9 that three types of sound are embedded around the physical sculpture with visual hints. The design of this interaction scheme requires the user to actively walk around the sculpture to obtain an augmented listening experience. Notably, interaction schemes in this work were novelly realised using the physical sculpture's 3D model which as an integrated invisible hologram to reference the relationship between the user and the physical sculpture. In this way, the HL-1 headset can perform real-time SLAM between the user's location, interactive features in the HIWAAR system and the physical sculpture.

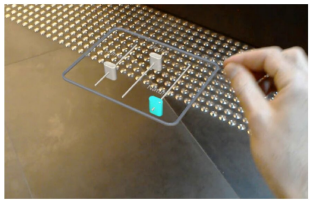

Figure 2.8: Interaction scheme A: UI Mixer

Figure 2.9: Interaction Scheme B: Locative Audio

Figure 2.10: Two Users Exploring "Listening To Listening"

The pilot user study of the "Listening to Listening", reported in [22], indicated that such augmented sculpture HIWAAR experience has enabled a personalised experience for visitors in exploring sculpture, particularly with the location-interaction scheme that is able to prompt a more active engagement. However, no formal studies were conducted to analyse what and how the use of visual overlays, sound, and gesture interactions contributed to such rewarding sculpture appreciation experience. In other words, the question

of whether the use of additional virtual elements and the invisible hologram contribute to a better immersive experience remains unclear. Also, a critical evaluation of its novel method that uses 3D sculpture hologram as the reference mapping HIWAAR and real environment is required. Furthermore, as addressed by Martin et. al. [22], limitations such as restrictive field of view, hand gestures, and flexibility in sound programming in HL-1 have also stopped the work from the ease of use (UI Mixer), as well as a better user experience that allows user to be more actively engage with the physical sculpture. That being said, all remained limitations require further investigation.

Museum Experience through Gaze Interaction in HIWAAR Strickland's work *Envisioning the Museum Voice* developed a prototype application on HL-1 to explore both eye gaze and voice input as the control in providing a narrated-based audio augmentation guide for an art portrait *The Arnolfini Portrait* (Figure 2.11) [41]. Motivated by the traditional museum audio guide, Strickland's work aimed at providing a more integrated interaction scheme for the museum audio guide using HL-1. In his work, the audio introduction of narrated-painting is split into three modes with a general rationale introduction as the beginning, and come with hidden hotspots containing specific painting's information which require user to through eye-gaze input (Figure 2.12). The additional visual information panel is given next to the painting in the HIWAAR environment allowing the user to choose between modes.

Figure 2.11: User Confirming Eye Gaze Selection through HL1

Figure 2.12: Three Modes of Painting Introduction in HL1

Although the prototype's user evaluation has indicated the use of eye gaze and voice input as interactions is more engaging and informative for a painting visiting experience, practical issues including the design of eye cursor for prompting eye-gaze interaction were raised. Furthermore, the issue of around tracking in HL-1 was also revealed, indicating that the prototype struggled in locating the physical painting. Last but not least, rare implementation details

were presented by Strickland in how the prototype was realised in HIWAAR experience, as well as critical evaluation and discussion regarding the use of HL-1 in implementing such augmented experience among other digital devices.

2.3 SCULPTURE EXPERIENCE IN DIGITAL (NON-AR) TECHNOLOGIES

Although only a few applications are explicitly related to sculpture experience, there are still many works that have utilised the sculpture concept for various design purposes. Some of the insights are useful for this project from both design and technical aspects. We provide a brief discussion of noted works.

Figure 2.13: Two Users Exploring "See Me, Feel Me, Touch Me, Hear Me"

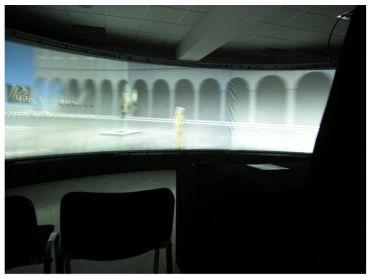

Figure 2.14: VMS Panoramic Powerwall

"See Me, Feel Me, Touch Me, Hear Me" In this work, Fosh et al.[14] applied the HCI concept of trajectories [4] to design an augmented sculpture trail in a sculpture garden. They created a system mainly using textual and audio instructions to direct the user to view, touch and engage with the sculpture in a mobile device such as smartphones. The motivation of the work came from observations on visitors' poor engagement in a sculpture garden, such as rare touch with the physical sculpture. Visitors also tend to spend a very short time appreciating each physical piece. A user study of the work looked at the use of the accompanying music with instructions providing a multi-sensory sculpture visiting experience, including to prompt different viewpoints, touch the physical sculpture and listen to the music at the same time. Such a design of the system was shown to be effective to simulate users' imaginations while trying to understand sculptural works. Furthermore, the user study also implied improvements for the design of trajectory, which appears to be helpful for the design of augmented sculpture experience in general. In particular, the topic *considering access to physical resources* and *considering seams during the trajectory experience* were presented, emphasising the importance of considering how visitors can view and interact with the sculpture with different physical actions, as well as a more seamless transition of triggering interactions to maximise their visiting experience. However, as addressed by Fosh et. al., the user study only evaluated users' experience while visiting individual sculpture. Neither did they evaluate the whole experience of the sculptural trail, nor did the follow-up study to investigate whether the work

had effective impact towards users sculpture appreciation experiences over time, which the later one has been crucial in an art appreciation experience [15, 19].

The Virtual Museum of Sculpture Carrozzino et al.[9] crafted an entirely virtual reality sculpture museum - the Virtual Museum of Sculpture (VMS) of Pietrasanta, which provides visitors with a different sculpture visiting experience. The sculptures in VMS were selected from the project's partner museums database. Essentially, the VMS was hosted at a panoramic power as a new means for sculpture works learning and appreciation. Their works reported on the insights obtained regarding the use of such novel mixed reality technologies for museum experience applications during their development. They specifically reflected that the potential of combing virtual and real-world setting as novel metaphors can be useful for the design of applications for real/virtual exhibitions. Although no user study was conducted for the VMS, Carrozzino et. al. further justified in their later works that the use of AR in such CH context provides an easy, engaging and friendly way for visitors to access the CH's information as well as an reward augmented CH appreciation experience [8].

3 SHAPING DESIGN REQUIREMENTS

To study the potential and shape the design of the augmented HIWAAR sculpture experience in this project, a grounded theory approach was adopted through interviews with art professionals for a certain input. This study also attempted to address aspects of RQ1 set out in our research questions.

For this initial study, four art professionals participated in the interviews either by in-person or by zoom calls following COVID-safe rules. The interviews were semi-structured, centering on the topics of: i) the understanding of sculpture, ii) the potential and ideas of designing an augmented experience in supporting sculpture visiting experience, and iii) using HIWAAR system for the creation of such experience. Thematic analysis was used to analyse the interview data, with the emergent themes being reveal that shape the design of our work Sonic Sculptural Staircase (SSS).

Section 3.1 provides our interview study configuration details including participants recruitment and data collection.

Section 3.1.4 discusses the interview results including important themes produced and the new inspirations acquired for our work.

Section 3.2 presents discussion and reflection how the interview result was utilised for our work SSS. The section also attempted to answer our research question RQ1.

3.1 INTERVIEWS WITH ART PROFESSIONALS

The interviews were constructed with 7 semi-structured questions (Appendix Section 7.1), including participant professional backgrounds, sculpture and sculpture experience knowledge, and opinions in using HIWAAR system for creating augmented sculpture experience. In questions related to HIWAAR system, we presented participants a picture of users in "Listening to Listening" [22]. We describe the interview process details and results in the following sections.

3.1.1 *Participants*

Four art professionals participated in this study, as shown in Table 3.1. These participants were chosen due to their experience with sculpture and mixed reality technology artistic practice. The participants were drawn from the ANU community and had experience as sculptors, artists, professionals or students with knowledge and experience in technology-based art. They were initially in touch by email with the enquiry of interest for this study.

3.1.2 *Data Collection*

The ethics application of this study was initially submitted and approved prior to the COVID-19 outbreak at Canberra, and was designed to be conducted

Participant No.	Participant Poistion	Related Background to Sculpture
P1	Sculptor	Sculptor and University Lecturer in Sculpture
P2	Artist	Artist working in drawing, experimental animation, AR and interaction installation, and University Lecturer in Print-media and Drawing
P3	Undergraduate Art Student	Bachelor of Visual Arts has works in Virtual Reality
P4	PhD Student	Holds degrees in linguistics and art history

Table 3.1: Interview Participants Details

in person without the consideration of related COVID-19 safety implementation. However, formal interviews were occurred between the transition of the implementation COVID-safe rules at ANU. We thus decided to move all remained scheduled interviews online following health guidelines. That being said, the interview with P1 was conducted in person and the rest three were conducted remotely via video conferencing.

The interviews were 35-50 minutes in length, consisting of introduction, interview questions and summary/follow up questions three sections. Interview audio was recorded for further analysis.

3.1.3 *Data Analysis*

The initial interview transcripts were transcribed using NVivo transcription. The interview transcripts were further edited manually by the author to correct errors.

Interview data were coded and analysed using thematic analysis in NVivo software [20], which such methodology is widely used in grounded theory [7, 10]. At the initial stage, the author went through the interview transcript and coded interesting features. At the second stage, these codes were collated into potential themes based on their relevance and the interview topics. This stage was done iteratively for reviewing and refining the themes. At the third stage, thematic maps were generated by grouping themes. In particular, these themes were gathered with the objectives of *what*, *why*, and *how* in response to our aim in designing an augmented HIWAAR sculpture experience.

3.1.4 *Results*

Overall, the four participants provided very different answers given their professional background. Two of the participants gave more abstract and conceptual understandings of sculpture and sculpture experience (*P1* and *P4*), while the other two participants (*P2* and *P3*) provided practical insights and their experiences regarding using technology in creating art experiences. In total, five main themes were emerged from this analysis. We discuss each theme below together with the relevance of that to the design of our work.

Theme 1: Sculpture operates 3D space with its context

Even though participants have different background related to sculpture or sculpture experience, all of them agreed that sculpture is identified as an art

form that operates in three dimension (3D) space. The creation of sculpture is a wide field depending on techniques and purposes: sculpture can be virtual or created in a virtual world, it can be an installation, a temporal work, a video work, a performance or a collaboration work. However, given such complicated sculpture forms, the unique aspect of such art form is that it requires visitors to be able to walk around the sculpture, observe, as well as to contextualise the work in its surroundings to understand sculpture.

Relevance to design: The definition of sculpture is really diverse, it doesn't necessarily need to follow certain principles: if a work operates in 3D space, it can be identified as a sculpture (sculptural) element. In terms of the design of SSS, the architectural element of the sculptural staircase fits into this broad definition of sculpture.

Theme 2: Sculpture as a public role for entertainment or meanings

When participants were asked about whether sculpture has a role in public for providing an art experience, two participants (*P1* and *P2*) addressed that sculpture has a role in delivering messages to the public. Sometimes sculpture works are commissioned to enhance the cultural or aesthetic vitality of a community.

***P2**: "But to make art, it's important to make an artwork that means something in the world. I think it either speaks about the place that it's installed in or something that is happening in the world right now or environment."*

As such, participants mentioned that sculptors or art practitioners always consider how their works can please audiences or encourage engagement while making sculptures.

***P1**: " ... how people can interact with it, whether they kind of want to interact with it, how they might respond to it', which are necessary for public works design...I think the audience should be a very large consideration. You must think about whether people would understand certain elements and things like things*

Relevance to design: Some sculptures are designed with messages or meanings for the public. It is important that the public should get an understanding of it, or at least try to understand. Otherwise, some of the sculpture values might be reduced. That being said, "usability" is an important attribute while creating sculptures.

Theme 3: Sculpture experience: Interaction as means to understand the sculpture

Participants mentioned that interaction is an important means in understanding sculpture. By providing interaction opportunity or interaction stimuli, one can get more engaged with the details of sculpture. In particular, one participant (*P2*) said that a good sculpture work can provide audiences a feeling of discovering something new through interacting with the sculpture.

However, this participant further addressed the hygiene issues while physically interacting with the sculpture, especially given that this interview was conducted at the time when the COVID-19 pandemic got serious.

P2 also mentioned that interaction was an incentive to enlarge audiences' sculpture experience.

***P2**: "...because of my media arts background, I looked at interactivity in forms of something to be interactive. It needed to change when the person was interacting with it"*

Relevance to design: It seems that interaction can be important part of sculpture appreciation experience, and some media art sculptors put efforts in considering it as a part of their work during the design. Interaction can also expanded visitors engagement and understanding of sculpture.

Theme 4: Visual overlays and sound augmentation: bringing sculpture back to context

While discussing the ideas and potential of using additional elements such as music or visual overlays to improve audiences' sculpture experience, one participant (*P2*) shared insights regarding the motivation of such ideas. The participant pointed out visual or sound augmentation must relate to the original context of the work, making additional elements as a medium to re-energise the original work and bring it back to our attention.

Other participants thought that would be a good way of getting people to engage with sculpture and expand their art experience. One particularly mentioned that using some specific or novel technology may improve their art experience overall.

***P3** -"...I mean personally I found especially regarding technology, for example, people just find it interesting and it's a really good way to kind of get people to engage with things as kind of utilising new technologies... "*

Relevance to design: Using additional visual or audio elements to the sculpture should still relate to the original work content. Using novel technology to realise such elements may further motivate visitors to get more engaged with sculpture works.

Theme 5: Augmented Sculpture Experience through head mounted Augmented Reality: accessibility, information, public space and experience

All participants shared their positive attitudes about using AR to enhance people's sculpture experience and understanding. Overall, they thought that AR can be used in different ways with different design ideas to bring value to sculpture experience. These are categorised to four sub-themes discussed as follows.

(i) Accessibility Three participants (*P1*, *P3* and *P4*) think AR can expand people's accessibility to sculpture, and thus bring new experience or appreciation in understanding sculpture works which has been addressed in Theme 4. One participant particularly explained its advantages by giving a comparison to traditional sculpture experience:

***P4** -"An example I can think of is that in more traditional sculptures, people would be like ... just look at a photo of it from the front and that's it. I don't have to*

walk around it. That's what a lot of people think. But, ... in the digital space, you are welcoming them and encouraging them to sort of interact with it... that's a different experience of sculpture"

(ii) Information Two participants (*P2* and *P3*) thought that AR can be used as a platform or medium to provide information in guiding people understanding sculpture.

P2 *- "I think provide guidance would be useful, but maybe it also depends on how much the artist wants to give away. Like do they want that audience member to know all that extra information or do they want"*

P3 *– "You can teach people how to use certain things or show people how you think it's best to look at it... I get it a lot when I visit galleries, even with paintings. You're seeing something and you're interested in it and be like, I don't know what's going on. I would love to know..."*

But both participants mentioned that the design of content or information in the platform should be careful. Furthermore, *P2* suggested to be wary of the overload information in such platform. Too much information would affect their own sculpture appreciation experience.

In addition, *P2* pointed out that the design of guidance or content should relate to current social context of the sculpture:

P2 *- "I think particularly to perhaps keep physical sculptures like current and up today. So, if there was a sculpture that was made a long time ago, then adding these additional elements could maybe use that object from the past to talk about something that's happening now. So again, like updating it to fit into the current kind of space that it's been and in terms of like what the world is today."*

(iii) Public space Three (*P1*, *P2* and *P3*) of the four participants mentioned the influence and use of public place in designing such AR sculpture experience. One participant (*P1*) pointed that public space may affect such experience :

P1 *- "it's a public space. So people will be quite self-conscious about how they interact with something in a public space compared to what they would see as a gallery that might be seen as a performative space."*

While another participant (*P2*) pointed out that the boundary of augmenting the sculpture or the space around in the design, this result in difference of the work:

P2 *-"if you're augmenting the public space , which you're allowed to do anything in or if you're augmenting an artwork which you can't really change...I think that's the kind of boundary."*

P2 further addressed:

- "So it was kind of like a guerrilla kind of intervention using AR because we've this is another interesting thing about what you're doing . Is it like digital space is completely public . So there's nothing stopping you from activating any space digitally . I think it's when it's specifically engaging with a sculpture that you kind of run into those programs of needing to consult with the artists."

(iv) Experience Participants provided different ideas about what kinds of AR experience can be built in improving the sculpture experience:

One mentioned about using light:

P3 *-"being able to change the lighting of what you're looking at, how she would be really hard if you had if you had a sculpture in a room that had completely flat lighting . So it's not influenced by any windows or anything . Potentially you could be able to change like how the how the lighting is hitting the sculpture , which you like . I don't know . Technology would work well enough for that kind of be hard...spend some time looking at a sculpture in that way , almost kind of like dissecting different elements of it and getting people understanding . And then actually they're taking it off and just looking at it without all of that and seeing how your appreciation might have been elevated or anything like or the details that people might have missed. yeah, it's definitely an interesting one. I'd say one thing you definitely want to shy away from potentially is getting late to too analytical like really the like too much information , a bit of an information overload .At least with some things because you don't want to. Sometimes when you analyse..."*

Or encompassing a story of the sculpture:

P4 *-"I think maybe if a sculpture is in the public space, ... it could be about a story...And then they can design performances or design music that goes along with it. And it can be a different artwork when you have the performance and the music, and it becomes more like a performative piece of work with a sculptural element...you can still have the sculpture there and be open to other people's interpretations based on their different types of musical performance, and it can then have taken on different layers of meaning. So like any art viewer will project their own meaning onto it. So by then, projecting like music or different elements is just another way of interacting with the sculpture, and I think that increases its value rather than detracts from it."*

or ***P2*** *-"it could bring in a lot of new kind of forms and meanings to the work ... perhaps keep physical sculptures like current and up today...maybe use that object from the past to talk about something that's happening now ...like updating it to fit into the current kind of space..."*

Relevance to design: Using AR technology to present an augmented sculpture experience itself is attractive and may increase visitors interests to in original sculpture. Such an augmentation should be careful to differentiate whether the additional elements are added on top of the original work, or the space around. As the former one may violate the original work.

In addition, the findings also indicate there are two directions regarding the design of augmented sculpture experience: one is about proving information or guidance to understand the sculpture work, which is a quite straightforward/objective experience. Another one is about creating an experience using visual, sound and interaction elements. This one tends to be providing a more emotional/subjective experience, requiring visitors to digest and reflect on the information provided.

3.2 DISCUSSION AND DESIGN IDEATION

The interview results provided useful background about sculpture experience as well as high-level ideas to shape the design of creating an augmented sculpture experience in the AR/HIWAAR system. These findings also provide insights in addressing certain aspects of RQ1.

In general, the study shows that a sculpture experience is normally achieved by looking or walking around the sculpture. In this way, visitors can notice

the sculpture details and deepen their reflection by relating to the surrounding. However, this kind of experience are restrained sometimes considering the hygiene or safety concerns when visitors want to interact with the work physically.

As for the potential of using AR or HIWAAR system to construct an augmented sculpture experience, all participants hold positive attitudes and thought that such technology opens a digital space with different creative potentials. In other words, participants think such AR experience could unfold another layer of sculpture experience with the benefits of technology that is normally unavailable. Besides, visual overlays, sound and interaction are considered beneficial and could trigger a different sculpture experience. In particular, elements that embody interaction could be used to prompt visitors' active engagement with sculpture works and thus obtain a rewarding experience. The design features of any HIWAAR system should be aligned with the purpose and context of the sculpture (or the sculptural element) which the experience built upon. Furthermore, the study also indicates that the (public) space around the sculpture (or the sculptural element) is encouraged to be used, which connects their context and does not violate the appearance of the physical work. That being said, given such findings, the RQ1 can be addressed: it is conceptually confirmed that an interactive AR experience is possible to enhance the understanding of a sculptural element or architectural space. Although to what extent and how such experience could contribute an enhanced experience require further examination through the design, development and evaluation of a concrete prototype.

Given such, several general design ideas were produced based on the analysis and inspirations from each theme:

1. A guidance platform that provide information about the sculpture (or sculptural element) that includes visual, audio and interaction
2. An experience that entails the relate context of the sculpture (or sculptural element) through user's active engagement with designed features
3. An augmented experience that let people discover something new
4. To widely use the (public) space around the sculpture (or sculptural element) in the design of the experience rather than putting additional elements on top of the original sculputre
5. Design two versions of HIWAAR sculpture experience: one mainly focuses on providing information (the guidance), another one mainly focuses on providing an experience

Combined with these design ideas, the interview study's discussion has shaped the preliminary design of SSS in this project. In summary, the prototype would be developed with two different versions: an informational version that guides visitors in understanding the sculpture (or sculptural element) and an experiential version that activates visitors understanding and appreciation through their engagement with the sculpture (or sculptural element). Both versions are based on the same design purpose, which provides an augmented experience to enhance visitor's appreciation in understanding a sculpture (or sculptural element). These two versions have different set-up in combining

visual overlays, sound and interaction to examine the effectiveness of the HIWAAR system and to address research questions RQ2 and RQ3. Design details will be addressed in the following chapter.

4 SONIC SCULPTURAL STAIRCASE: DESIGN AND DEVELOPMENT

Drawing on findings from the interview study in Chapter 3, the sculptural staircase located at the Hanna Neumann building (HN building) at the The Australian National University (ANU) was selected to be the subject of our installation. Prior to such decision, a fair amount of time was spent deciding a suitable sculpture with considerations of where it situates at, the applicability that fits our design and hardware equipments, etc. Details regarding the design decision-making process is presented in Subsection 4.1.1. Furthermore, the design concept of SSS is discussed in Subsection 4.1.2.

Two specific HIWAAR experience conditions: informational and experiential, were then designed in Sonic Sculptural Staircase (SSS) to reflect on the use of visual overlays, sound and interaction. Each condition contained different features mapping to their theme (informational or experiential), but with different design aspects in visuals overlays, sound and interaction. Our work aimed to provide an augmented sculptural staircase appreciation experience for people who have been working in the HN building. We discuss our high-level design principles as well as two experience conditions in Section 4.1.

In regards to technical aspects, the SSS was realised in Microsoft HoloLens Gen 2nd (HL-2) and programmed in Unity platform. Additional toolkit and implementation were done to achieve location-specific interaction design in the staircase. Implementation details is discussed in Section 4.2.

4.1 DESIGN: HEAD MOUNTED AUGMENTED REALITY EXPERIENCE IN SCULPTURAL STAIRCASE

4.1.1 *Design Considerations*

Based on interviews results regarding the design of augmented HIWAAR sculpture experience, several noted points were emerged for the design of SSS:

- Sculptures (that are designed to be augmented using HIWAAR) need to be in a public place
- Sculptures could be outdoors or indoors, however, lighting constraints on the HLs meant that outdoors sculptures needed to be in areas of significant shade.
- For a sculpture appreciation experience, it is important to know that sculptures should complement their surrounding environment and vice versa. Given such, when designing an augmented sculpture experience, the designed system should be able to be in a world aware fashion by HLs so that it understands the physical location of the sculpture and provide features that integrate with the sculpture and surroundings.

- An ideal sculpture candidate and its surrounding environment is able to enable an "immersive" experience by HL2 which fit into research questions' purposes.
- For practical development and experiment reasons, an ideal sculpture candidate would not be very far away from ANU.

Overall, six possible sculptural sites on the ANU campus were inspected and the sculptural staircase located at HN building was selected to be the subject of our installation. It was chosen because it had fairly stable lighting conditions. It was also spectacular, which allowed the development of HIWAAR experience that involved walking through the sculpture as well as viewing it from different sides. Last but not least, the staircase was also public and was constructed with a strong message, which will be discussed below.

4.1.2 *Design Concept*

Sonic Sculptural Staircase is a Highly Immersive and World Aware Augmented Reality artwork aiming to provide an augmented appreciation experience on the sculptural staircase and its surroundings at HN building at ANU. The work is designed with two conditions: informational and experiential, with different interactive features utilising visual overlays, sound and interaction to prompt a users' engagement as well as convey the aesthetic background of this sculptural staircase and its architectural space.

These two conditions are designed equally with aspects of the amounts of information and interactive features, but with different design focus to our goal. The information experience focuses more on delivering **narrative information** using audio and textual visuals, while the experiential experience encloses indirect information, which requires the user to **actively explore, experience and thus obtain information**. Both experiences are designed to last about the same experience duration, which is about 5 minutes. Details of each condition are given as follows.

Informational Experience This AR experience is delivered by narrative audio guidance with some virtual visual hints to provide the background information about this physical sculptural staircase. The audio guidance includes four major parts, allowing the user to walk around and trigger the related audios embedded and access the background information. During the experience, the participant is also recommended to look at different parts of the staircase and surroundings guided by the audios to understand its aesthetic context. Feature details are illustrated in Figure 4.1.

Experiential Experience This AR experience requires the participant to actively engage with the staircase to obtain the aesthetic context of this sculptural staircase. It contains ten different interactive features (Fig 4.2), mainly enclosing indirect audio information such as field recordings of the HN building or music pieces with specific themes related to the staircase aesthetic context. Additional visuals are embedded into these features as the support of the sound to prompt users' engagement. The user is asked to explore these

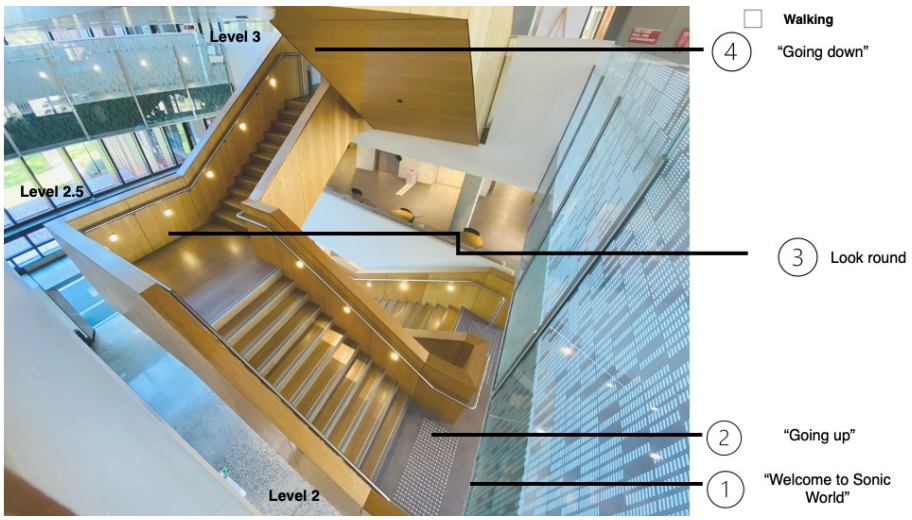

Figure 4.1: Informational Experience Features

features either by walking up the staircase or hand touch interaction at the middle-level platform to obtain the related information of this sculptural staircase.

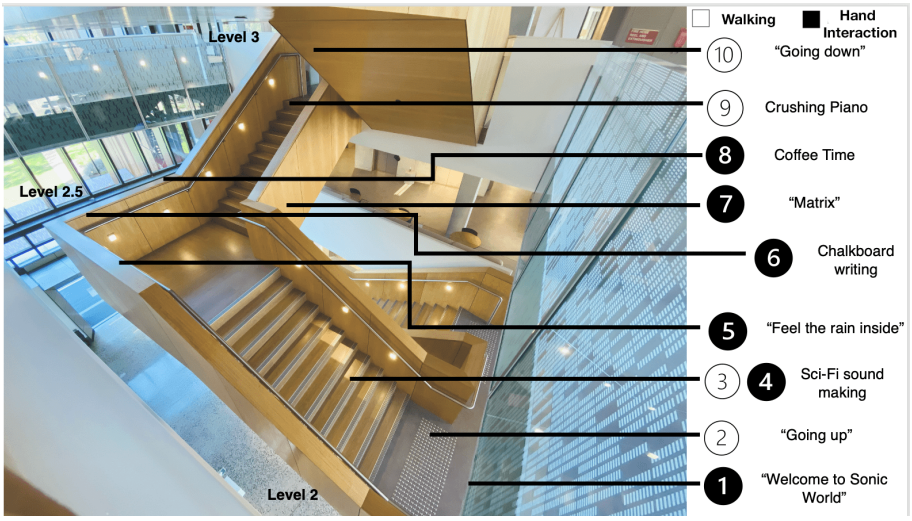

Figure 4.2: Experiential Experience Features

4.1.3 *Why this Sculptural Staircase?*

The sculptural staircase was carefully chosen with both practical and artistic consideration drawn from the interview study in Chapter 3.

First, the sculptural staircase itself is an interesting art piece situated inside an architecture space. The term "sculptural" lies at the intersection between

sculpture (purely for aesthetics) and architecture (mainly for functional purposes) [34]. The term "sculptural" acts as an integral part of an architecture for embellishment or decoration, presenting viewers a sense of beauty or art experience while serving its functionality in an architecture [12]. In particular, our background research shows that this sculptural staircase located at the HN building was designed to reflect the building's heritage context as well as its anticipated residents: The staircase is situated at the centre of the building as an interface linking the mathematics and computer science departments in the HN building[23]. Its sculptural form was designed with the concept of a collaborative stair embedding the message of collaboration across disciplines [2]. The embedded coding in the façade and interior of the building details not only address brick patterns from the previous building that was located at this place, but also present a series of mathematical puzzles throughout levels[35].

Second, this sculptural staircase provides a public space allowing people to naturally interact and appreciate it from different viewpoints. This is an essential element in providing a sculpture (or sculptural element) experience. The spatial structure of this staircase, both inside and outside the stairs, also provides a good capacity for blending digital information and creative visuals and audio.

Furthermore, technically speaking, this sculptural staircase is an ideal platform for the construction of HIWAAR experience. The staircase is located inside of the architecture, which is able to present a stable HIWAAR experience without the impact of lighting issues in HL-2, which we have addressed in Chapter 2 Subsection 2.1.1. What's more, the firm structure and large size of the staircase allow people to flexibility walk around and interact to prompt an engaging appreciation experience.

Given such, the sculptural staircase is a good candidate for the creation of the augmented HIWAAR sculpture (sculptural element) appreciation experience that reflects many of the opinions and wishes surveyed in Chapter 3.

4.1.4 *Sonic Sculptural Staircase Feature Details*

In this section, feature details of each experience condition: the informational and the experiential experience are presented. The design of these features follows three core principles: visual overlays, sound and interaction, addressing the findings revealed in the interview study. These three design principles are not exclusive to each other. Each feature is a combination of two or three principles with the consideration of realising a more perceptual effective experience. We will describe the three design principles in section **Feature Design Principles** section and how these principles were integrated into features in each experience condition in he **Features** section.

Feature Design Principles: Visual overlays, sound and interaction

Table 4.1 shows the different types of visuals, sound and interaction designed to map each experience condition. With the aspect of **sound**, it is mainly used as the information channel to prompt the user's engagement and conveying

	Types	Experience Condition	
		Informational	Experiential
Visual	Textual	✓	
	Thematic to the feature		✓
Sound	Fielding recordings		✓
	Electronic		✓
	Narrative	✓	
Interaction	Hand interaction		✓
	Walking (up or around)	✓	✓

Table 4.1: Feature Design Principles: Visual, Sound and Interaction

the aesthetic information in each feature. With the aspect of **visual**, it is used as visual hints or stimulus to complement the feature. With the aspect of **interaction**, it is used as a way for user to access the information in each feature (Figure 4.3).

Figure 4.3: Different Visual Types with Different Interaction (Left: Walking with stair high-lightened; Right: Hand interaction for grabbing coffee cup)

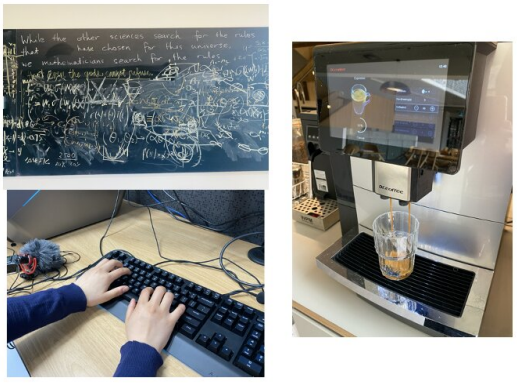

Figure 4.4: An Example of Sound materials: Mathematics, Computing and Working Environment

In particular, three types of sound sources were used in this work to covey

the information (Figure 4.4). They are: field recordings, electronic music and narrative audio. The first two were used for the experiential condition, and the narrative audio was used for the informational condition. Furthermore, three sound materials were included in the experiential condition: sound relate to mathematics (e.g. chalkboard writing), computing (e.g., keyboard typing), or the working environment and aesthetic context of the building (e.g., swipe-card sounds). More details can be found in the experiential condition features Table 4.3.

Features

In this section, details regrading each feature in each condition and how it reflects with aspects of visual overlays, sound and interaction are presented.

Informational Experience Table 4.2 illustrates features in the informational experience and how they match feature design principles.

It can be seen from the table that all the sound used in this condition were narration, mainly using walking to explore the experience with additional visual hints.

	Feature Name	Sound	Interaction	Visual
			Walking (up or around)	
1	"Welcome to Sonic World"	Welcome Narration Script		Dynamic hotspot
2	"Going up"	Going up Narration Script	✓	Hand coach
3	"Look Around"	Look Around Narration Script	✓	Hand coach
4	"Going down"	Going down Narration Script		

Table 4.2: Informational Experience Feature Details

s

Experiential Experience Table 4.3 illustrates features in the experiential experience and how they match feature design principles (next page).

It can be seen from the table that all the sound used in this experience is either field recordings (Feature 1,2,5,6,7,8,9,10) or electronic music (Feature 3 & 4). It can be seen that there were two types of interaction: walking or hand interaction. Different visual elements were designed which relate to the feature theme.

	Feature Name	Sound	Interaction		Visual
			Hand interaction	Walking (up or around)	
1	"Welcome to Sonic World"	Swapping card sound	✓		Button-like swirl
2	"Going up"	"level 2" & "going up"		✓	Stage colored
3	Sci-Fi sound making	sci-fi sound pitching		✓	Changing color
4	Sci-Fi sound making	sci-fi sound pitching			Swirl effect
5	"Feel the rain inside"	keyboard typing	✓		Matrix effect
6	Chalkboard writing	chalkboard writing	✓		Chalk powder spreading effect
7	"Matrix"	coffee machine sound	✓		A coffee cup
8	Coffee Time	rain drops	✓		Raindrops
9	Crushing Piano	piano notes		✓	Stage colored
10	"Going down"	"level 3" & "going down"		✓	

Table 4.3: Experiential Experience Feature Details

4.2 SYSTEM DEVELOPMENT

This section describes the implementation details of two HIWAAR experience conditions which were discussed in the previous section.

4.2.1 *Overview*

The experience was realised on a Microsoft HoloLens Gen 2nd (HL-2) (Figure 4.5) and programmed in Unity version 2019.3.7.f1. The Microsoft's Mixed Reality Toolkit (MRTK)[28] and World Locking Tool (WLT)[31] have been applied during the development to achieve real world location-specific interactive features. The development environment details are listed in Table 4.4.

The concept of "object-oriented" programming paradigm was used throughout the development following the guideline from Unity and Microsoft Hololens, where each component was considered as "game object"[44, 27]. All HIWAAR features in the experience including visual overlays, sound and interaction were built based on the whole 3D staircase holograms as game objects in Unity.

Figure 4.5: Microsoft HoloLens (gen 2nd)

The features contain visual overlays and interaction were implemented by MRTK and collider detection algorithm written in C# , while the sound used in the experience, including field recordings and external Disunity, were imported by Audio script component in Unity.

The core philosophy behind the implementation of these HIWAAR experiences is the mapping between the HIWAAR coordination system and the physical environment. To achieve the location-specific features, a 3D staircase model was used as the reference to model the relationship between the user (HIWAAR headset) and the real-world staircase in Unity. The 1:1 scale staircase model was then manually mapped to the real-world staircase using WLT (Figure 4.6).

In general, the development workflow include three main steps. First, the real-world staircase was modelled in Cinema4D[43] based on its physical structure and used as holograms. The 3D staircase model is composed by

Figure 4.6: Using staircase's 3D Model as reference to map between reality and HIWAAR experience (From Left to Right: Physical Staircase, Staircase's 3D Model, HIWAAR Experience Development in Unity)

Name	Version	Notes
Unity	2019.3.7f1	Use for HIWAAR experience development
MRTK	2.5.4	Mixed Reality Tools
World Locking Tools	1.1.1	For virtual/real staircase mapping
Disunity	1.0	Audio Synthesiser scripts for Unity
Cinema4D	S22	Model the staircase model
Microsoft Visual Studio	2019	For low-level implementation in Unity
Operating System	Windows 10	The main operating system

Table 4.4: Sonic Sculptural Staircase Development Environment

series of child holograms that illustrated in Figure 4.8 (next page). Second, the staircase model was manually aligned with the physical staircase using WLT to achieve the location-specific AR features. Third, sound sources, visuals and interactions were integrated into specific child holograms to realise features matching the design concept. These implementation details of each step will be discussed in the following Section 4.2.2 respectively.

Development Environment

Table 4.4 lists the development environment and software versions used in Sonic Sculptural Staircase (SSS).

4.2.2 *Implementation Details*

In this section, we give details of the workflow in each step in for the development of SSS.

Step 1: 1:1 Staircase Model

The staircase model was constructed in Cinema4D following the measurement of staircase object in reality (Figure 4.7 & 4.8).

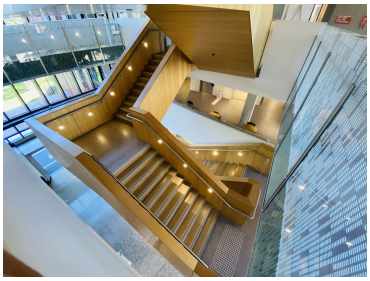

Figure 4.7: Staircase in Reality

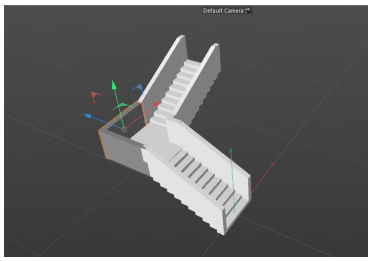

Figure 4.8: Staircase 3D Model in Cinema4D

Step 2: World Locking Tool for aligning staircase model to real world staircase

In order to achieve the location-specific features for our AR experience, the staircase hologram that contains front-end features needs to be aligned with the real world sculptural staircase at the HN building. This step was achieved by using Ray Pin example scripts provided by the WLT engine [30].

The Ray Pin contains a series of virtual spatial markers indicating the real world's geographic cardinal and intermediate directions. The markers can be manually pined through the UI panel in the HIWAAR environment to match the real-world geographic direction[37]. In this way, the staircase model can be aligned with the physical staircase. The WLT thus is able to maintain the spatial relationship between the physical and the hologram from the back-end. What's more, the WLT engine automatically enables auto-save and auto-load functionalities, allowing the persistence of the aligned staircase in the physical space.

In this project, an additional marker "Me" was added in addition to markers provided in Ray Pin to mark the user's position for assistance during the development. The configuration of WLT and Ray Pin followed WLT set-up documentation. Figure 4.9 & 4.10 show how the WLT engine worked with staircase hologram as well as other HIWAAR feature objects in the hierarchy windows. Figure 4.11 and 4.12 show the early process of pinning virtual markers to match the physical staircase. Two anchors of the staircase were specifically picked and measured its real-world geographic direction using the compass as the reference in aligning the staircase modelling HIWAAR environment.

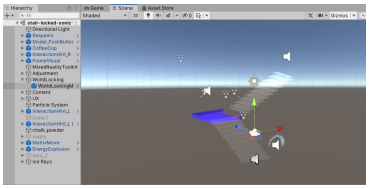

Figure 4.9: WLT engine shown in Experiential Experience Development

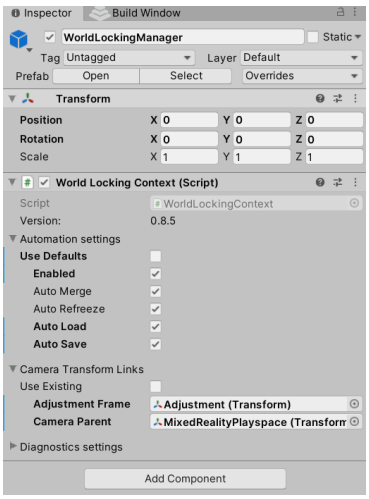

Figure 4.10: Details of WLT engine

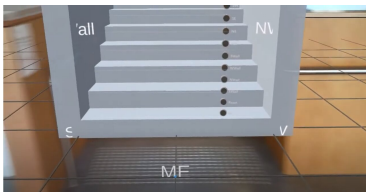

Figure 4.11: "Me" markers in Specifying the Starting Point of the Experience
Video

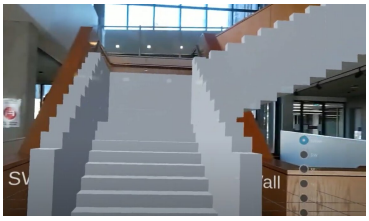

Figure 4.12: UI Panels Containing Virtual Spatial Markers and How They Mapped to Physical Staircase

Step 3: Feature Implementation in Unity

This section provides details of how each feature listed in the design section 4.1.4 was technically realised with aspects of visual overlays, sound and interaction.

Each feature was implemented through one of the child holograms of the staircase model(Figure 4.13). The front-end AR development was realised with MRTK toolkit following the Microsoft HoloLens development guideline[28]. Each child hologram can be assigned different front-end components such as audio clips, hand interaction or shader (Figure 4.15 & 4.14). Here, several key implementation details from each aspects are introduced.

Visual Effect The visual overlays used in the system can be categorised as dynamic and static. For dynamic visual effect, it was achieved by particle system in Unity. For static, it was achieved by attaching visual rendering such as texture or materials on the target hologram.

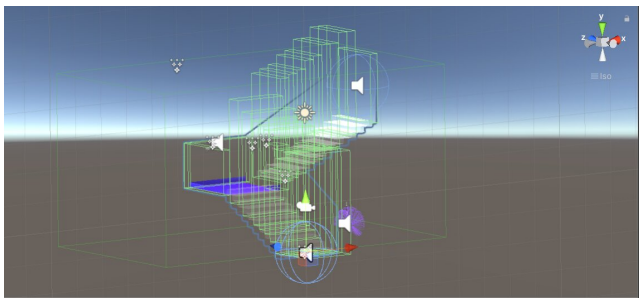

Figure 4.13: The Staircase Model as A Series of Child holograms in Experiential Experience

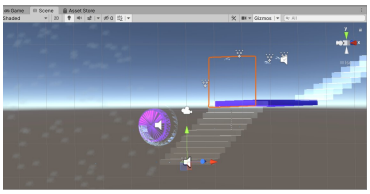

Figure 4.14: An Example of Cube.1 Child hologram - "Feel the Rain" in Experiential Experience

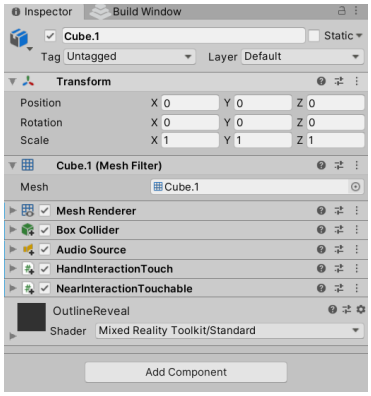

Figure 4.15: Assigned Front-end Components to Cube.1 Child hologram

1. Particle System:

   Particle system is a class of game object used to simulate particle effect such as moving liquids, clouds, and a whole slew of other effects [45]. It has different properties and method can be set up to suit different needs. In this project, the particle system was used to realise feature 4, 5 &6 in the experiential experience (Figure 4.16 & 4.17). In addition to the basic properties set up, the effect was set to be triggered in the condition when human hand hovers on the staircase.

2. Rendering:

   In unity, meshes, materials, shaders and textures are used to achieve the appearance of given game objects. In this project, all graphic features user were imported from MRTK toolkit[29].

Sound There are two types of sound used in the system: field recordings and real-time generated digital music by the Disunity Synthesiser Toolkit (DisunityST) [38].

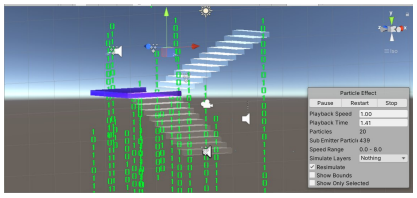

Figure 4.16: An Example of Cube.1 Child hologram - “Feel the Rain” in Experiential Experience

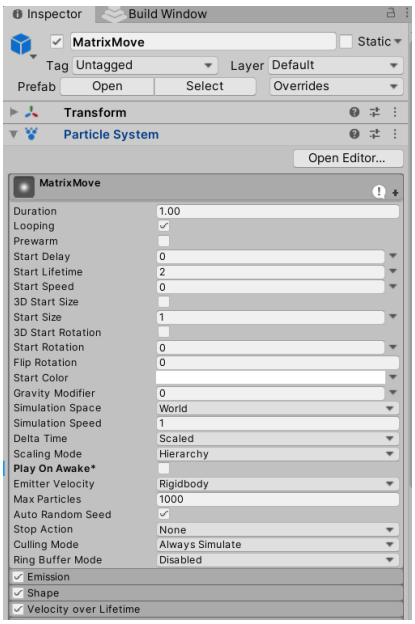

Figure 4.17: Assigned Front-end Components to Cube.1 Child hologram

The set up for playing audio sources was based on the Unity manual with sound sources and play options.

1. Sound Clips

   In this project, all field recordings were recorded with audio recorders and further trimmed in Adobe Audition 2020. The files were then added to audio source component illustrated in Figure 4.18 & 4.19.

2. Disunity

   The sci-fi sound designed in feature 3 in experiential experience was realised using Disunity. The toolkit includes basic digital synthesiser components. Figure 4.20 & 4.21 illustrate how the toolkit was used in produce the electronic music.

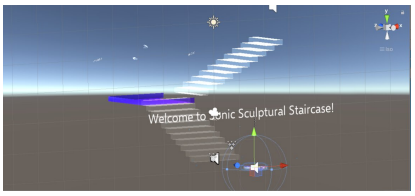

Figure 4.18: An Example of start_icon Child hologram - " Welcome to Sonic World" in Informational Experience

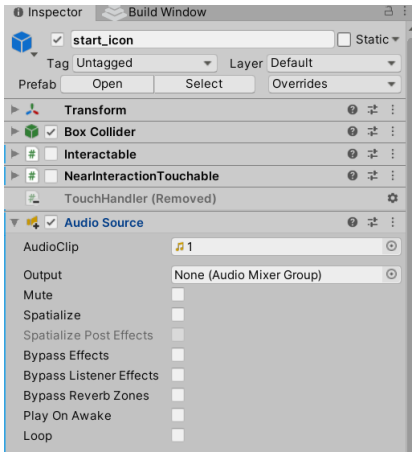

Figure 4.19: Assigned Audio Source to start_icon Child hologram

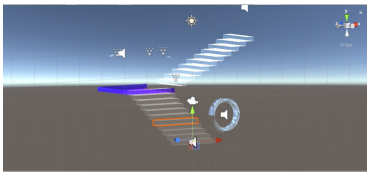

Figure 4.20: An Example of Cube.1 Child hologram - "Feel the Rain" in Experiential Experience

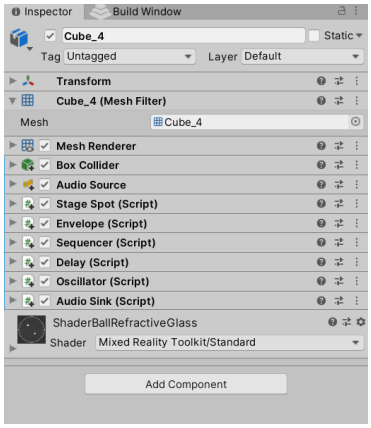

Figure 4.21: Assigned Front-end Components to Cube.1 Child hologram

Interaction The are two types of interaction: hand interaction and walking in the system. The hand interaction was designed and achieved through hand interaction with virtual holograms using MRTK toolkit, while the interaction using walking to trigger features were achieved by collider detection written in C#. Both interactions were achieved through the input management system in MRTK with HL2 hardware device.

1. Hand Interaction: MRTK interaction

   The hand interaction was realised through MRTK. MRTK offers a great range of interaction options that can be used to interact with virtual objects including virtual object near interaction, manipulation,etc.

2. Walking: Collider Detection

   Features involve triggering visual effect or sound using hand through walking (i.e, all features in informational experience to play audio) in the system were realised by collider detection written in C#. There are two scripts: StageSpot.cs & StageSpotChaner.cs, which the first one was assigned to child holograms as listeners waiting for the headset enters into its collider area, the later one was assigned to our headset object (as camera in Unity). Once colliders of a child hologram and headset collide, the child hologram will trigger related evens such as visuals, around or interaction.

4.3 SONIC SCULPTURAL STAIRCASE PICTORIAL ESSAY

The following figures and videos provide an overview with references to the feature details in Figure 4.1 and Figure 4.2.

4.3.1 *Informational Experience*

This section illustrates how features were shown in HL2 in the informational experience condition. Given the work is run-time dynamic, it's strongly recommended to watch the informational experience in the video by clicking it in this digital pdf file.

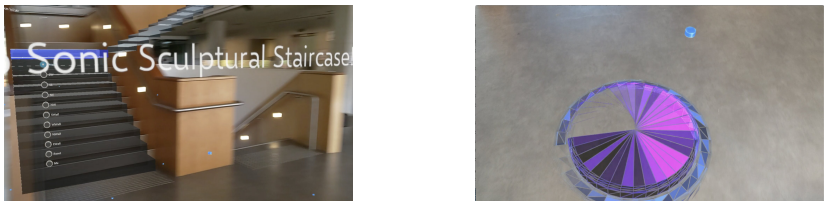

Figure 4.22: **Feature 1 - "Welcome to Sonic World"** : a button showing Feature 1 starting point with audio playing

Figure 4.23: **Feature 2 - "Going Up"**: the view of the experience standing at Feature 2 point (Top Left and Right);A virtual hand welcoming walking up further in Feature 2 (Bottom Middle)

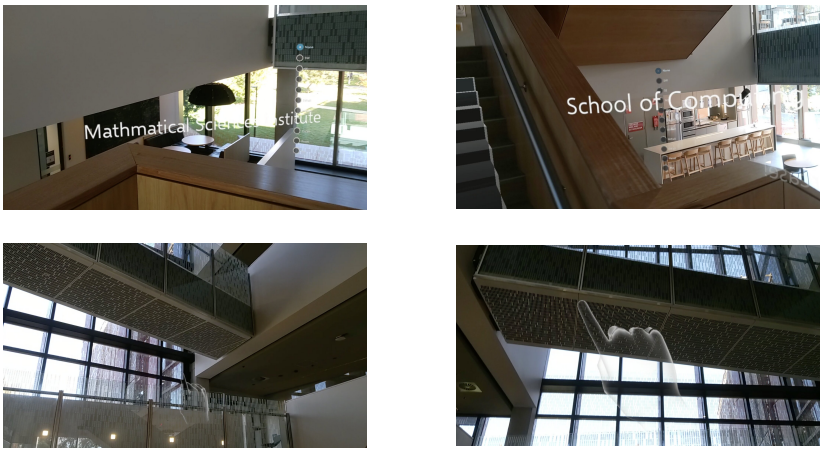

Figure 4.24: **Feature 3 - "Look Around"** : MSI sign with audio playing (Top Left); School of Computing sign(Top Right); A dynamic virtual hand showing to look up with audio(Bottom Left); The virtual hand(Bottom Right)

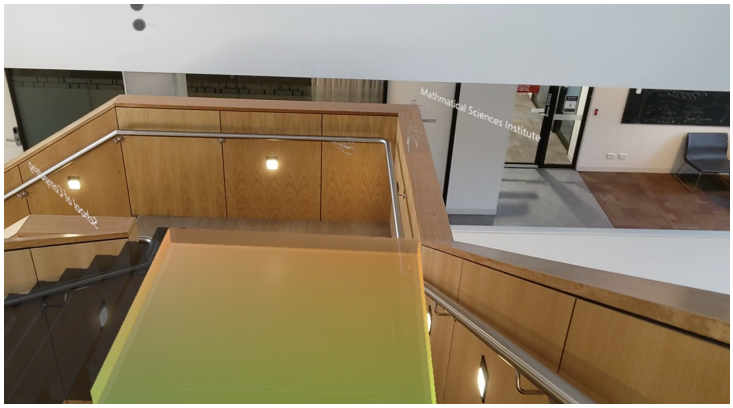

Figure 4.25: **Feature 4 - "Going Down"**

4.3.2 *Experiential Experience*

This section illustrates how features were shown in HL2 in the experiential experience condition. Same as above, please watch the experiential experience in the video.

Figure 4.26: **Feature 1 - "Welcome to Sonic World"**

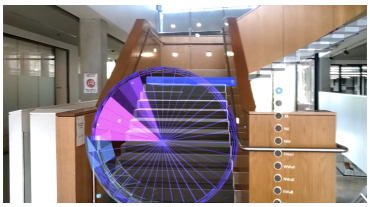

Figure 4.27: **Feature 2 - "Going Up"** : use hand to push the virtual button and start the experience

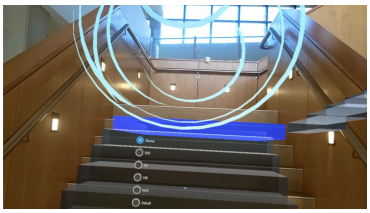

Figure 4.28: **Feature 3& 4 - Sci-fi Music Pitching** (Left); A outside view of the user experiences in Feature 3 &4 (Right)

Figure 4.29: **Feature 5 - "Feel the rain inside"** (Left); A outside view of the user experiences in Feature 5 (Right)

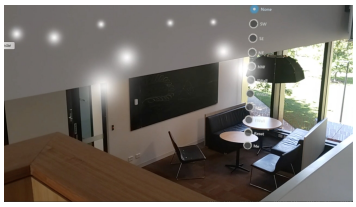


Figure 4.30: **Feature 6 - Chalkboard Writing** (Left); A outside view of the user experiences in Feature 6 (Right)

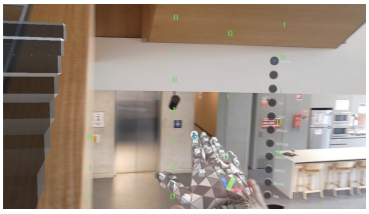


Figure 4.31: **Feature 7 - Matrix** (Left); A outside view of the user experiences Matrix effect in Feature 7. (Right)

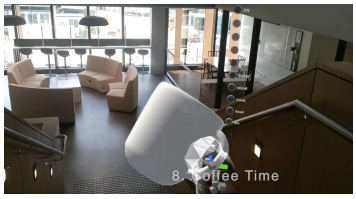

Figure 4.32: **Feature 8 - Coffee time** : holding the virtual coffee cup with sound effect

Figure 4.33: **Feature 9 - Crushing piano** : playing piano by walking up stairs

Figure 4.34: **Feature 10 - "Going Down"**

5 EVALUATION PROTOCOL

This chapter describes the user study design and configuration details of Sonic Sculptural Staircase (SSS) in response to research questions. It starts with a general overview of the user study objective and its methodology in Section 5.1, including the consideration of potential risks involved while running the user study. It then discusses user study details in Section 5.2, including participant recruitment and the user study process. Section 5.3 provides the user study data collection details.

5.1 OVERVIEW

The two sculptural staircase HIWAAR experience conditions: the informational and experiential experience, were evaluated between levels 2 and 3 of the HN building in this project. The objective of this study was to examine the effectiveness of such experiences in enhancing people's appreciation of the sculptural staircase and its surroundings.

The study consisted of four parts including participant recruitment, user evaluation, post-evaluation study and follow-up study. The post-evaluation study consisted of two parts: a quantitative Likert-scale questionnaire and a semi-structured interview. This study was conducted immediately after each participant finishes evaluating the experience with the aim of answering our research questions RQ1 & RQ2. In addition to this post-evaluation study, the follow-up study was designed to answer the research question RQ3.

There are various hazards and risks involved in the execution of the user study, including in-person interviews, the safety concern regarding the use of physical staircase with HIWAAR system and the use of HLs. Thorough risk and ethics consultations and assessments were conducted with related authorities upon the ethics approval of the user study (Ethics Protocol 2019/738). The details are discussed in Subsection 5.2.3.

5.2 USER STUDY CONFIGURATION

The user study in this project was conducted as a between-subjects study where participants were randomly allocated to one of two equally sized groups, and were asked to experience one of the HIWAAR experience conditions while walking up the staircase. Given the staircase safety concern and potential for other human traffic, the study was scheduled to be conducted at a relatively quiet time of the day. In addition, printed signs with information about the study were placed at the top and bottom to inform other users of staircase before and during the experiment. In accordance with WHS, the use of the staircase for public was closed to ensure both the public and participant safety during the experiment. The researcher would also ask the participant to follow the route shown in Figure 5.1 to keep the test participants close to the banister if they need it. The participants were encouraged to use the banister if they

felt unstable at any time. Participants were also told that they can choose to terminate the experiment at any time if they wish to.

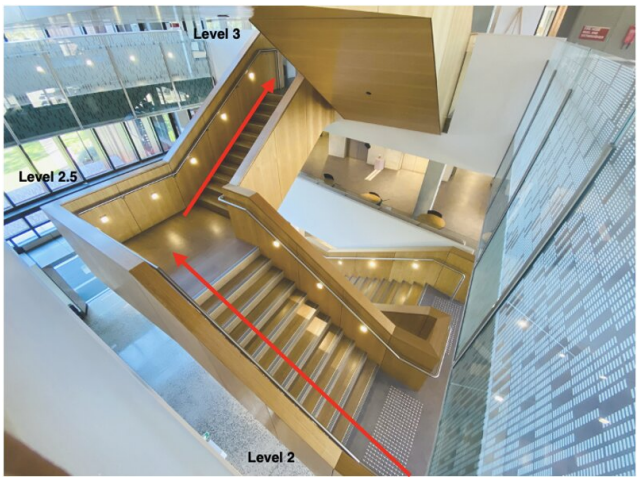

Figure 5.1: Suggested Evaluation Route

After the experience, the participants were immediately asked to finish a post-study questionnaire and an interview regarding the HIWAAR experience. The participants were also asked to join a short follow up study after one week, four and eight weeks regarding their HIWAAR experience.

Prior to the formal user study, both experience conditions were tested with a non-participant to verify that they would take about the same amount of time without hazards.

5.2.1 *Participant Recruitment*

Participants in this project were recruited from academics and students who work or study at the building where the HIWAAR experience was built upon at the HN Building at ANU. They were contacted either by email invitation or poster which was put up around the building. Participants who are qualified and agreed to join the user study were provided a short tutorial video regrading the use of HL2 before the experiment to get them more familiar with the the user study condition. A tutorial was also given to participants before the formal user study. The condition assigned to participants was based on the order of their email replies, was as "1" (informational) or "2" (experiential).

5.2.2 *Process*

The user study process followed a formal evaluation script and checklist to ensure that all participants receive the same information as well as the study's completeness. These documents can be accessed at Appendix Section 7.2.

Overall, the process of the experiment was:

1. Before the formal study, the researcher gave an introduction about the work and user study set-up in SSS. Participants were asked to complete the demographic questionnaire and sign consent form for the experiment.

2. Participants were given a short tutorial about using HL-2 headset and the work by the researcher.

3. Participant were asked to start the informational HIWAAR experience at level 2 in front of the staircase and complete it at the end of this staircase at level 3.

4. Once participant informed the researcher his completion of the experience, the participant were asked to take off the headset and complete a post study questionnaire regarding their experience.

5. Participant were asked to join a short follow up interview study after 1 week and 4 weeks about the impact of this experiment in response to their understanding or appreciation of the sculptural staircase and its surroundings.

6. Repeat step 1-5 for the experiential HIWAAR experience condition.

5.2.3 *Risk management*

As mentioned at the start of this chapter, concerns and risks with the use of staircase (i.e walking up the staircase with HL during the study) and COVID-safe were consulted with ANU Work Health and Safe (WHS) group, in addition to the regular ethics assessment. The formal risk assessment were conducted and approved by ANU WHS and Research Ethics Committee to address both the general concern in using HIWAAR hardware, participants safety while walking up the staircase as well as COVID-safe related hygiene issues. The researcher in this project had also received COVID training and risk assessment. Details can be found at Appendix Section 7.2.

5.3 DATA COLLECTION

The data collected from this user study was divided to two sections mapping the user study configuration: the post-evaluation study and the follow-up study.

Both quantitative and qualitative data were collected including questionnaire, semi-structured or short written question to examine the two sculptural staircase HIWAAR experiences in response to research questions.

5.3.1 *Post-evaluation Study*

In the immediate post-evaluation study, both quantitative and qualitative data were collected to examine the two sculptural staircase HIWAAR experiences

participants had experienced. Quantitatively, a 7 scale Likert-scale questionnaire was designed to assess certain aspects of our work. Qualitatively, a semi-structured interview with participants was conducted regarding their experiences. Details are given below.

The post-evaluation study questionnaire This questionnaire was designed in Likert-scale style to assess multiple criteria of the given HIWAAR experience condition, including ease of use, learnability, immersiveness, pleasure, engagement and personalisation of experience. Questionnaires were given to the participants immediately after the HIWAAR experience evaluation. Each question made a statement that participants had to agree upon using a 7 point Likert-scale, lowest being strongly disagree and highest being strongly agree. This questionnaire can be accessed in Appendix Section 7.2.

Immediate-After Interview This was a quick exit interview conducted immediately after user evaluation. The interview questions is semi-structured to collect opinions and suggestion regrading the overall built prototype, their impression and experience in the the sculptural staircase HIWAAR experience.

5.3.2 *Follow-up Study*

The follow-up study was designed to examine the effectiveness and impact of the HIWAAR experience that participants have experienced over time. This study was specifically designed to answer RQ3 in research questions.

One, Four and Eight weeks after Follow-up Study Following the immediate interview, the participants were in contact again one week, four and eight weeks after the user evaluation regarding their memory of the HIWAAR experience they have tried and whether the experience has bring them a new insight when they use the staircase with the change of time. This interview includes two Likert-scale questions and a written question. The Likert-scale questions mainly assessed how well the participant can recall their experience and whether they felt such experience enhance their awareness of the physical staircase and its surroundings. The written question asked specific features that contribute to their enhanced experience.

6 EVALUATION RESULTS

This chapter discusses the results and analysis of the data collected from the post-evaluation and follow-up studies, and an overall discussion on what the results mean in terms of our research questions RQ1 - RQ3. Section 6.1 discusses the demographic data obtained from the participants of the study, including their experiences and opinions of the sculptural staircase prior to their HIWAAR experience. Section 6.2 discusses the quantitative data collected from the user study. These quantitative data was in the form of a 7 scale Likert-scale questionnaire on the participant's response to certain criteria of the HIWAAR experience. Their responses were further coded to numeric values for analysis. Mean values of each criteria among each condition and each participant were computed, and were visualised to present the result. The Mann–Whitney–Wilcoxon test was also adopted to study the difference on the two experience conditions. Section 6.3 discusses the qualitative data collected from the immediate-after interview study. These qualitative data were transcribed from interview audio and further coded using thematic analysis. Important themes were produced to address the user study goals. Section 6.4 presents summaries of the results from above sections and interesting observations. It also discusses the results from both sets of data as a whole and address how they respond to research questions.

6.1 PARTICIPANTS

There were 10 participants (3 female, 7 male) in our user study. Five participants were asked to evaluate the informational experience, and the other 5 participants were asked to evaluate the experiential experience. All participants work in the HN Building from levels 2 to 4 with ages range from 18 to 55 or above, holding various academic positions. All participants said that they regularly used the part of the staircase that was the subject of the SSS. On average they reported that they used this part of the staircase 16 times during a week.

Answers to the demographic questionnaire showed that participants have very different attitudes and insights towards the design of the staircase and its related architecture: one participant (from the experiential experience) in particular who holds a extreme negative feeling;

- "Initially, I hated it. I thought It was very cold. But ..."

and another one indicated that they never ever thought much about it. While the remaining participants provided positive insights, some of the selected are:

- "I enjoy the overall architecture of the building. The way the staircase narrows from level 1 to level 2 is interesting. The materials connect to natures, yet it is also industrial and not necessarily efficient."

- "... I think the design is very interesting and friendly for users who would like to know about the building."

-"I like how the building is structured around the staircase. The staircase almost acts as another lounge where you meet people."

The actual user study for both experience condition took approximately same time, which was about 5 minutes for each, varied by participants.

6.2 QUANTITATIVE DATA

Overall, we got 98.6% questionnaire answer rates with one out of 70 questions (7 questions $\times$ 10 participants) not being answered. The unanswered question was Q6 -b, the informational condition(see below). The data collected from questionnaires with 7 scale Likert-scale rating were further coded to numeric values $0 - 6$, mapping as Strongly Disagree - Strongly Agree, for analysis. The mean values of participant responses for each questions, and for each experience condition were calculated separately. These results were then visualised in graphs given in subsections below.

To formally examine the statistical significance among two conditions, the non-parametric Mann–Whitney U test was used and obtained p values for each question. Given that the user study had very small samples of the data collected (10 in total and 5 for each experience condition), the Mann–Whitney U test's result was only used as a supplementary in addressing the findings.

The following section outlines the overall SSS experiences average rating for each question, and separate informational and experiential experiences conditions for each question, and then discusses individual questions ratings and findings that deemed interesting.

Here, a mapping regarding the post-evaluation study questionnaire questions' index and its header is presented, so that readers do not need to keep referring to the Appendix Section 7.2.

Q1 : Ease of Use

Q2 : Learnability

Q3 : Immersiveness

Q4 : Pleasure

Q5 : Engagement

Q6 : Personalisation of the Experience

a) How well you can recall the experience?

b) Does the HIWAAR sculptural staircase experience change your daily routine in this building?

6.2.1 *Overall Sonic Sculptural Staircase Experience*

Overall, all questions received high ratings from participants (all are greater than value 3 - neutral), irrespective of which experience conditions they tried (Figure 6.1). In particular, Q4 (Pleasure) received the highest rating with mean values 5.7 out of 6. This shows that participants obtained a pleasant experience

for our designed experiences. Q3(Immersiveness) and Q1(Ease of Use) received relatively high ratings following Q4 with mean values 4.9, 4.8 respectively. These indicate that participants felt that our HIWAAR experiences are easy to use as well as present a high immersive feeling. Noted, Q5 (Engagement) received mean values 4.7, only 0.1 less than Q1, showing the participants felt engaged with the staircase while exploring features in the HIWAAR experience too. Q6-b (Personalisation of Experience) got the lowest mean values 4.1, which indicate that participants did not strongly feel that features/elements in the HIWAAR were able to relate their personal experience with the staircase or the building.

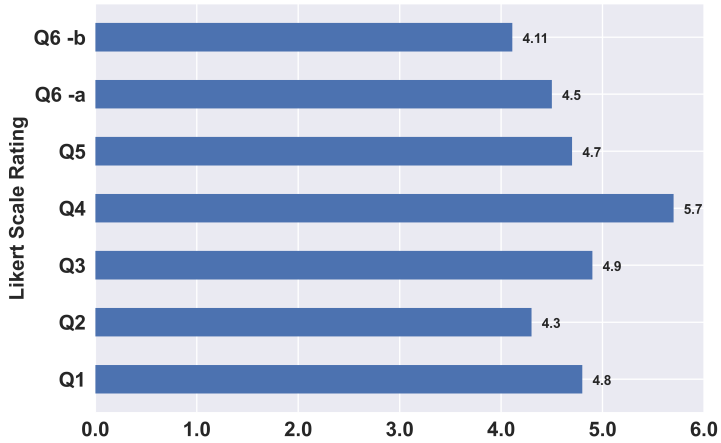

Figure 6.1: Average Ratings on Questions regrading Sonic Sculptural Staircase Experiences

As for the distribution of ratings for each question, it can be seen from Figure 6.2 that Q6 (-a. & -b.), Q3 and Q1 received relatively large fluctuation in participants responses with standard deviations(std) of 1.35 and 1.26, 1.29, and 1.14 respectively in descending order. In contrast, Q4 and Q5 received first and second-lowest std values: 0.48 and 0.95. These further confirmed the above findings, in which participants felt almost consistently pleasant and engaged in our HIWAAR experience. What's more, it is interesting to note that Q3 scored large std values 1.287 with lowest rating 2 and highest rating 6. However, this question also received second high average rating. Such large fluctuation among participants responses but with high average rating may imply different distribution on ratings between informational and experiential conditions, which will discuss in the next section.

6.2.2 *Information versus Experience Experiences in Sonic Sculptural Staircase*

As it can be found from Figure 6.3, there are apparent differences in average ratings between two different experience conditions. This result presents us with details and insights regarding why and how the overall experience ratings were formed, which have briefly discussed in the previous section.

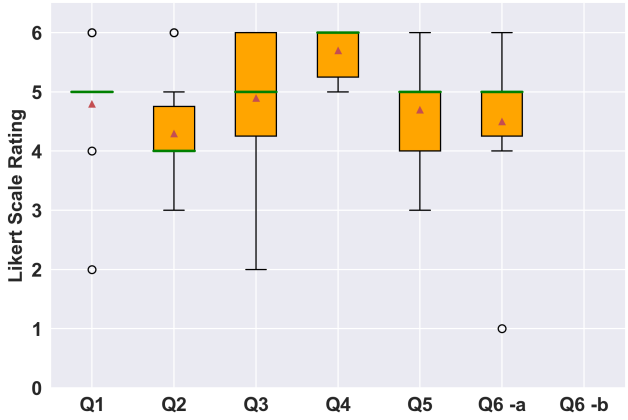

Figure 6.2: Distribution of Average Rating on Each Question

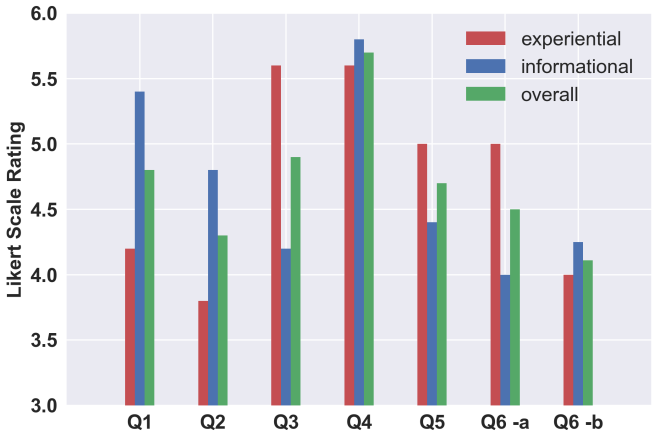

Figure 6.3: Informational vs Experiential Experience Average Rating on Each Question

First, it can be noticed that the experiential experience received higher average ratings in Q3, Q5 and Q6-a compared to the informational experience. While the informational experience received higher average ratings in Q1, Q2, Q4 and Q6-b. This shows that the experiential experience contributes more with aspects of immersiveness and engagement, while the informational experience performs better on ease of use, learnability/effectiveness and pleasure. Noted, it can be seen that there is not much difference in Q4 (pleasure) among the two conditions, indicating participants were pleasant with both experiences overall.

Second, for Q6, the experiential condition performed better on sub-question a, which indicates that it provides more flexibility for participants in exploring HIWAAR experience. For sub-sequence b, it only has 0.25 minor difference values. This may due to we only received 4 responses (1 unanswered) instead of 5 from the informational condition. While it can be concluded that

both groups of participants considered Sonic Sculptural Staircase experiences failed to let them relate their own experiences related to the staircase and the building, which have previously addressed.

As for the distribution of ratings within questions for both conditions, it can be seen from Figure 6.4 that informational experience has large fluctuation among participants response in Q2 even though both conditions have the same median values. Same as Q2 and Q6 -b. also demonstrates large fluctuation in response for experiential experience, which only scored median value 3 compared to informational one with 4. This indicates that the experiential did not better contribute to participants' personalisation of their relation to the staircase and the building, compared to what they normally have in walking this staircase.

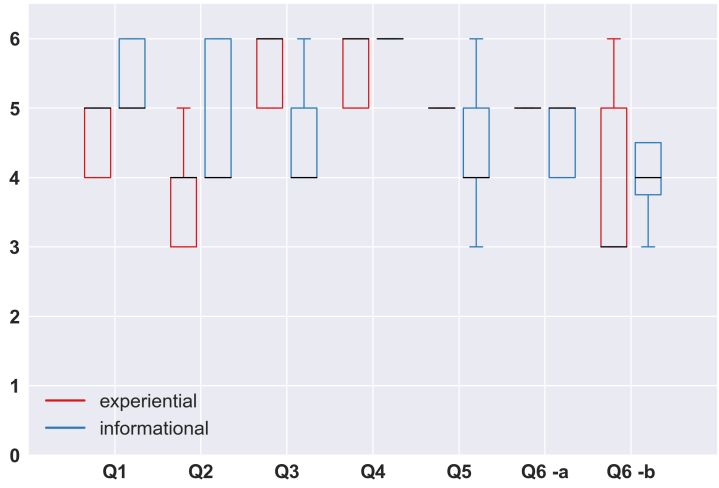

Figure 6.4: Distribution of Informational vs Experiential Experience's Average Rating on Each Question

As for Q5, it can be found that all participants shared the same strong response to its criteria *engagement* for the experiential experience, while such varies significantly for the informational experience.

Furthermore, it's interesting to note that both conditions have a quantitatively different response in Q3: experiential experience scored highest ratings with median value 6, while informational only got median value 4. This shows that experiential experience presents a significant strong presence of immersion compared to information experience.

Last but not least, the Mann–Whitney–Wilcoxon (MWW) was also used to compute the p-value in observing whether the ratings show strictly significant different among two conditions. As it can be seen from Figure 6.5, p-values on all questions are greater the 0.05, indicating there is not a significant difference among the two experience conditions. However, the results do show that Q1 and Q2's p-values are closer to the benchmark, indicating there is **a marginally difference** from these two experiences with aspects of ease of use and learnability.

```
Wilconxon Test Regarding the Significant Difference on Each Questions
Q 1 0.0 P Value: 0.05878172135535886
Q 2 0.0 P Value: 0.05878172135535886
Q 3 0.0 P Value: 0.06559969214707187
Q 4 0.0 P Value: 0.31731050786291415
Q 5 0.0 P Value: 0.0832645166635504
Q 6 0.0 P Value: 0.10247043485974937
Q 7 1.5 P Value: 0.4142161782425252
```

Figure 6.5: Mann–Whitney–Wilcoxon Regarding the Significant Difference on Each Questions (Note: Q7 refers to Q6-B)

6.2.3 *Follow-up Questions*

For the follow-up study, the same analysis method given above was applied to process the data collected after one week and four weeks of the user study. The Q1 was aimed to examine how well the participant can recall they experience, and Q3 was aimed to examine whether the awareness of the staircase has been enhanced after our HIWAAR experience. The written question Q2 asked what specific features contribute to their answers in Q1 and Q3.

The full follow-up questions are provided here with findings discussed as follows.

Q1 : How well can you recall the particular sculptural staircase AR experience that you tried? (Note that "neutral" is about as well as you can recall anything else that happened at about the same time that you undertook the AR experience.)

Q2 : What stands out in your memory of this experience? (Please list all things that come to mind.)

Q3 : After trying out this experience, has your awareness of the physical staircase and the building been enhanced in your daily life as you use the building?

One-week after

From Figure 6.6 on the left, it can be seen that participants could still well recall the HIWAAR experience they evaluated with the mean values 4.6 out of 6 for Q1. However, the relatively low mean values 2.9 were obtained for Q3, which is 0.1 lower the neutral value 3. This result shows that participants did not feel that such experience can enhance their daily life related to this building. The distribution of participants responses in Figure 6.7 on the left further demonstrates reason for such low mean values. It can be found that participants responses in Q3 is widespread with two outliers scores 0, 1 respectively, which affect the overall mean value.

Furthermore, observing participants' responses on the two experience conditions individually from Figure 6.8, we can see that participants responses from the informational condition are more fluctuated compared to the experiential one. That being said, it is the variance from the informational experience participants that results in the overall low mean values in Q3.

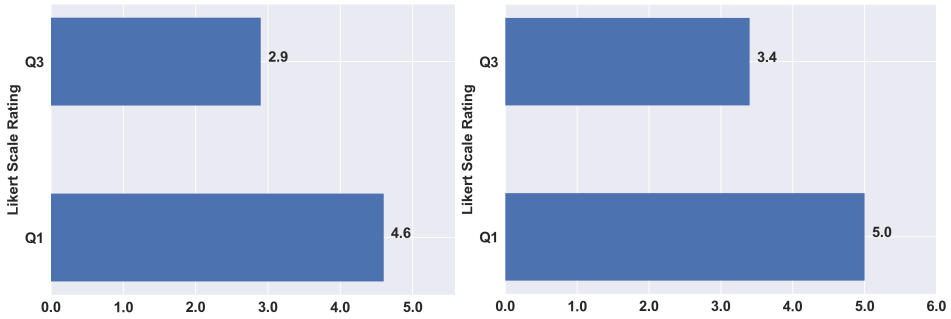

Figure 6.6: Average Rating regrading How Well Participants Recall their experience: 1-week after (left); 4-weeks after (right)

As for Q2, participants provided detailed information regrading what specific features stands out in their memory. For the experiential experience, most frequent features were *coffee cup sound* and *staircase music*, along with the overall experience of interacting with the staircase. The *coffee cup sound* was mentioned from all participants in this experience. For the informational experience, most frequent features were *sound effect (audio guidance)* and *visuals*.

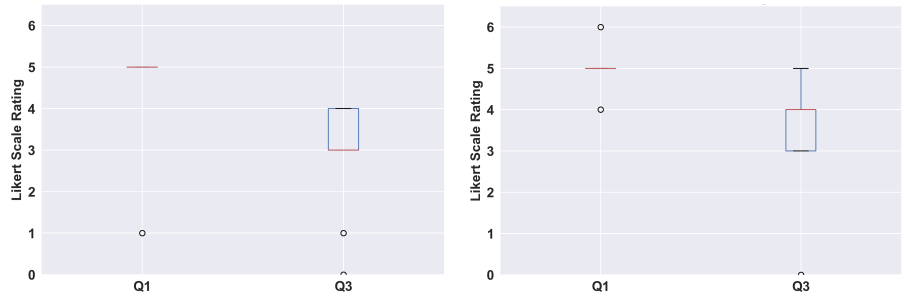

Figure 6.7: Distribution of Participants Response on Each Question: 1-week after (left); 4-weeks after (right)

Four-weeks after

After four weeks of the SSS user evaluation, participants were in contact again and asked to give responses to the same follow-up questions. Figure 6.6 on the right presents overall mean values regrading participants responses with mean values 3.4 and 5.0 out of 6 for Q1 and Q3 respectively. Such results show participants can still recall the HIWAAR experience they tried and feel that such experience has enhanced their awareness of the staircase and its surrounding overtime. Looking further into the distribution of responses in each question in Figure 6.2 on the right, it can be noticed that two outliers are identified in Q2: one gave high rating indicating, and another one gave less which is below the overall mean value. As for Q3, there is one outlier identified with score 0.

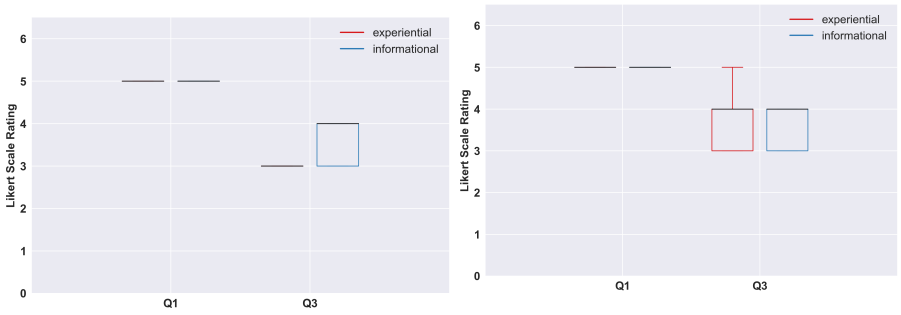

Figure 6.8: Distribution of Informational vs Experiential Experience of Participants Response on Each Question: 1-week after (left); 4-weeks after (right)

What's more, observing participants responses on the two experience conditions individually from Figure 6.8 on the right, it can be found that there are not much fluctuations in participants response on both questions. For Q1, it can be seen that both conditions keep a steady score 5, indicating all participants gave same ratings. While for Q3, it can be seen that the experiential experience has a slightly large variance with max rating 5 and min rating 3, compared to the informational experience with max rating 4 and min rating 3.

As for Q2, it was found that participants answers for the four-week after survey were much shorter than compared to for the 1-week after survey, although their answers were mostly same. For the experiential experience, the feature *coffee cup* was still mentioned across all participants. The *music staircase* was also mentioned in some of the answers. The main difference was the shorter description in explaining such impressive points, mainly in the disappearance of verbs of describing features. For example, in one-week after study, the participant 10 mentioned: *"manipulating the coffee mug"*, while in four-weeks after study, their answer changed to *"coffee cup"*, which the memory relating to the interaction of such feature had disappeared. The informational experience encountered the similar situation, where participants answers were shortened but the content mostly remains the same. Most mentioned features were *audio* and *visuals*. One participant also noted that they couldn't remember the details. However, it was interesting to address that some of answers related to *visuals* had expanded as *visuals of the staircase model*, which such did not occur in the 1-week after study for the informational experience.

6.2.4 *Observation on 1 week and 4 weeks after*

In addition to individual one-week and four-weeks after follow-up analysis, the difference of each participant's responses is computed on Q1 and Q3. The y axis shows the difference values which were subtracted between four weeks and one week in each participant. That being said, if the value is 0, it means the participant response of that question doesn't change. If the value is greater than 0, it means the participant response of that question becomes positive (i.e.

For Q1, it means participant feel they can better recall the HIWAAR experience after 4 weeks, compared to 1 week after the evaluation), and vice versa.

Figure 6.9 shows the distribution of such difference values. For Q1, it can be noticed that most participants responses didn't change much over time, with the mean value 0. However, there are two outliers identified. One shows that they can significantly recall the experience after 4 weeks, compared to 1 week after. While another one showing subtly less recall the experience. As for Q3, there is a huge difference on participants responses overtime. Two participants feel that HIWAAR experience they tried on has changed their experience to the staircase and the surrounding overtime. In other words, they did think about the experience while using the staircase after our user study. While one participant was significantly negative in feeling this experience could associate his daily life in relation to the building.

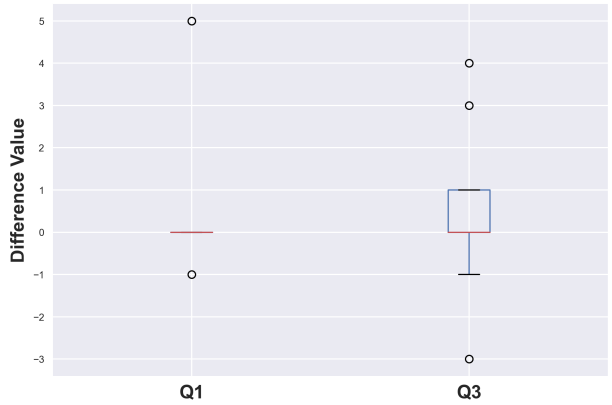

Figure 6.9: Distribution of Difference Responses among 1-week/4-weeks on Participants

Looking to two experiences separately in Figure 6.10 and Figure 6.11 , it is found that the **experiential experience** contributed more to the participants' changed responses, with minimum value -4, and maximum value 3, showing

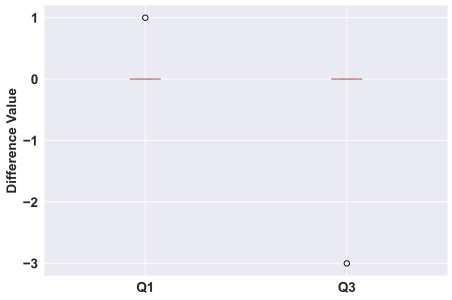

Figure 6.10: Informational experience: Distribution of Difference Responses among 1-week/4-weeks on Participants

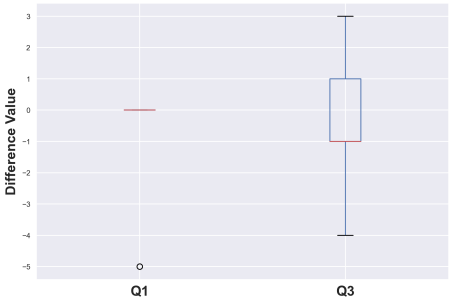

Figure 6.11: Experiential experience: Distribution of Difference Responses among 1-week/4-weeks on Participants

that participants responses drastically changed. While for the informational experience, it is found that two outliers were identified with one for each question. The one in Q1 reveals an improved response that the participant can better recall the experience. In contrast, the one in Q3 reveals the participant was negative in feeling that the experience contribute to his awareness of the physical sculptural staircase.

6.3 QUALITATIVE DATA

The interview data collected from immediate-after interviews were 5-20 minutes in length and transcribed using NVivo transcription. The transcripts were manually corrected to resolve typos errors. These data were then further coded in Nvivo[20] to identify important codes to our interview questions, which were:

1. The overall feelings towards the *Sonic Sculptural Staircase* experience
2. Particular impressive points/features
3. Suggestion for the developed prototype

These codes were further ranked by their frequency and experience conditions in a spreadsheet, which were produced by query running in Nvivo.

6.3.1 *Results*

This section provides interview results for each interview questions. It starts by discussing participants overall feelings about their experience, with subsections particularly addressing the condition they tried. It then discusses particular impressive points to participants Sonic Sculptural Staircase experience. It provides both design and technical suggestions to our work given by participants at the end.

6.3.2 *Overall feelings and experiences*

Overall, participants from both experience conditions provided positive feelings to the HIWAAR experience they tried. Frequent coded themes are "relate to my daily routine evironment","very good and interesting experience", "creative", "first HIWAAR experience", "creative", "engaging" and "enjoyable" in descending order. Three participants particularly mentioned that this is their first HIWAAR experience, which may bring more excitement to their overall experience during the experiment.

For the theme "relate to my daily routine evironment", participants commented that some of the elements presented in the experience are what they have been familiar with.

Informational Experience

For the information experience, important codes drawn from the interview data are mainly clustered at these three themes: "first HIWAAR experience", "engaging" and "very good and interesting experience" in descending order.

In particular, one participants commented that the explanation given in the audio were good and let him get engaged with the staircase.

- "It was a good experience. Like I have no prior experience... this is like more engaging... because I like to walk up the stairs and look around. It sort of gave me a sense of the of the architecture. I like the buildings. And, yeah, I actually didn't have

any I AR experienced before. So the audio guidance, it was pretty good. And like the explanations and everything was good like."

Experiential Experience

From the experiential experience, important themes coded are more widespread compared to the informational experience, including "a sense of achievement", "creative", "do not feel artificial at all", "short buy enjoyable" in addition to themes discovered from informational experience. Frequent themes appeared in this experience are: "relate to my daily routine evironment", "creative" in descending order.

In particular, the theme "short but enjoyable" was addressed by one participant saying he especially enjoyed this short but coherent experience, which won't let him feel tired at the end.

In addition, there is a negative theme raised by a participant during his experience: "a big drop in the experience". He commented that when he noticed the virtual coffee cup in the experience, he intuitively felt annoyed and wanted to put it as far away as possible.

6.3.3 *Particularly impressive points*

Several noted themes were produced from the interview when participants were asked by what specific points/features contribute to their good/bad experiences. These themes are: "a totally different staircase experience/never ever have before", "being able to explore the space", "3D staircase model", the experience is straightforward, easy to navigate" and " sound complements the feeling of presence" from both conditions in descending frequency order. Participants from both experience conditions commented that this HIWAAR staircase experience was quite different to the staircase experience they had before. For the experiential experience participants, they mentioned;

- "I didn't really imagine myself to experience that in a before."

-"I've never really thought about it as an art piece before, so it was weird kind of playing around on the staircase as opposed to like using it as a means from get to one place, from one place to another."

And for the informational experience;

-"I think the experience is quite interesting. And I kind of see that the. videos and messages the structure of the staircase? It's quite new. "

In addition, both experience conditions showed a flexibility of exploring the space from the code "being able to explore the space". Furthermore, the result also shows that participants from both experiences mentioned frequently about the 3D staircase which is aligned with the physical one. One participant said they really liked how the staircase model was integrated with the actual one, presenting a sense of triangulation of the space.

While there were two participants mentioned that the staircase model did not perfectly fit into the actual one. Though one mentioned having a staircase model shown in the experience still made the experience compelling:

-"actually, I find some of the 3D modelling of the staircase. It's not fit perfectly with the real stairs. But what I find impressed is when I start from the lower half of the staircase, I find I can see I can see through the on the barrier off. They or say the

handholding are from from the upper stairs with a 3-D modelling structure. I feel that is very interesting and impressive"

Another one indicated that the staircase model results in a delay/downside of their experience.

Informational Experience

For the informational experience, important themes are mostly clustered to " a totally different staircase experience/never ever have before", "space" and "3D staircase model". One participant further explained that they got a kind of nostalgic feeling while listening to the audio during the experience, which they felt quite different from their normal staircase experience.

-"Because if you heard something you're familiar with are, you'll also find it's some kind of nostalgic or something."

Another participant further commented on the use of space implied by this experience, prompting them to explore more.

-"The platform being highlighted as a particular space, both through the placement of that space and the highlight, but also the audio key. When you arrived at the space that that turned on and started telling you about the space. So that was that was really good. I think I have a tendency to want to either go fast through things to find out what they are. "

Experiential Experience

For the experiential experience, important themes are widespread again compared to the informational condition. Additional themes "prominent", "open for exploration", "being more present" and "suit into the culture of the building" are produced.

In addition to provide a different staircase experience, one participant further addressed such experience highlight existing features in the reality and made them more prominent.

- "This experience made more prominent with it that when it played...the chalkboard zones near the chalkboard...it brought back that experience to the forefront that...there is a blackboard that I can see from this place. And I remember that, I look at that blackboard every time I find myself walking up...this is quite interesting."

Furthermore, another participant mentioned the experience made them feel more present in the staircase.

-"I found myself kind of experience actually being more present in the staircase."

6.3.4 *Suggestions to the work*

Throughout interviews, participants provided useful insights and suggestions to our work. These themes can be categorised to design and technical perspectives given as follows.

Design

Overall, our thematic analysis shows the codes are clustered to three categories: visual, sound and interaction, which also map research questions RQ2.

Visual For the category visual, themes "using visual guidance to complement audio information/sound", "visual that fully presented", "visual for people in different culture background" and "visual is a bit abstract" were produced based on their frequency in descending order. Participant from both experiential and informational conditions mentioned more use of visuals are expected for the construction of such augmented sculptural staircase experience.

For the experiential experience, one participant mentioned that the visual is a bit abstract when it appears with the assigned sound.

Another participant further commented;

-"... but the ambiguity of visuals makes sometimes makes me feel confused, especially when you hear the sound of the writing using chalk writing on the board. You you don't know where to look at."

Besides, a participant mentioned the solution to vague/abstract visuals:

-"I think it would be nice to make more prominent in the places where something is supposed to happen, the coffee cup is obvious that I could see it, but the edges like that age was kind of active right there. I could do something. Yeah, but it took me some time to realize that there's something here to do. So maybe if it kind of glowed in some different color when I went past it or gave some indication of the fact that here was an element that was interactive, that would be nice."

For the informational experience, two participants addressed the lack of complemented visuals for showing where to look at while listening to the audio guide.

Sound For the category sound, two subcategories were produced given different sound used for both experience conditions. Themes clustered to audio guidance (informational condition) mainly related to the design of information delivered through audio. The frequent themes are: "more clear information about how long the experience lasts and listening options", and "make the audio more spatial".

Other themes are clustered to field recordings and electronic music used for the experiential condition. The themes are "adjustment of piano scale" and "make the sound more prominent to HN building environment". In addition, themes that appeared in audio guidance were also shown in this condition with further comments on more instructions desired during the experience:

-"but if I use a like one time experience, I would like more instruction. For example, there is a footprint on the stairs and get me where to go. Even though you show me the feature map prior to the study, I can't remember like exactly when I actually I am so it might."

Interaction As for the category interaction, both conditions produced theme "more features" desired during the experience. In particular, the majority comments were from the informational condition with two participants stating that they were eager to explore more:

-"they may have been more to explore. So they could be...more things that I would want to find out about...not that necessarily you have to tell every story or but you having...options so that you can say if you want to find more out more about this than you could have...something that would follow on or dive deeper into. Maybe some other parts of the story of the building"

-"But I'd like to if we can have more chance to interact with the system. So if you can, for example, put but put some kind of virtual virtual objects."

For the experiential condition, one participant suggested whether it could introduce more sophisticated interaction:

-"...but I was expecting as my interactions changed, it had more of a complex reaction than what I was hearing and what I was seeing for sure what the coffee cup. But I thought as it was searching, it would get a different sound or something."

6.3.5 *Technical Implementation*

There were only a few themes produced for the technical aspects of suggestions. Themes are mainly clustered to "staircase model", "not very clear to see" from both experience condition, and "technical delay on music stairs" for the experiential condition in particular.

Participants from both experience conditions stated that they could see the 3D staircase model not perfectly fitting to the physical one (one from experiential and two from informational).

For informational:

-"one of the major observations is that the virtual staircase did not fit perfectly with the actual staircase."

-"I find a 3D modeling of the staircase is not fit perfectly with the real staircase but and it's still fun. And hopefully this one can be improved in the future study. So I think that's that's my thinking"

And for experiential:

-"It's more immersive if you don't see the staircase and see other things."

Conversely, the theme "not very clear to see" is all from one participant in experiential condition, saying it is hard to see the graphical features during the experience.

6.4 DISCUSSION

This section provides discussion from our quantitative and qualitative data analysis. It first discusses our interesting observations and findings for each separately. It then provides a overall summary weighting on both data.

6.4.1 *Quantitative Data Summary*

Weighting on both overall and individual experiences analysis, we can demonstrate several noted points regarding both informational and experiential experiences quantitatively.

First and foremost, our two SSS HIWAAR experiences quantitatively received high ratings from participants overall, particularly with respects of pleasure, immersiveness, ease of use and engagement. This result shows our work is both functional and emotionally satisfying. In particular, participants felt pleasant and interesting in trying out our work.

Second, the informational experience scored high in response to pleasure, ease of use, and learnability effectiveness among two conditions. This result

confirms our design aim for the informational experience, which mainly used the audio guidance in providing information as well as delivering the experience. The clarity of information demonstrated through the audio could make participants feel confident in exploring and obtaining a pleasant experience. Participants could also access related aesthetic context by the audio through such experience. The experiential experience scored high with aspects of immersiveness, engagement and flexibility in personal exploration, which also confirms our design aim. As the experiential condition includes different interaction features with complemented visuals, which allows participants to explore by themselves during the experience and obtain a more emotional attachment.

Furthermore, follow up studies revealed that participants could still well recall the HIWAAR experiences after four weeks of the user evaluation. It was also found that participants impression on the experiences as well as awareness of the physical staircase have increased over time. Further analysis showed that it was the **experiential experience** mainly contributed to the enhanced awareness of the sculptural staircase. Besides, specific features were mentioned addressing what particular points contributed to participants enhanced experience. It was interesting to note that *sound/audio* and *visuals* were frequently mentioned in participants answers, regardless of which experience conditions. It was also found that more descriptions of visuals were mentioned specifically in four-weeks after study for the informational experience, which implied that visuals may contribute more in supporting a long-lasting HIWAAR experience. That being said, it was the design of *sound/audio* along with *visuals* in Sonic Sculptural Staircase provided the rewarding augmented sculptural staircase experience in particular.

6.4.2 *Qualitative Data Summary*

Overall, the qualitative data results have shown two experiences in Sonic Sculptural Staircase obtained positive feedback from participants. Participants mainly pointed out that the experience they tried were interesting, creative, engaging and enjoyable. They also addressed some issues remained in our work from design and technical perspectives, like desiring more instructions during the experience from both visual and sound perspectives, as well as the unfitted alignment between 3D staircase model and the physical one in HIWAAR environment.

Diving into these two conditions separately, it was found that themes produced from informational conditions were clustered to the topic of *information*, including the design of the content in audio guidance, information was delivered clear in providing HN building's context or suggestions such as having more visuals to complement the information, etc.

For the experiential condition, it is clear to see there are lots of themes related to the use of visuals in the experience, including positive ones saying visuals making physical features more prominent and reflecting on the context of HN building, and negative ones saying visuals are abstract and not very clear to see in some situations.

Both results are reasonable as well as further verified our design aim for these two conditions discussed Chapter 4in Section 4.1.2: the informational

one focuses on providing straightforward information about the staircase, and the experiential one focuses on letting users actively engage with staircase. Both of these were achieved through the use of visuals, sound and interaction.

Another interesting observation from our result is that participants provided opposite suggestions to the experience condition they tried, which such suggestions have been implemented in the other condition. For example, participants from informational condition stated the needs in more features to allow them to explore more in the experience, including the use of space, more visuals, etc. These requirements have been designed in the experiential experience. Conversely, for experiential condition, participants asked more clear information/instruction during the exploration of this experience.

In addition, our result does mention some technical limitations/flaws produced from our HIWAAR device, which results in some of (minor) negative feelings to participants' overall experience. These issues are mostly related to the limitation of hardware, including the delay in detecting physical environment and sensitive to lights, and yet to be solved at the current stage [25].

6.4.3 *Summary*

In summary, this chapter analysed the data collected from the immediate-after user study as well as follow-up studies. Even though there were limited participants for conducting two experience conditions for our work, a marginally significant on immediate-after survey, as well as interesting insights were obtained from qualitative results.

Affirmative feedback regrading our work Sonic Sculptural Staircase were obtained for both conditions. All criteria examined in the questionnaire scored better than average including ease of use, learnability, immersiveness, engagement and personalisation of experience. In particular, criteria pleasure, immersiveness, ease of use and engagement ranked as the highest three scores, demonstrating our work is both emotionally and functionally satisfying in delivering HIWAAR augmented sculptural staircase experiences.

While among these two experience conditions, a marginally significant difference was obtained from our analysis. This indicates that **there is a tendency** demonstrating there might be a difference among these two experience conditions in delivering augmented sculptural staircase, with aspects of visuals, sound and interaction. Nevertheless, given the limited participant numbers, it was unable to elaborate more at this point. Furthermore, follow-up studies revealed that both experience conditions provided enhanced awareness on the physical sculptural staircase overtime. In particular, it was found that the **experiential experience** may contribute more in the results of enhanced awareness of the staircase. It was also discovered that it was the design of *sound/audio* along with *visuals* mainly contribute to the enhanced HIWAAR experience overall.

As remarked, our analysis from the interview has further demonstrated our quantitative results. Participants further explained reasons or specific points which contribute to their satisfied HIWAAR experience. Overall, features/content in both conditions are able to provide more information related to the context and aesthetics of the staircase and the building. Throughout the

experience, participants were able to get more engaged with the staircase and relate their own experience to their working environment (HN building). In particular, it was found that such is at the advantage of delivering information directly to enhance their appreciation or understanding from informational experience. The experiential experience is better at providing a relative new staircase experience using visual augmentations and sound, which indirectly reminds users to get and reflect on their experience. More importantly, it was interestingly found that participants provided suggestions of existing conditions that map the opposite design: the information one requires more visuals, while the experiential one requires more direct information in the system. This result may indicate that an ultimate HIWAAR sculptural staircase experience would be one that combined the advantages of both of informational and experiential experiences.

7 CONCLUSION

In this thesis, a Highly Immersive and World Aware Augmented Reality (HIWAAR) installation, Sonic Sculptural Staircase (SSS), has been developed to evaluate whether the creation of augmented sculptural experiences can enhance people's appreciation of sculpture and its surroundings. Specifically, two conditions, *informational* and *experiential* experiences, were included in this installation to reflect on the use of visual overlays, sound and interaction in the HIWAAR system to address our research questions.

This work was particularly motivated by the latest evolution in HIWAAR that enables a spatial-aware augmented reality experience, as well as the existing literature of using AR to complement art experiences such as sculpture or paintings to activate users' engagement. Although a few works have attempted to implement such ideas, the analysis of existing literature has revealed limitations and inflexibility of design,which were partially restrained by hardware capabilities. The installation presented in this project advanced the use of visual overlays, sound and "instinctual interaction".

The work described in this thesis commenced by interviewing with art professionals to obtain more solid ideas for the HIWAAR art experiences. With the results produced through interviews, high-level design ideas for SSS were developed. These ideas also acted as empirical directions for answering our research question RQ1. The SSS was then designed and developed mapping high-level ideas from the interviews to an architectural staircase as a target environment. Two experience conditions were particularly included, the *informational* and the *experiential*, to reflect on the different use of visual overlays, sound and interaction in providing such augmented sculpture appreciation experience. During the development, the virtual-real-world object alignment as well as location-specific interactive features were realised in order to achieve highly immersive experiences. User evaluations were then conducted to evaluate and compare these two experience conditions ("informational" and "experiential"). Each participant was asked to experience one of the two conditions and then to complete a questionnaire, an interview and follow-up questionnaires after one and four weeks.

The results from the collected user study data showed that, overall, both experience conditions received positive feedback and that aspects of functionality and emotional quality were shown to enhance the appreciation experience of the augmented sculptural staircase. Participants scored "pleasure" as the highest ranked criterion examined in the quantitative questionnaire. Having a closer look at the two experience conditions in the quantitative data individually, it was found that participants from the informational experience indicated the strength of ease of use and learnability were the two most important aspects affecting their ratings, while for the experiential condition participants indicated the strength of engagement and immersiveness were the two most important aspects, showing such condition provides more emotional attachment. Although it was difficult to obtain statistically significant results given the limited number of participants, the data support **a marginally significant** difference between the two conditions (informational and experiential) for

questions with aspects of ease of use, learnability and immersiveness.

Later analysis of qualitative data further demonstrated our result. In particular, participants from the informational experience condition indicated that using narrative-based audio as informational channel could directly inform related knowledge regarding the staircase. For the experiential condition, participants indicated that such an experience provided a new way of engaging with the staircase and required them to explore its aesthetic context in a more indirect way. Interestingly, the qualitative data showed that participants provided *complementary suggestions* to the implementation of the condition they evaluated: the informational experience desired more visuals and interesting features, and the experience experience desired more straightforward information in navigating in this experience. Generalising from this insight, an ultimate ideal version of our work should using strengths from both conditions.

Follow-up user studies after one and four weeks revealed that participants could still recall the experiences they tried well after four weeks, and the awareness of the physical sculptural staircase was enhanced over time. In particular, the design of sound and visuals were shown to be effective in contributing such enhanced awareness and experience.

Overall, the contributions of this work can be summarised as follows:

- A grounded theory study conducted with art professionals yield the potential of HIWAAR for augmented sculpture experience
- An installation, the Sonic Sculptural Staircase (SSS) has been developed for augmented HIWAAR sculptural staircase experiences that includes two experience conditions: informational and experiential, with different uses of visual overlays, sound and interaction
- A virtual-real-world physical feature alignment and location-specific interactive features have been achieved for providing a highly immersive and world aware experience to engage with real-world features in real time
- The effectiveness of the SSS in providing augmented sculptural staircase appreciation experience has been demonstrated to activate users' engagement

In the next section, it will provide specific discussion in response to research questions set out in Chapter 1.

7.1 REFLECTING ON THE RESEARCH QUESTIONS

RQ1 : **Can an interactive HIWAAR installation enhance the understanding of a sculpture element or architectural space?**

The findings of the the interviews with sculptors in Chapter 3 conceptually validated the idea that a HIWAAR experience can be a mean of providing an augmented sculpture experience. In particular, some of our art professionals discussed how such technology can open a digital space as well as a new layer of sculpture appreciation experience. However,

our interviewees also opined that whether and how much the experience of sculpture could be enhanced would be dependent on the nature of the sculpture and on the design of the HIWAAR experience itself.

The evaluation of the SSS appears to have provided some empirical evidence in support of RQ1. Immediate-after user evaluations quantitatively and qualitatively demonstrated that the SSS provided an experience, which allowed users to obtain complementary information in understanding the design of the staircase itself while actively engaging it either through narrative audio or in a novel experiential experience.

RQ2 : **How can HIWAAR contribute to the creation of such an experience by integrating interaction, visual overlays and sound?**

Following the interviews described in Chapter 3, this question was focussed onto the design aspects of building "informational" or"experiential" experiences and the differences between them.

The informational experience was designed as a narrative audio guidance to navigate users in engaging and understanding the sculptural staircase. Some virtual visual hints were provided as an assistance to complement the audio experience.

The experiential experience was designed with different interactive features that combined visual overlays and sound. This experience required the participant to actively engage with the staircase and reflect on the context of the sculptural staircase.

The quantitative and qualitative results and analysis of this work described in Chapter 6 showed that participants enjoyed such experiences to engage with this sculptural staircase: the information experience was good at providing straightforward information in understanding the staircase, while the experiential experience was good at providing a new experience for exploring the staircase. It was also found that the two experience conditions should balance the use of visual overlays, sound and interaction and that the informational experience could absorb some benefits from the experiential experience and vice versa, based on the suggestions from participants. That being said, a proper amount of the use of visual overlays, sound and interaction is important, neither too thin, which only highlights one aspect (the informational experience), nor too substantial, that attempts to incorporate lots of aspects with complicated features. In addition, as addressed in answering RQ1, such design considerations need to tie in closely with the design of the concrete sculpture (and surrounding context) itself.

RQ3 : **Can HIWAAR installations change a person's daily experience which relates to the environment?**

The follow-up studies described in Chapter 6 showed that participants' awareness of the physical sculptural staircase had been enhanced over time, comparing results between one week after and four weeks after results. These follow up studies appear to show that the *experiential* experience may have a stronger impact on participants' awareness than the informational experience. It was also worth noting that follow-up survey data indicated that the design of visuals and sound primarily

contributed to effectiveness of people's enhanced daily experience of the sculptural environment to the related environment.

7.2 LIMITATIONS AND FUTURE WORK

As addressed in the Chapter 6, we failed to obtain a statistically significant result in differentiating the informational and experiential experiences due to limited number of participants. The number of participants were limited due to the extended period of social distancing during the COVID-19 pandemic response of 2020 and the amount of time needed to obtain work health and safety and human ethics approval for this experiment. More user evaluations may produce a clear distinctions in the results between these two experiences, as well as help to address how the different uses of visual overlays, sound and interaction can contribute to an immersive augmented sculpture appreciation experience.

Second, follow-up studies have presented positive results suggesting that the HIWAAR installation have enhanced participants awareness of where the work physical relates. However, these studies were conducted only one week after and four weeks after the user evaluation. The proposed eight weeks after study is yet to run due to the time limit upon the submission of this thesis. That being said, the eight weeks after follow-up study will still be conducted and hopefully can be incorporated into a future publication.

Finally, user evaluations also revealed that the SSS experiences were occasionally affected by lighting conditions and led to latencies or inaccuracies while interacting with certain features. This may contribute to some of deficient data collected for analysis. In a future experiment, particularly one involving more participants, it should be possible to check whether variations in lighting conditions affected conclusions inferred from the data.

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APPENDIX

INTERVIEW WITH ART PROFESSIONALS ETHICS DOCUMENTS

Interview questions:

1. Can you describe the nature of your interest in sculpture?
    a. Are you a sculptor?
    b. For how many years have you been interested in sculpture?
    c. Approximately how many exhibitions of sculpture have you attended?
    d. What is your age range?
        i. 15-30
        ii. 31-45
        iii. 45-60
        iv. 60+

2. How much should a sculptor create sculptures with the viewing public in mind?
    a. Please comment on:
        i. When should a sculptor consider the public during the process of creating and installing a sculpture? Initial idea? During construction? In the final stages of work? When installing it?
        ii. How might a sculptor imagine members of the public interacting with/experiencing your sculpture?
            1. Is there a difference between "private" (exhibition/collections) and "public" sculpture in imagining how people might interact with it?

3. Should sculpture be able to be physically touched by members of the public? Are there controversial aspects to this? What about hygiene (coronavirus!)?

4. What kinds of additional elements do you think might improve the experience of sculpture and why? (E.g. music/lights?) Can music, live visuals (such as the projections of the Enlighten festival) or dance performance improve the experience of sculpture?

5. As a sculptor, how do you feel about other artists, or just members of the public "remixing" your work using music, dance, painting, projections and so on? Should the original artist be consulted (or paid) to authorise remixing?

6. Have a look at the following figures. They show a sculpture called The Great Listening in the Synergy building at CSIRO Black Mountain Laboratories. Members of the public are wearing augmented reality headsets that allow them to see the sculpture overlayed with "holographic" 3D projections. Using a **"visual touch"**

interaction in **free space**, people can interact with the holograms to, for example, play music or to control visual projections overlayed on the sculpture. What do you think about such a concept?

7. New AR headsets allow a complete tracking of all of your fingers. This would allow users to use finger gestures or to touch and stroke a **physical** controller (that might be an abstract scale model of a sculpture) and to allow members of the public to stroke and manipulate such a scale model to generate visuals and sound that might overlay or just complement the experience of the sculpture itself. What do you think about such a concept?

Participant Information Sheet

Researcher: This research is part of a research project conducted by master student Yichen Wang and academic staff member Associate Professor Henry Gardner in the Research School of Computer Science, College of Engineering and Computer Science, at the Australian National University.

Project Title: Augmenting the Experience of Sculpture

General Outline of the Project:

- **Description and Methodology:** The purpose of this study is to gather information for designing an immersive visualisation artefact for augmenting the experience of sculpture. In this study, an interview will be conducted using a set of open-ended questions in order to understand basic knowledge of sculpture creation and possible ways to augment sculpture-viewing experiences. The collected information will be further analysed and used for artefact design in Augmented Reality environment. The interview will take approximately one hour and the audio will be recorded.
- **Participants:** Participants will be professionals, students and members of the public familiar with the general field of sculpture. The majority of participants will be sculptors, sculpture students and art professionals.
- **Use of Data and Feedback:** It is intended that this data will be used for a research thesis, and for the potential publication in a scientific journal. Participants can request to access the results after study completion.

Participant Involvement:

- **Voluntary Participation & Withdrawal:** Participation in the project is completely **voluntary** and you may, without any penalty, decline to take part or withdraw from the research at any time during the experiment without providing an explanation, or refuse to answer a question. If you choose to withdraw, your data will not be analysed. Given that participation is anonymous, it will not be possible to decline to have your data included at a later date after the experiment as we will not be able to identify which data is yours.
- **What does participation in the research entail?**
  The participants will be asked to undertake an interview with the researcher. During the interview, the researcher will go through prepared questionaries and ask the participant questions. We may contact you for clarification on any of the information discussed in the interview. The audio of the interview will be recorded.

- **Location and Duration:** Interviews will take place online via Skype or another video conferencing tool or by phone. Interviews are expected to last about an hour.

- **Remuneration:** No remuneration is being offered for your participation in these interviews.

- **Risks:** There are no known risks, discomforts, hazards or side effects from participation. Because of the small number of interview participants there is a small risk that published data could be reverse engineered to identify a particular participant. However, participant names and contact details will not be included in any research publications.

- **Benefits:** The outcomes of these interviews will be used to inform the design and evaluation of systems to enable the immersive visualisation artefact for augmenting experience of sculpture.

Confidentiality:

- **Confidentiality:** The data from the study will be anonymised so that no participant will be able to be identified from any data collected. All results published will be in regard to the overall findings from the cohort of participants and not on an individual basis. Up until three months after the interview, if you give your permission, your contact details will be retained for follow-up questions. The data may be used in follow-up research by researchers not listed on this form. All researchers who will gain access to the data collected in this research will be listed under the same human ethics protocol as the current researcher.

Privacy Notice:

In collecting your personal information within this research, the ANU must comply with the Privacy Act 1988. The ANU Privacy Policy is available at https://policies.anu.edu.au/ppl/document/ANUP_010007 and it contains information about how a person can:

- Access or seek correction to their personal information;
- Complain about a breach of an Australian Privacy Principle by ANU, and how ANU will handle the complaint.

Data Storage:

- Data collected from these interviews will be stored securely in the Research School of Computer Science, ANU, and destroyed after three months. Anonymised data from the experiment will be stored securely in the Research School of Computer Science, ANU.
- If a research publication results from this work, anonymised data will be stored for a minimum of 5 years following the date of any publication. This publication data will be kept in secure storage at the Research School of Computer Science, ANU.

Queries and Concerns:

Contact Details for More Information: For further requests for information or queries regarding the study, please contact Yichen Wang. email: Yichen.Wang@anu.edu.au or Henry Gardner.
email: Henry.Gardner@anu.edu.au.

Ethics Committee Clearance:

The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee (Protocol 2016/156). If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: +61 2 6125 3427
Email: Human.Ethics.Officer@anu.edu.au

WRITTEN CONSENT for Participants

Interview for the project Augmenting the Experience of Sculpture

I have read and understood the Information Sheet you have given me about the research project, and I have had any questions and concerns about the project (listed here) addressed to my satisfaction.

I agree to participate in this interview. YES ☐ NO ☐

I agree to have the audio of this user evaluation recorded. YES ☐ NO ☐

Signature:.....

APPENDIX

SONIC SCULPTURAL STAIRCASE USER STUDY ETHICS DOCUMENTS

Participant Information Sheet

Researcher: This research is part of a research project conducted by master student Yichen Wang, academic staff member Associate Professor Henry Gardner and Dr. Charles Martin in the School of Computing, College of Engineering and Computer Science, at the Australian National University.

Project Title: Sonic Sculptural Staircase Experience Evaluation in Mixed Reality Headsets

General Outline of the Project:

- **Description and Methodology:** The purpose of this study is to evaluate two distinct interactive AR experience of the "sculptural staircase" between levels 2 and 3 at the Hanna Neumann, ANU. These experiences are called "informational" and "experiential". In particular, this study aims to examine their effectiveness in providing a rewarding and long-lasting experience that enhances people's appreciation of the sculptural staircase and its surroundings. The study consists of three parts: user evaluation, post study questionnaire and interview study. Participants will be firstly asked to experience one of AR experiences while walking up the staircase. After the experience, participants will be immediately asked to finish a post study questionnaire and interview regarding their experience. The participant will also be asked to join a short follow up interview study after 1 week, 4 weeks and 8 weeks regarding their experience. The collected information will be further analysed and used for the conclusion of the work. Overall, the study will take approximately one hour including user experience, post study questionnaire and interview. The follow up interview will take approximately 15 mins.

- **Participants:** Participants will be recruited from academics and students who work at the building where the AR experience was built upon (the Hanna Neuman Building at ANU) through email invitation or poster put up around in the building. Ideally, participants will be students or staff who are co-located on Level 2 or 3 of the Hanna Neuman Building at ANU where the work is being undertaken.

- **Use of Data and Feedback:** It is intended that this data will be used for a research thesis, and for the potential publication in a scientific journal. Participants can request to access the results after study completion.

Participant Involvement:

- **Voluntary Participation & Withdrawal:** Participation in the project is completely **voluntary** and you may, without any penalty, decline to take part or withdraw from the research at any time during the experiment without providing an explanation, or refuse to answer a question. If you choose to withdraw, your data will not be analysed. Given that participation is anonymous, it will not be possible to decline to have your data included at a later date after the experiment as we will not be able to identify which data is yours.

- **What does participation in the research entail?**

  In this study, you will be asked to experiment one of two distinct interactive AR experiences while wearing a Microsoft Hololens2 in a staircase. Given the staircase's safety concern and potential for other human traffic, you will be asked to follow the route based on the researcher's instruction so that other users of the staircase can have access to it if needed and to keep you close to the bannister in case you need it. You will be encouraged to use the bannister if they feel unstable at any time. You will also be told that you can choose to terminate the experiment at any time.

Australian National University

After finishing all the tasks, you will be asked to finish a questionnaire and interviewed to provide general feedback on what you experienced, answer some specific questions regarding the AR experience. The record will be analysed, and the results will be shown in the research report, and these records can only be accessed by people with authorization. The researcher may approach some participants directly to ask whether they mind including a photo of themselves in a publication.

- **Location and Duration:** The task and interview will be taken at level 2, Hanna Neuman Building, ANU. The task and interview may take one hour to finish including reading time. The follow up interview will take approximately 15 mins.

- **Risks:**

    - There are some general risks involve in using a Mixed Reality headset. Some participants may experience eye strain when the watch the little screen. When using the application, there might be a trip when you walk and look around in Headset, and you might be dizzy because of the MR environment. When this happens, the task will be terminated, and you have to rest and take necessary aid action according the issues. Please also be careful while walking up the staircase, use the bannister if needed at any time.

    - The main risks involved with this study are cross-contamination of the augmented reality headsets when being moved from one participant to another and the associated COVID19 risks associated with that cross-contamination. It also includes the use of public staircase while following COVID-safe guideline. We discuss the mitigation of these risks in the following points.

    - All test participants will have completed the Australian Government induction and ANU forms related to managing the risks of COVID19. Prior to a new participant using this equipment, the equipment will be cleaned with an alcohol wipe without being touched. The new participant will start by cleaning the equipment once again before their personal use.

    - During use of the headset, only the participant will touch the headset and participants and the study supervisor will keep a minimum of 1.5m away from each other.

    - The participant will be asked to have good personal hygiene practice (including handwashing using sanitizer) before the experiment. The research will provide personal protective equipment (e.g. face masks) where appropriate for the participant. Participant will also be asked to check in use “Check In CBR” app to provide contact details under public health direction when entering Hanna Nueman Building.

    - The WHS hazard and risk assessment have been conducted and approved regarding the safety and hygiene concerns during the experiment for participants from School of Computing. The staircase between level 2 and 3 at Hanna Neuman Building will be engaged in routine cleaning and disinfection of surfaces follow COVID-19 safe rules.

    - This proposed protocol will be revised if the situation in the ACT changes dramatically. At present, there are no recorded cases in the ACT. A “dramatic” change would be if there were to be more than 10 cases recorded in the ACT. In this case, we will revisit this proposed protocol.

- **Benefits:** The outcomes of these interviews will be used to inform the design and evaluation of systems to enable the immersive visualisation artefact for augmenting experience of sculpture.

Confidentiality:

- **Confidentiality:** The data from the study will be anonymised so that no participant will be able to be identified from any data collected. Confidentiality will be protected to the extent permitted by law. All results published will be in regard to the overall findings from the cohort of participants and not on an individual basis. Up until three months after the interview, if you give your permission, your contact details will be retained for follow-up questions. The data may be used in follow-up research by researchers not listed on this form. All researchers who will gain access to the data collected in this research will be listed under the same human ethics protocol as the current researcher.

Privacy Notice:

- In collecting your personal information within this research, the ANU must comply with the Privacy Act 1988. The ANU Privacy Policy is available at https://policies.anu.edu.au/ppl/document/ANUP_010007 and it contains information about how a person can:
  - Access or seek correction to their personal information;
  - Complain about a breach of an Australian Privacy Principle by ANU, and how ANU will handle the complaint.

Data Storage:

- Data collected from these interviews will be stored securely in the School of Computing, ANU, and destroyed after three months. Anonymised data from the experiment will be stored securely in the School of Computing, ANU.
- If a research publication results from this work, anonymised data will be stored for a minimum of 5 years following the date of any publication. This publication data will be kept in secure storage at the School of Computing, ANU.

Queries and Concerns:

- **Contact Details for More Information:** For further requests for information or queries regarding the study, please contact Yichen Wang. email: Yichen.Wang@anu.edu.au or Henry Gardner. email: Henry.Gardner@anu.edu.au.

Ethics Committee Clearance:

The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee (Protocol 2016/156). If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: +61 2 6125 3427
Email: Human.Ethics.Officer@anu.edu.au

Date: **Experiment No.**

Section 1: Post Study Questions on the experience of Sonic Sculptural Staircase (Rate on Likert Scale 1-7)

1) Ease of Use – Overall, it was easy to explore this sonic experience in Head-Mounted AR environment.

☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly Agree Neutral Strongly Disagree

2) Learnability/Effectiveness – The experience has enhanced my understanding or brought me some new insights of this sculptural staircase and its architectural space.

☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly Agree Neutral Strongly Disagree

3) Immersiveness – With the support of sound and visual overlays (e.g. matrix effect or virtual information panel), I felt more emotionally involved in experience this interactive AR experience.

☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly Agree Neutral Strongly Disagree

4) Pleasure – It was pleasant/interesting to explore this sculptural staircase work with interesting features in Head-Mounted AR environment.

☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly Agree Neutral Strongly Disagree

5) Engagement – Overall, I felt more engaged with this sculptural staircase and by exploring features in this sonic AR experience.

☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly Agree Neutral Strongly Disagree

6) Personalisation of Experience:
   a. Overall, I was able to explore this work with flexibility and spent more time on features I was interested.

☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly Agree Neutral Strongly Disagree

   b. While trying out different features (that provides sound and visual feedback) in this work, they could relate some of my own experience in this staircase or the building.

☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly Agree Neutral Strongly Disagree

Section 2: Follow-up Interview Questions

Immediately-after follow-up questions

Q1. How was your sculptural staircase AR experience? What impresses you most?

Q2. Did it bring you some new insights regarding the building?

Q3. Any suggestion to the implementation of the experiment?

1/4/8 week-after follow-up questions

Q1. How well can you recall the particular sculptural staircase AR experience that you tried? (Note that "neutral" is about as well as you can recall anything else that happened at about the same time that you undertook the AR experience.)

☐ ☐ ☐ ☐ ☐ ☐ ☐

Extremely Poorly Neutral Extremely well

Q2. What stands out in your memory of this experience? (Please list all things that come to mind.)

Q3. After trying out this experience, has your awareness of the physical staircase and the building been enhanced in your daily life as you use the building?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Much Less Aware Neutral Much More Aware

Pre-Experience Questionnaire

Participant: Date:

Q1. What is your gender?

A. Female B. Male C. Other D. Prefer not to say

Q2. What is your age?

A. 18 - 24
B. 25 – 34
C. 35 – 44
D. 45 – 54
E. 55 and above

Q3. Do you work in this building? What kind of work do you do? How long have you been in this building?

Q4. Which floor do you work on? Do you think much about this staircase?

Q5. Do you use this staircase much? How many times do you use it during a week?

Q6. What do you think of this staircase and the design of this building?

Sonic Sculptural Staircase User Study Evaluation Script

Note: a formal script will be read to each participant so that all subjects receive the same information with the added benefit of ensuring completeness in following steps. It may not be completely necessary to adhere to strict scripts in the real user study situation but utilised as a checklist.

Evaluation Details

Participant	
Date	
Start Time	
End Time	
Venue	
Researcher	

No.	Script	Summary	Location
1	Thanks for joining the user study of Sonic Sculptural Staircase here today. I have a script which I will read through to you. This might seem to be a bit formal, but I just want to ensure that all participants receive the same information. <pause/offer opportunity for questions after each script number>	Welcome participants.	Rest area in front of the staircase at level 2 HN building
2	The purpose of today's activity is to ask you experience and evaluate one of the two sonic AR experiences while walking up this sculptural staircase using Microsoft HoloLens 2, which is a part of my honours project. Given the safety concern, you will be asked to follow the route shown in figure 1. After trying out the experience, you will be asked to finish a post-study questionnaire and interview regarding the experience. You will also be asked to join a short follow up interview study after 1 week, 4 weeks and 8 weeks regarding your AR experience. (You won't need to try it out again). The whole experiment will take about an hour.	Brief the participants.	Rest area in front of the staircase at level 2 HN building

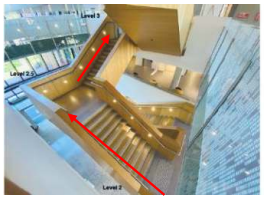

Figure 1 Suggested Route

<show appendix about suggested route>

For your experiment condition – either informational or experiential: seen Appendix

In general, our study aims to examine the effectiveness of such head mounted augmented reality technology in providing an augmented sculpture (or sculptural element) appreciation experience.

I also want to inform you that our study has been approved from ANU Human Research Ethics committee as well as risk assessment from WHS group (including COVID-safe) to make sure your safety and privacy from this experiment. The information you give us is confidential, and your name will not be stored with this information. In the experiment, you are encouraged to use the bannister if you feel unstable at any time while wearing the AR headset. You can choose to terminate the experiment at any time if you wish to.

Before the formal experiment, I'll provide you a quick tutorial about using Hololens 2 as well as let you try it out in the staircase to make sure that you are familiar with it. There isn't much interaction required in the experiment, but I just want to get you be more familiar with this AR environment for our study. I will also be stand-

	by throughout the experiment in case you need any help. <show information sheet, and allow time for his/her reading> <pause/offer opportunity for questions after each script number>		
3	Can you please read this consent form, and sign it if you agree? You are welcome to ask anything that is not completely clear in this form. <Give participant the consent form, and allow time for his/her reading and to sign> Thank you	Obtain consent	Rest area with table in front of the staircase at level 2 HN building
4	We will start the tutorial. You would feel easier I you have watched the tutorial video I sent to you. Anyway, let's start. Could you please perform the task following my instruction? • Take up HoloLens headset adjust the size to fit your head. • Turn HoloLens on. • Put HoloLens on your head and adjust glass position to be just in front of your eyes. • Use your finger to operate the HoloLens. • Ask the me for any guidance if you need to. • Find the menu and open 'playground' app • If you have watched the quick tutorial video I sent to you previously, you can start trying it out. • Otherwise - please follow me. ○ First, you should see a virtual object in front of you.	Offer training	Open space near the rest area in front of the staircase at level 2 HN building (ensure it won't disturb others in public)

	○ Please hover you hand on this object, you may see a bounding box surrounding the object. ○ You could try to make this object bigger or smaller, rotate, grab or move by using this bounding box as hint. Cool, so this is generally how to use the HoloLens. Now, could you please try to walk up the staircase for a few steps? Do you feel any inconvenience or discomfort? If everything is good, let's start the experiment!		
5	• Please stand in front of the staircase at Level 2, Hanna Neuman Building • Open menu and open "sonic_experience_1" • Wait for application to load. • When loading has finished, look around in HoloLens environment. • Let me know if there is any issue. Otherwise, please start walking up the staircase and exploring the features given in the experiment	Initiate the formal study	In front of the staircase at level 2 – starting point
6	The task for AR experience has finished.	End the AR experience experiment.	The exit of the staircase at level 3
7	I would like to finish this questionnaire regarding your experience and ask you three questions about. Would you mind going to the tearoom area and finish this section? <provide the questionnaire> Let me know when you finish the questionnaire so that we could start interview.	Conduct post session questionnaire and interview	Tearoom area at level 3

	<work through post evaluation questions and start audio recording>		
8	The whole session has finished. Thank you very much for your time today. <escort participants from the test area> <Collect notes and any other materials from the observers, if any, and tidy the test area>	Offer final thanks. If data collection forms have been used, collect them from all involved.	Tearoom area at level 3

Appendix 1: User Study Configuration

This study aims to evaluate and compare two distinct sonic AR experiences of the "sculptural staircase" between Levels 2 and 3 of the Hanna Neumann Building (figure 1). These experiences are called "Informational" and "Experiential". This study aims to examine their effectiveness in providing a rewarding and long-lasting experience that enhances people's appreciation of the sculptural staircase and its surroundings. The features involved in each experience are shown in figures 2 and 3.

This study will be conducted as a between-subjects study where participants will be randomly allocated to one of two equally sized groups and will be asked to experience one of AR experience conditions while walking up the staircase. Given the staircase's safety concern and potential for other human traffic, the experiments will be conducted at a relatively quiet time of the day. In addition, printed signs with information about the study will be placed at the top and bottom to inform other users of staircase before and during the experiment. The researcher will ask the participant follow the route shown in figure 1 (keeping at the left) so that other users of the staircase can have access to it if needed and to keep the test participants close to the bannister in case they need it. The participants will be encouraged to use the bannister if they feel unstable at any time. Participants will also be told that they can choose to terminate the experiment at any time if they wish to.

After the experience, the participant will be immediately asked to finish a post-study questionnaire and interview regarding the experience. The participant will also be asked to join a short follow up interview study after 1 week, 4 weeks and 8 weeks regarding their AR experience.

Overall, the process of the experiment is:

1. Before the experiment, the researcher will give an introduction about the work and two AR experiences set-up in Sonic Sculpture Staircase. Participants are asked to sign the information sheet and consent form about the experiment.
2. Participant will be given a short tutorial about using AR headset and the work by the researcher.
3. Participant will be asked to start the informational AR experience at level 2 in front of the staircase and finish it at the end of this staircase at level 3.
4. Once participant informs the researcher his completion of the experience, the participant will be asked to take off the headset and finish a post study questionnaire regarding their experience.
5. Participant will be asked to join a short follow up interview study after 1 week, 4 weeks and 8 weeks about the impact of this experiment in response to their understanding or appreciation of the sculptural staircase and its surroundings.

6. *Repeat step 1-5 for experiential AR experience condition.*

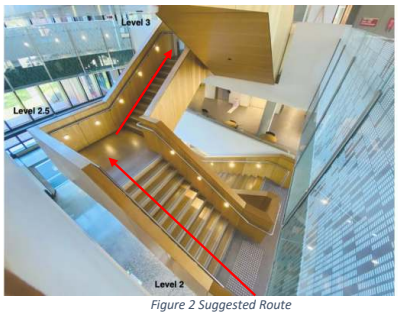

Figure 2 Suggested Route

Appendix 2: Description of AR experiences in Sonic Sculptural Staircase

Informational experience:

This AR experience is delivered by audio guidance with some virtual visual hints to provide background information about this physical sculptural staircase. The audio guidance includes four major parts that inform the information. During the experience, the participant is able to look at different parts of the staircase and surroundings to understand its aesthetic context.

Figure 3 Features in informational experience

Experiential experience:

This AR experiential experience requires the participant to actively engage with the staircase to obtain a rewarding understanding of its aesthetic context. Ten different features are included in this experience allow the participant to explore by walking or hand touch interaction in the head-mounted AR environment. Sound and visual augmentation will be prompted through participants' active engagement, which reveals information related to this sculptural staircase background.

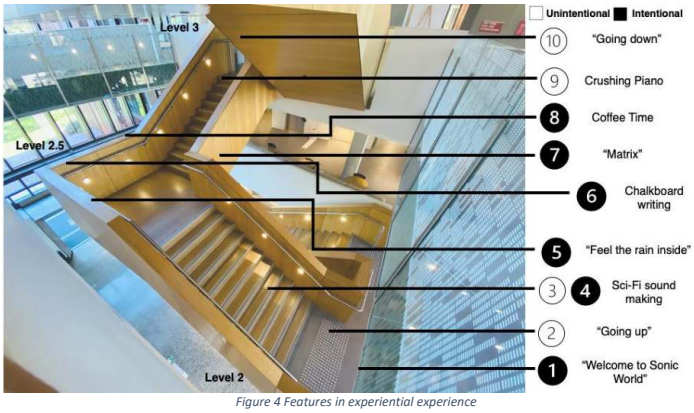

Figure 4 Features in experiential experience

Sonic Sculptural Staircase User Study Preparation Checklist

Experiment No.
Date:
Hololens No:

Before the study:
- Clean hardware
- Check software
- Prepare all docs
- Place notice and warning stand

After the study:
- Check hardware
- Check all docs has collected
- Collect notice and warning stand

All check details:

Hardware		Comments	Check	
			Before	After
Microsoft HoloLens (H19 or H21 depending on experiment condition)	Battery is 100%			
	Has hygiene • The surface except glasses has been wiped by cleaning wipes			
Software				
	AR artefact worked			
	Staircase model aligned with real world staircase			
Admins				
	Staircase cleaned before/after study for area touched by study participant			
	Notice has put up before the study			
	Warning stand has set up at *the entry* and *exit* of the staircase at level2/3			
	Double check participant do not have any psychological issues i.e epilepsy would not be qualified for this study)			
Documents				
	Consent form			
	Information sheet			
	Questionnaire			
	Interview script			

1

	Evaluation script			
	User study checklist			
	Evaluation process map			

WRITTEN CONSENT for Participants

User study for the project Sonic Sculptural Staircase Experience Evaluation in Mixed Reality Headsets

I have read and understood the Information Sheet you have given me about the research project, and I have had any questions and concerns about the project (listed here) addressed to my satisfaction.

I agree to participate in this user study. YES ☐ NO ☐

I agree to have the audio of this user evaluation recorded. YES ☐ NO ☐

Signature:……

SONIC SCULPTURAL STAIRCASE USER STUDY PARTICIPANTS LIST

	Q1	Q2	Q3	Q4-a	Q4-b	Q5-a	Q5-b	
X	M	B	PhD in cs - 2 years	3	No	Yes		18
Z	F	B	PhD in cs - 1.5 years	2	No	Yes		5
P	M	E	PhD in cs	2	Working near this work's author and it makes me think about the stiarcaxse. And they architecturenof the sapc			20
HS	M	B	honors student in cs	2			~20	
C	F	B	PhD in cs - 1.5 years	2	Not much.	Yes	5~6	
XC	M	B	PhD in cs - 1.5 years	2	Yes	Yes	3~4	
A	M	A	Master student working in t	2	Yes	Yes	>10	
RC	F	A	PhD in cs	2	No	Yes	1~2	
RC	M	B	PhD in cs	2	No	Yes		20
A	M	B	academic	4	Yes. I like the staircase - it's so open and invinting.	Yes	~10	

Q6
Nothing
It looks good but get bored after a while.
I enjoy the overall architecture of the building. The way the staircase narrows from level 1 to level 2 is interesting. The materials connect to natures, yet it is also industrial and not necesaryily efficient.
I quite like it, it's a bit unique - and I like wood:)
The staircase is located in such a way that we can view the surroundng buildings. Design or the building -> central area of each follor has a lot of space which anyone can use which I think is good.
I feel space is lost in this design. Having a separate bridge in level 3 and 4.
I always have my coffee go through the staircase, so I love some special feeling about this staircase. I think the design is very interesting and friendly for users who would like to know about the building.
Initially, I hated it. I thought It was very cold. But I like the staircase as a central feature for the building. I thought it brought a lot of mcj needed warmtn into the space.
The design of this building is very modern. I like the infrasture and the clean and bright environment. I didn't think too much of the staircase though.
I like how the building is structured around the staircase. The stiarcase almost acts as another lounge where you meet people.