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Digital Interactions for Low Vision Spatial Engagement

A 120 point thesis submitted to the Victoria University of Wellington in partial fulfilment of the requirements for the degree of Master of Architecture (Professional).

by Zachary Cooper

Victoria University of Wellington
School of Architecture
2019

PROLOGUE 0.0

ABSTRACT

Vision impaired persons require specific forms of spatial information for them to navigate the built environment successfully. Unfortunately, a majority of our existing infrastructure does not adequately address the needs of this community, thus harming their ability to participate in society independently. Solutions that address these environmental deficiencies fall into two broad categories, assistive technology or universal design. Both forms of solutions are incapable of compensating for the inadequately considered design of public spaces and are subject to widespread criticisms from both the vision loss and architectural community (Human Rights Commission, 2012; Pawluk et al., 2015).

This thesis recruits the native capabilities of emerging consumer-level digital technologies to explore new solutions to this complex problem. This design-led research saw the proposition tested through the development of a digital platform. The outcome is a virtual engagement scheme which draws upon the design strategies of universal design and assistive technologies and combines them with theoretical perspectives from a broad range of fields. This integration resulted in unique modes of engagement that improved the spatial comprehension abilities of the visually impaired.

Early design outcomes focused on establishing two distinct modes of engagement with a mixed-reality (MR) environment. The first regarded direct bodily interaction, in which users local sensory perception is bolstered through an object-detection system which provides sensory cues that notify users to objects in their immediate vicinity. The second saw the creation of methods for distance-based spatial interaction. Ranged engagement with the environment significantly expanded the scale of potential spatial understanding. The modes of engagement allow users to explore spaces in a myriad of different ways, with each form of interaction providing unique environmental information through diverse sensory outputs. The later design stages critically reflect on these outcomes and formalise processes for development and evaluation. These processes allow broader observations to be drawn regarding the creation of these tools and what they may offer for spatial engagement and understanding. The final research conclusions outline a framework for future research which would assist in the digital adaptation of our currently inadequate infrastructure.

ACKNOWLEDGEMENTS

To Tane Moleta and Marc Aurel Schnabel, for their consistent enthusiasm and creativity. This thesis is as much a result of their efforts as it is mine. Any attempt to disentangle my contributions from theirs would prove impossible.

To the DARA team members, Amir, Chiara, Liam, Sam, Shuva, and Will for their comradery, encouragement and critical discussions.

To my friends and family, for their consistent support throughout my studies and for providing the fun and entertainment that kept me going.

To my cohort, for friendship and inspiration.

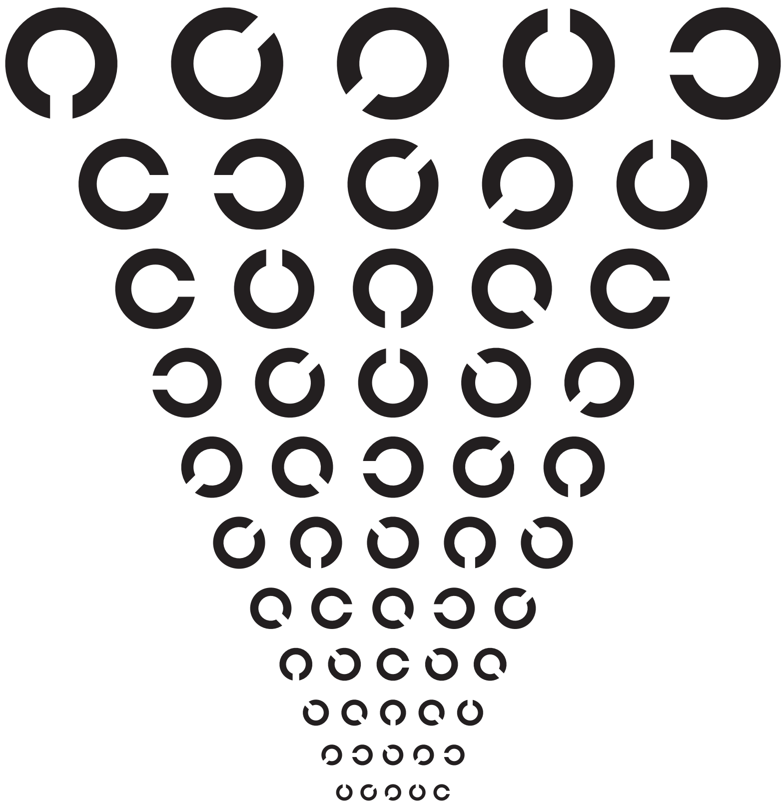
I thank you.

MOTIVATION

The motivation that underlies the project is both personal and academic. Throughout my life, I have had a significant amount of interaction with the visually impaired, including close family members. Their creativity, resolve, and unique approaches to daily tasks were inspiring and led to a personal interest in this community. A personal dissatisfaction that later compounded this was the visual emphasis placed upon many of the student projects I completed throughout my architectural studies. I felt that the visual concern reduced the evaluation of design into a question of artistic flair rather than holistic design skills. My architectural interests, which tended towards sensory design and practical issues, such as accessibility, were reinforced by this experience. The pursuit of this thesis provided an excellent opportunity to explore the intersection of both my architectural and personal interests.

CONTENTS

LANDOLT 'C' OPTOTYPE



Decimal	logMAR	Feet	Metres
0.10	1.00	20 / 200	6 / 60
0.125	0.9	20 / 160	6 / 48
0.16	0.8	20 / 125	6 / 38
0.20	0.7	20 / 100	6 / 30
0.25	0.6	20 / 80	6 / 24
0.32	0.5	20 / 63	6 / 19
0.4	0.4	20 / 50	6 / 15
0.5	0.3	20 / 40	6 / 12
0.63	0.2	20 / 32	6 / 9.5
0.8	0.1	20 / 25	6 / 7.5
1.00	0.0	20 / 20	6 / 6

DEFINITIONS

Standard Visual Acuity

Standard visual acuity is defined as 20/20 (Feet). These numbers indicate that the person tested is able to identify an object at 20 feet, that a person with standard visual acuity will be able to identify at 20 feet.

Visual Impairment

A term used to desribe various reduction in visual acuity. It is often prefaced with a term such as mild, moderate etc.

Low Vision

Low vision is defined as a reduction in vision that cannot be corrected through medicine, surgery or glasses/ contact lenses. This term is often used interchangeably with visual impairment.

Blindness

Defined as visually acuity that is less than 20/200. Blindness represents total or almost total vision loss.

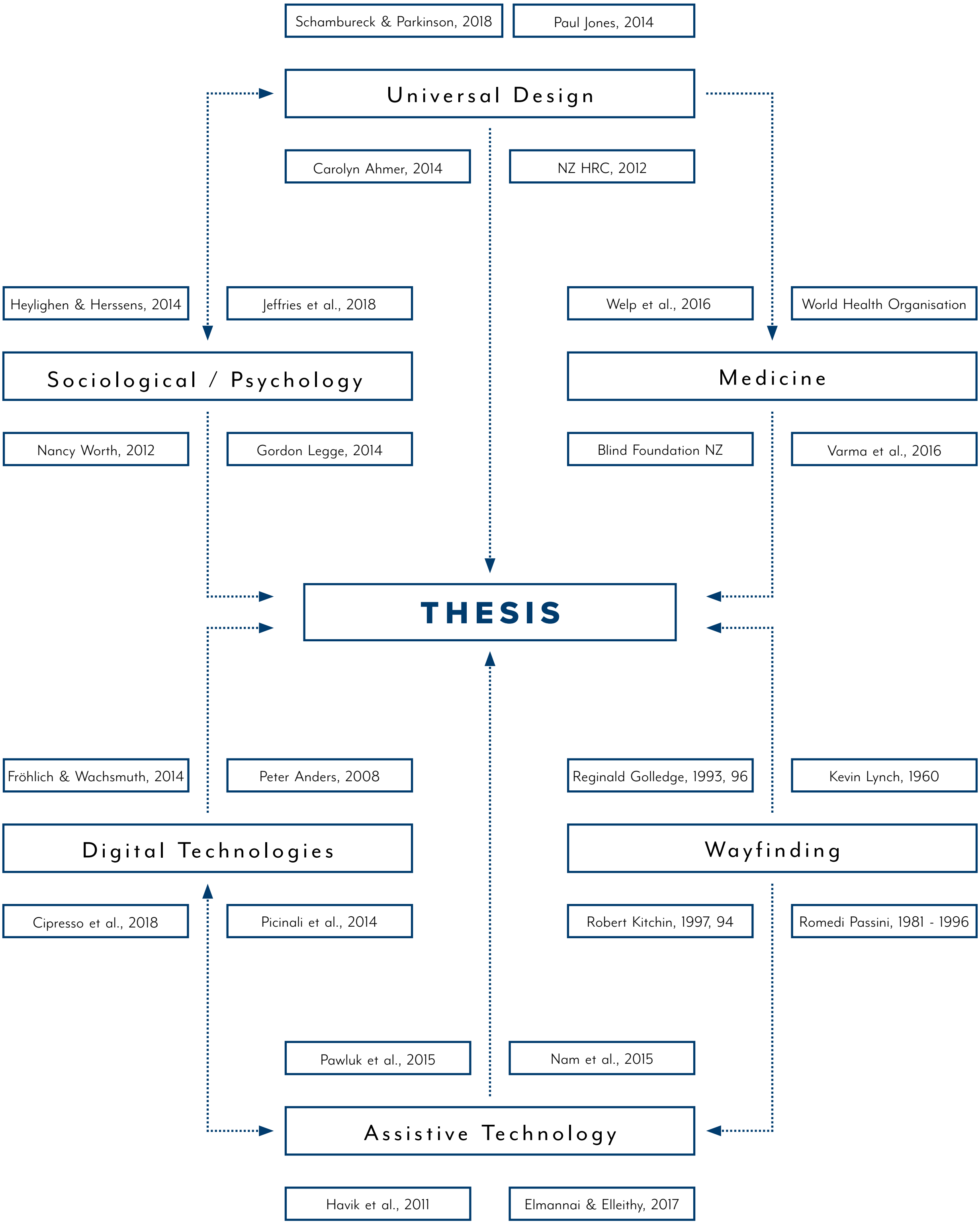
INTRODUCTION 1.0

1.1 INTRODUCTION

Estimates show that globally, 1.3 billion people are afflicted with some form of visual impairment (Blindness and Vision Impairment, 2018). Vision loss poses a severe risk to the general autonomy of those afflicted, often leading to social isolation, anxiety, and depression (Welp, Woodbury, McCoy, & Teutsch, 2016). Our existing environment exacerbates these issues through its lack of consideration regarding the communities practical and experiential requirements for functioning within built environments. Current approaches for the augmenting and adaptation our existing environment fall into two main categories, assistive technology and accessible design. Both of these fields suffer from many shortcomings and are insufficiently equipped to rectify the practical deficiencies encoded into our built infrastructure.

Digital technologies possess unique qualities that may provide alternative solutions to this multi-faceted problem. Emerging digital technologies, such as VR and AR, have recently become consumer-level devices, seeing rapid uptake into architectural practice and mainstream society. These tools possess computational development platforms, multi-sensory outputs, and freedom from real-world physical constraints. The available simulation capabilities allow them to address the experiential requirements of those with vision loss in an appropriate sensory format while the computational platform offers freedom to explore potential solutions with low costs of failure.

In response to the complicated relationship between vision loss and architecture, this design-led research investigates a broad range of unconventional solutions through the use of digital technologies. The project fundamentally situates itself at the intersection of these digital technologies, assistive technology, and universal design. A preliminary investigation uncovers the roots of the problem and evaluates the shortcomings of the existing solutions. Following this, a broad theoretical network is drawn upon to investigate how digital technologies may provide new opportunities for ameliorating the failures of the current built environment. The design investigation takes place within a mixed reality environment where new possibilities for architectural engagement and spatial understanding are created and examined.


Schambureck & Parkinson, 2018
Paul Jones, 2014
Universal Design
Carolyn Ahmer, 2014
NZ HRC, 2012
Heylighen & Herssens, 2014
Jeffries et al., 2018
Welp et al., 2016
World Health Organisation
Sociological / Psychology
Medicine
Nancy Worth, 2012
Gordon Legge, 2014
Blind Foundation NZ
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THESIS
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Reginald Golledge, 1993, 96
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Digital Technologies
Wayfinding
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Robert Kitchin, 1997, 94
Romedi Passini, 1981 - 1996
Pawluk et al., 2015
Nam et al., 2015
Assistive Technology
Havik et al., 2011
Elmannai & Elleithy, 2017

1.2 PROBLEM

Vision loss poses a significant issue worldwide, with an estimated 1.3 billion afflicted by some form of visual impairment (Blindness and Vision Impairment, 2018). The ageing population phenomena will further increase the prevalence of vision loss over the coming years (Varma et al., 2016). Even small reductions in visual acuity prove detrimental to the quality of life of those affected (Daga et al., 2017). Lesser visual capability hinders individuals ability to complete simple everyday tasks such as the identification of faces, driving, shopping, and cooking. These functional implications remove the autonomy of those afflicted, with concomitant factors such as social isolation, embarrassment over one's loss of vision and strain on interpersonal relationships leading to high rates of anxiety and depression (Welp et al., 2016).

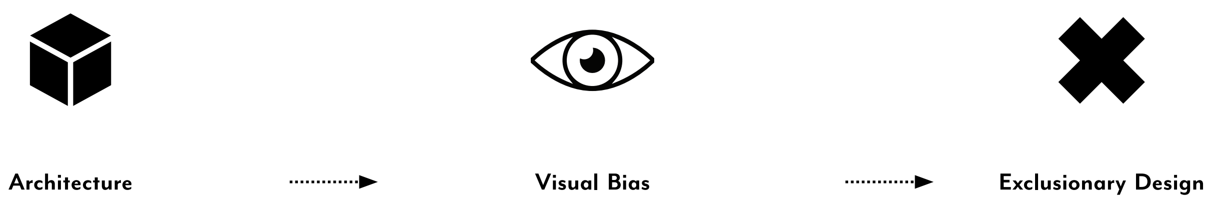
The loss of vision proves detrimental to spatial comprehension (otherwise known as cognitive mapping) a process fundamental to navigation through environments. Vision has well-established advantages over other senses for encoding spatial information, allowing for the perception of vast amounts of environmental stimuli and the rapid updating of this information (Fortin et al., 2008). Without vision, spatial understanding is left to our remaining sensory capabilities, primarily touch and hearing. While the blind and visually impaired demonstrate substantially more skill than sighted persons in the use of these senses, they are mainly useful for short-range perception. The memorisation of environments and inferential judgements, both cognitively stressful and challenging processes, are the only methods available for executing larger-scale spatial operations (Fortin et al., 2008).

Unfortunately, the majority of architectural production provides insufficient consideration of these practical limitations. The resulting negligence is now ingrained into our existing infrastructure (Human Rights Commission, 2012). The failure to accommodate these needs is argued to relate closely to the visual predisposition of the profession. Architects are often described as 'visual thinkers', paying particular attention to geometry and resultant form. In the words of Heylighen and Herssens architects "are able to both read and write in a language of objects" (2014, p. 319). This may be the favoured approach of architects when conceiving of space, but this lays the foundation for the issue of visual prioritisation. This method of conception heavily supports visual modes of representation and the resulting architectural conventions - sketching, rendering, and documentation drawings - are demonstrations of this. This approach to architectural ensures that the idea of spatial experience is systematically reduced to a matter of vision (Heylighen & Herssens, 2014). Within this paradigm, consideration of those who do not rely on sight to understand space is predictably absent, resulting in creations unsuitable for their inhabitation. These ongoing failures have resulted in accessibility-oriented negligence that is now encoded into our built infrastructure (Human Rights Commission, 2012).

Existing solutions and techniques for low vision design are organised into two categories, assistive technologies and universal design (also known as barrier-free/inclusive/accessible design). Assistive technology is a field dedicated to developing devices and applications that assist in the day to day lives of those with various conditions or disabilities. These devices aim to provide visually impaired users useful digital interpretations of environmental information; this supplements the lack of accessible information inbuilt into the user's surroundings. The existing devices that pertain to vision loss are subject to numerous issues, including high costs, use-ability, low coverage, and a lack of general effectiveness (Elmannai & Elleithy, 2017).

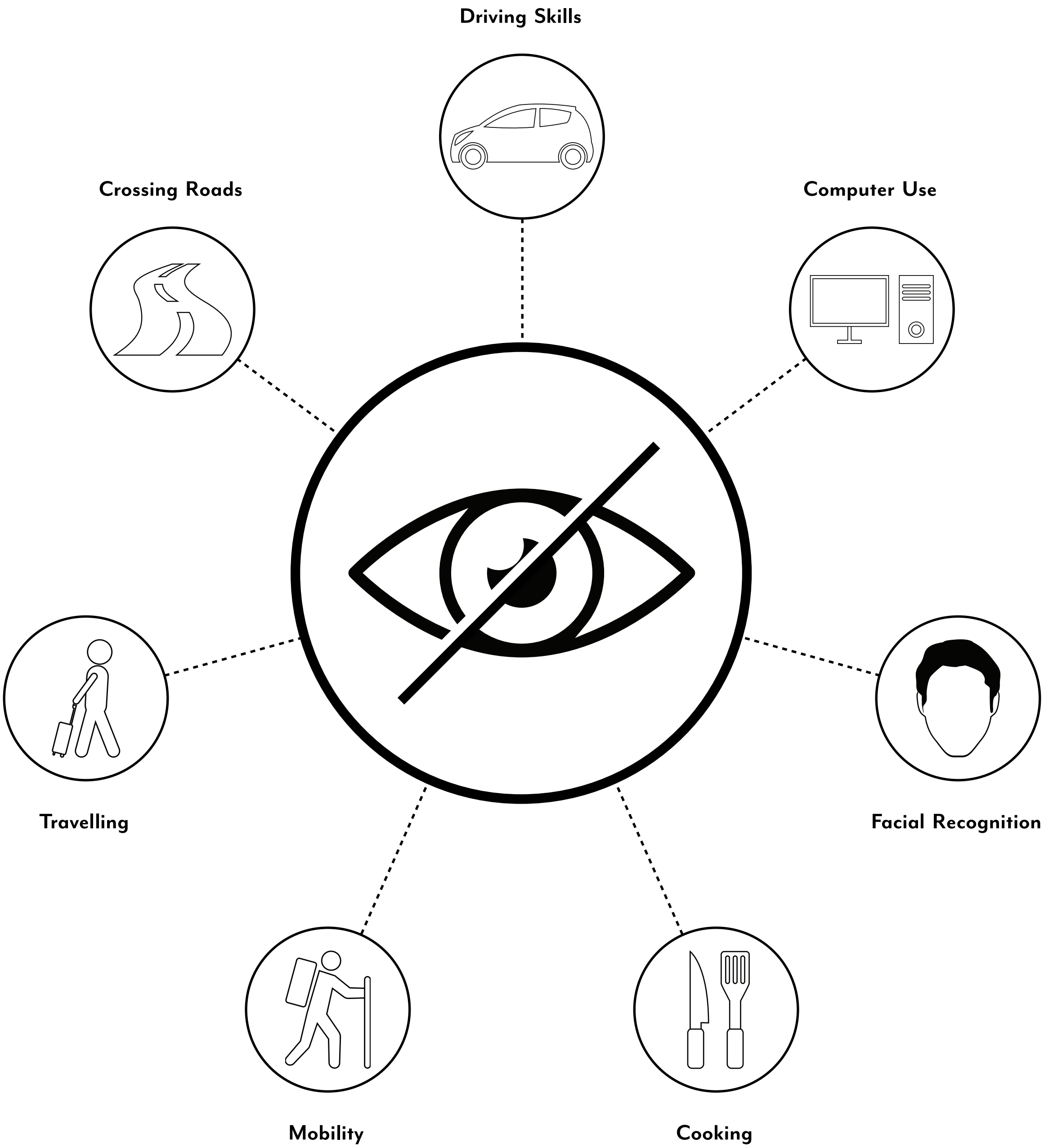
Architectural solutions often come in the form of low vision design typologies and accessible design standards. Vibrant coloured wayfinding objects, tactile flooring and handrails are standard accessibility-related features. The existing solutions draw significant criticism for their reductionist nature, lack of application, utilitarian approach to design, and detriment to aesthetic harmony (Ahmer, 2014; Human Rights Commission, 2012; Jeffries, Gilroy, & Townshend, 2018; Schambureck & Parkinson, 2018).

Thus, the visually impaired are left with a permanently unsuitable environment and no sufficient methods for its improvement. As creators of the built environment, architects must uphold the moral responsibility of correcting the errors made by a long history of negligence.



PROBLEM ORIGINS

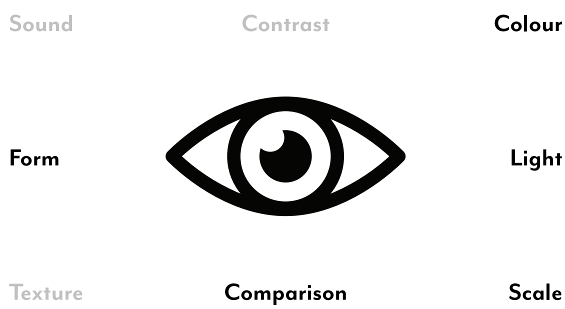
IMPACT

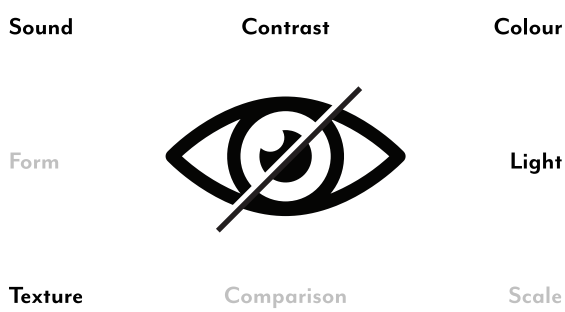


Taylor et al., 2016

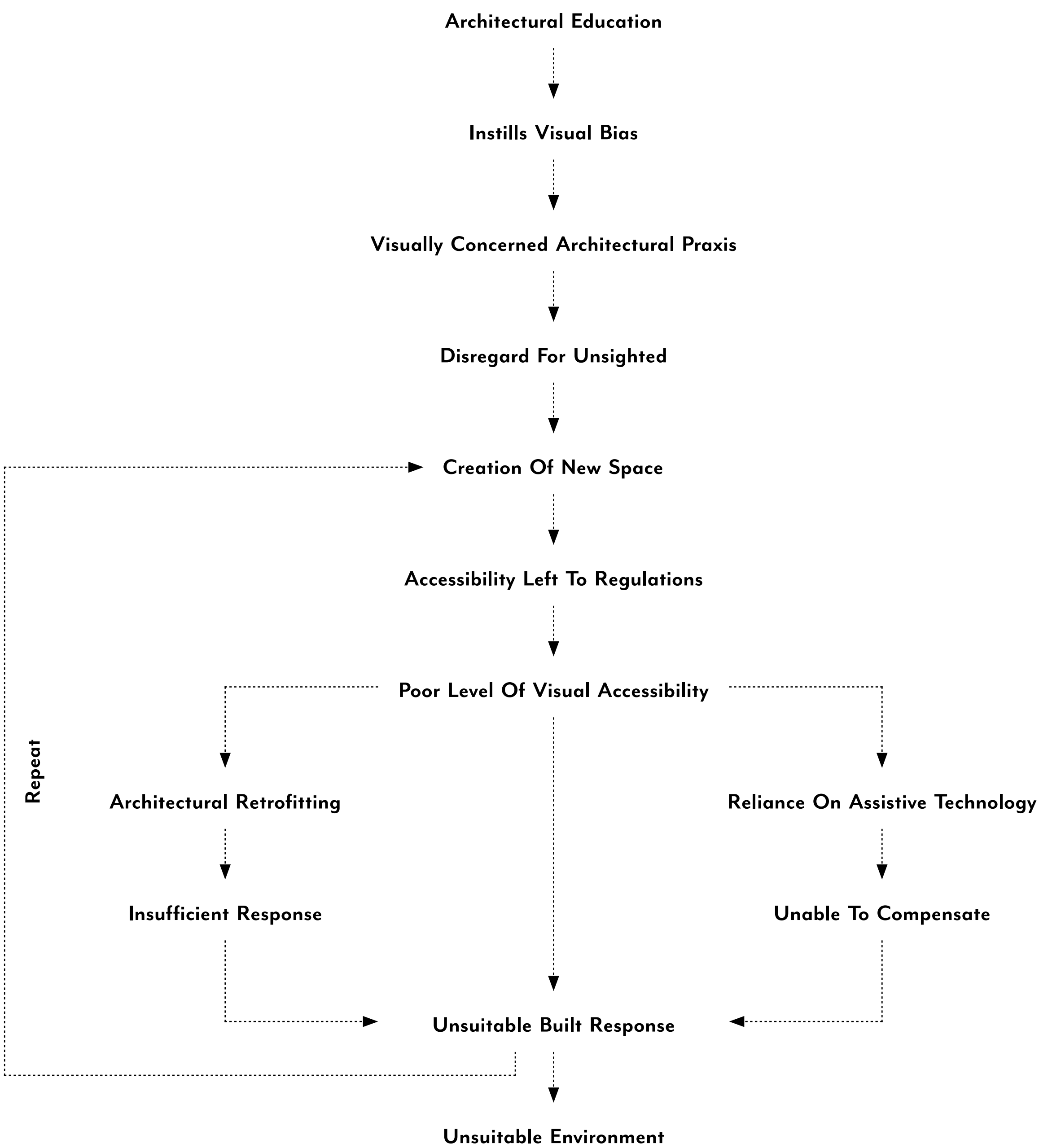
Hassell et al., 2006

ENVIRONMENT PERCEPTION





PROBLEM FLOWCHART



RESEARCH QUESTION

How may the use of digital technologies assist in the spatial engagement and understanding of the visually impaired?

1.3 PURPOSE

The primary aim of this research is to recruit the capabilities of digital technologies to develop new methods for non-visual spatial understanding. As alluded to, the increasing prevalence of vision loss and the lack of concern expressed in the built environment regarding this community pose a significant risk visually impaired persons health and quality of life. The unique capabilities of digital technologies provide an opportunity to enable members of this community to function in a broader range of spaces with increased comfort and efficiency.

Research Aims

-To establish useful and unique methods of non-visual spatial interaction through the use of digital technologies.
-To determine the success of these methods for building spatial understanding.

Research Objectives

-Understand the practical and experiential requirements of those with vision loss.
-Establish the limitations of existing solutions
-Establish methods of disseminating environmental information in a non-visual format through the use of digital tools.
-Provide a range of various processes or tools for engaging with the environment.
-Provide a method for evaluating the success of these methods/tools

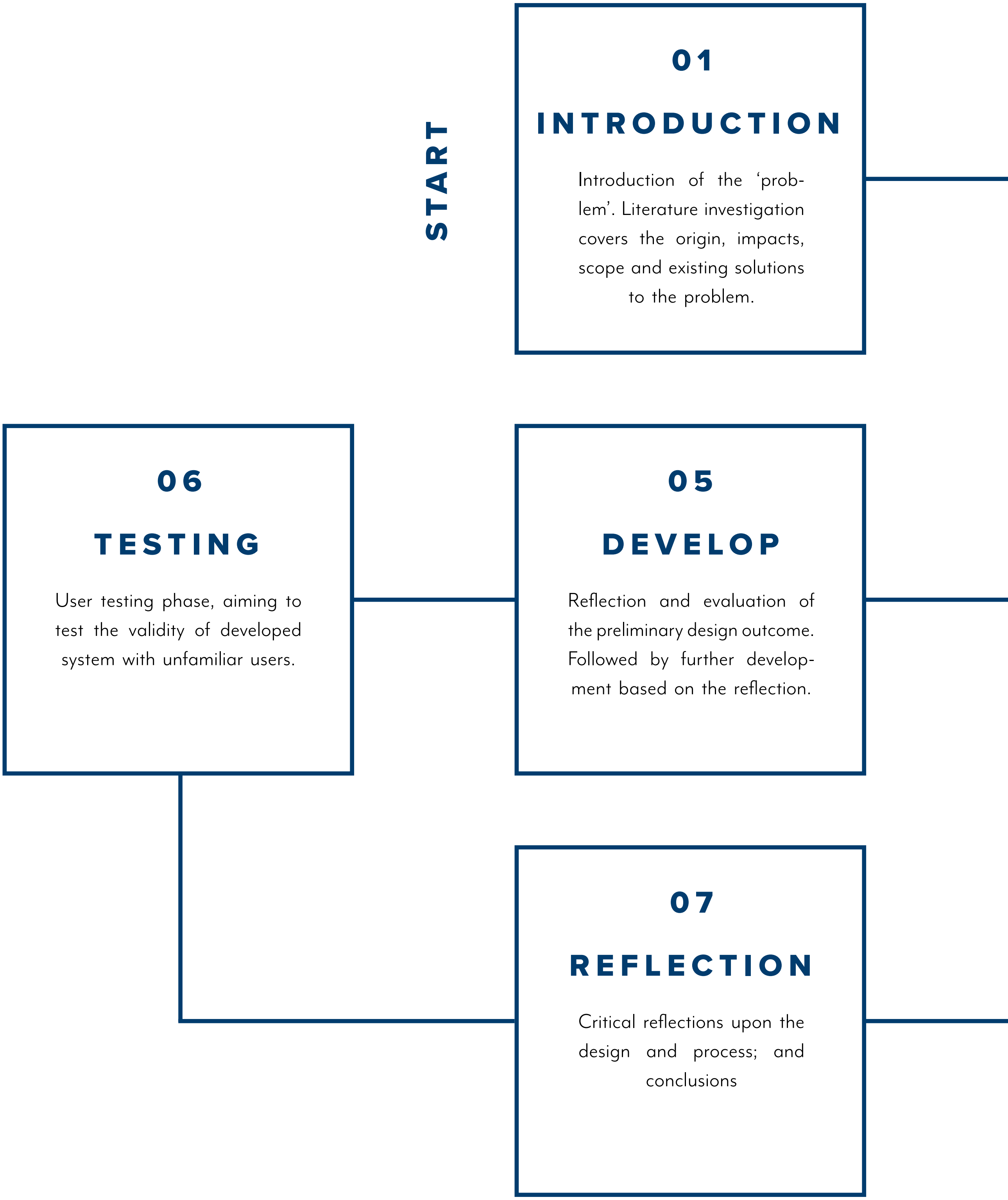
1.4 METHODOLOGY

This thesis adopts a mixed methodology approach to the research. A research-through-design methodology is employed throughout the design phases. As described by Groat & Wang (2013), this methodology understands research as a form of systematic enquiry intended to answer a research question or to validate a particular hypothesis. In contrast, design is conceived of as a generative form of enquiry which aims to solve a specific problem. While research and design are considered to be distinct from one another, there is overlap in their approaches. In research-through-design, this overlap is relied on to bridge the divide between the two and allows design investigations to function as research. The success of this methodology relies on the design investigation mimicking qualities native to the scientific method. An iterative approach to design ensures a systematic and rigorous approach to design creation. This is supplemented by ongoing critical reflection upon generated design outcomes, which is used to generate conclusions and ensure the validity of the process. Personal testing is employed throughout the preliminary and developed design stages for critical reflection. The testing functioned as the primary method for engagement with the design outcomes and evaluation of their successes and failures. Randomisation mechanics were employed throughout the later design stages to ensure that the personal testing process remained as unbiased as possible. The results of the research through design methodology are bolstered by qualitative research conducted in the final design stages. Qualitative data was collected via interactive observational testing. The results of this testing were used to validate the collective design knowledge, generate conclusions regarding the project, and act as a foundation for the proposal of further research.

1.5 STRUCTURE

The thesis consists of eight sections split into three phases. The first phase consists of two parts and addresses the theoretical basis of the project, introducing the main topics and documenting the literature summaries. The following stage consists of four sections and constitutes both the design research and user testing components. The final phase consists of two sections that outline the discussion, conclusions, closing remarks, and citations.

The first stage gathers an understanding of the scope, genesis, and impact of the issue from the perspective of various fields. The second phase is an in-depth literature study which addresses the key fields and theories that underly the design phase of the project. It also critically analysed the existing solutions to the problem, identifying successes and their shortcomings. These key fields are wayfinding, assistive technology, accessible/universal design and digital technologies. The third phase explores the possibilities of sensory simulation and interaction in virtual environments. A series of small iterative tests are completed with the available virtual reality hardware and software to establish the formal parameters (opportunities, limitations) of their simulation capabilities. These tests formed the basis of all subsequent design work. The fourth phase is the conceptual/preliminary design stage. This phase expanded upon the findings of the prior investigation and applied them in a small-scale scenario; this provided potential directions for the design response. The result was the creation of a small mixed reality environment and the development of mechanics for spatial engagement. The fifth stage is the developed design phase of the thesis. It reflects on the body of work created in the preliminary stage and uses this to create a systematic development plan and a testing protocol. This is followed by the development process itself, which reinterrogates the engagement mechanics, refining the sensory outputs and beginning the process of evaluation. The sixth stage concludes the design phase with a series of user tests. These tests place unfamiliar users into mixed-reality environments to establish the success of the mechanics in building spatial understandings. The seventh stage begins the conclusion phase and reflects on the thesis process, scope, design outcome and evaluative limitations and provides the conclusions for the project. The eight and final phase provides the bibliography and appendix.


START
01
INTRODUCTION
Introduction of the 'problem'. Literature investigation covers the origin, impacts, scope and existing solutions to the problem.
06
TESTING
User testing phase, aiming to test the validity of developed system with unfamiliar users.
05
DEVELOP
Reflection and evaluation of the preliminary design outcome. Followed by further development based on the reflection.
07
REFLECTION
Critical reflections upon the design and process; and conclusions

02

DISCOVERY

In-depth literature study which covers the main fields and theories that drive the project

04

DESIGN

Preliminary design phase which investigates potential applications for the discoveries of the previous section.

03

SENSORY

An investigation into the capabilities of the VIVE technology and the Unity game engine.

08

CODA

Bibliography and appendix.

FINISH

DISCOVERY 2.0

2.1 WAYFINDING

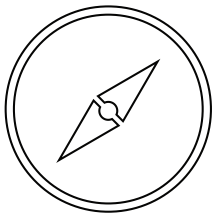
Wayfinding is a term used to describe one's way of orienting themselves and navigating through environments. The field of wayfinding saw its conception in the 1960s (Passini, 1996). It began with the work of Kevin Lynch (1960), who developed a theory of spatial orientation which relied on cognitive maps. Lynch reasoned that cognitive maps were the mental devices required to orient oneself within an environment and were created from five distinct features: paths, intersections of paths, boundaries, landmarks, and districts (Lynch, 1960). Cognitive mapping is defined as the process of gathering, collating and recording spatial information (Downs & Stea, 1973). Many alternative definitions of cognitive mapping have been offered, which were summarised by Robert Kitchin in a 1994 review of the topic. The consensus was that cognitive maps are a mental system that allows individuals to collect, simplify and organise the information presented to them by the environment (Kitchin, 1994). In 1981, Romedi Passini provided a detailed expansion on Lynch's model, instead proposing a three process model. The first process of this model is the cognitive mapping process; the decision-making process then follows this, and is concluded with the decision-execution process.

Passini (1984) further discussed the three information types available during the wayfinding process: sensory, memory and inferred. Sensory memory is gathered in real-time by the sensory cues of the area, whereas, memory information is generated and used through the memorisation and recollection of previous experiences. Finally, inferred information is obtained through logical reasoning predicated upon a combination of sensory and memory information. Downs & Stea (1973) dissented from this model, providing a two system classification: locational, and attribute information. Locational information is used in the subjective construction of 'where' given phenomena are located within a space and can be used to express directions and distances. Attribute information provides an idea of 'what' phenomena are in a location. Attribute information is further divided into two subclasses: evaluative and descriptive. Evaluative attributes are subjective judgements of quality, for example, 'ugly' stores or pleasant atmosphere. Descriptive attributes are the sensory identifiers that describe a place, for example, 'red' building or a 'large' shed.

Vision plays a central role in these conventional wayfinding processes, enabling instant access to the necessary geographic information (Schrenk et al., 2019). While a variety of theories, originating from various fields, have investigated the nature of wayfinding, it was only recently that scholars turned their attention to how these concepts apply to the visually impaired (Kitchin, Blades, & Golledge, 1997). Early research into the wayfinding performances of the blind or visually impaired can be separated into three main theories (Fletcher, 1980). The first, known as deficiency theory, postulates that those without adequate vision are incapable of developing even the most basic understanding of space (Senden, 1960). The second theoretical position is the inefficiency theory which argues that the blind or visually impaired can form ideas and conceptions of space, but that these are inferior to the ones of individuals with sight. The third and final position is difference theory in which those without vision or with visual impairments can construct and comprehend spatial ideas which are equivalent to those of sighted individuals, but that the process of doing so is slower and requires different information. While the first position is mostly discredited, there is

WAYFINDING MODEL

Cognitive Mapping - 01



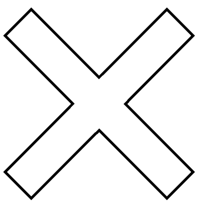
Decision Planning - 02

Decision Execution - 03

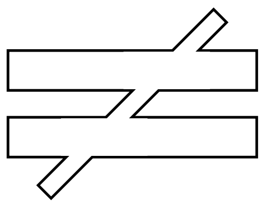
Passini, 1982

VISUALLY IMPAIRED WAYFINDING

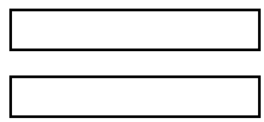
Deficiency Theory



Inefficiency Theory



Difference Theory



Kitchin, 1994

substantial support for the other two theories (Ungar, Blades, & Spencer, 1996). Thus, it can be concluded that the wayfinding processes of the visually impaired are either inferior or equal to, those of sighted individuals in terms of functionality. Other differences also occur in their methods of information gathering and overall process efficiency (Passini, Proulx, & Rainville, 1990).

A consensus is found regarding the exact differences in spatial knowledge acquisition between the visually impaired and the sighted (see Kitchin, Blades, & Golledge, 1997 for review). A lack of vision is agreed to impair the collection and processing of objects and their surrounding environment, restricting the potential for orientation, perception of scale and comparative judgement between points or objects (Golledge, Klatzky, & Loomis, 1996).

Additionally, a lack of vision often removes the ability for those with visual impairments to understand spatial identifiers such as: across from, next to, large, red, tall. (Golledge, 1993). This makes the processing and learning of spaces and navigation much more difficult. This range of differences can be mapped back onto conventional spatial information models of Passini and Downs and Stea. For Passini's model, the differences arise in the gathering of sensory and inferred information. Sensory information must be collected primarily through kinetic and sonic means and inferred information about space is mostly restricted to a human-scale due to the lack of vision. The same process can be applied to the model of Downs and Stea, where the locational and descriptive attribute information gathering will be impacted.

2.2 CURRENT SOLUTIONS

There are two main approaches employed in resolving the issues surrounding vision loss, referred to as accessibility and rehabilitation (Legge, 2014). Accessibility places emphasis on diversification of spaces and the removal of barriers to engagement with society. These principles are strongly associated with the notion of equality and gave rise to universal and inclusive design doctrines. Rehabilitation represents the medical approach to the issue, where visual conditions - as opposed to the environment - are the 'issue' to be solved. This approach attempts to ameliorate the disability by enabling those with visual conditions to function in the world as it currently exists. This outcome may be achieved through the use of taught coping strategies/techniques, devices and technology. The differences in the approaches may be characterised as adapting an environment to the individual versus adapting the individual to the environment.

New Zealand disability and building policies express strong support for the 'accessibility' approach. This sentiment is best captured in the following quote from the 'New Zealand Disability Strategy 2016 - 2026' administered by the Ministry of Social Development through the Office for Disability Issues.

> *Non-disabling is about removing the barriers in society that disable people with impairments. We consider this to be stronger and more meaningful than 'enabling', which will only help disabled people get around barriers rather than remove them completely. (p. 14)*

This sentiment is predictably supported throughout building standards, likely due to their integration with universal design and associated principles. The proximity and input from members of the disabled community in the creation of the disability strategy and the relevant accessibility building standards emphasise the importance of this approach.

Accessible Design Products **Design Typologies** **Building Regulations**

ACCESSIBILITY

—

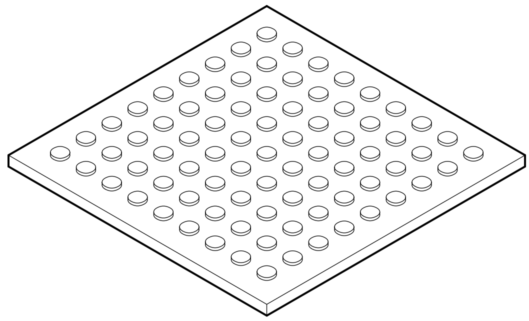
REHABILITATION

Glasses/Contact Lenses **Assistive Technology** **Medicine** **Surgery**

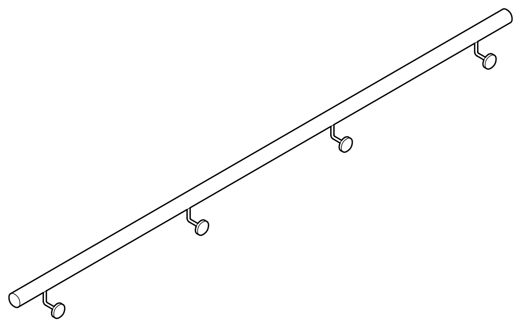
2.3 ACCESSIBLE DESIGN

The concept of universal design advocates for the inclusion of the needs of all less-abled groups in design (Ahmer, 2014). The field of architecture has seen adoption and implementation of such design strategies, primarily spurred by its entanglement with socio-political reality (Jones, 2014). Accessible design is firmly rooted in the principles of universal design and has seen integration with NZ policy and building standards.

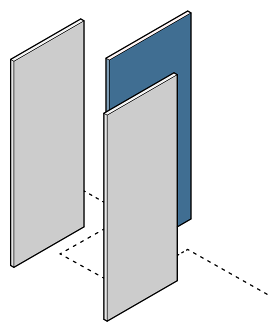
There are many different methods through which accessibility is achieved in the built environment nationally and abroad. NZS:4121 2001 is recognised as the most comprehensive accessibility standard in New Zealand and is the only cited compliance document by the New Zealand building code (Human Rights Commission, 2012). The New Zealand Blind Foundation provides specific resources regarding the creation of visually accessible environments. These resources include links to relevant information and building standards, guidelines for the design of signage, and contact with an environmental awareness team specialising in low vision design. In addition to native resources, there are large numbers of available accessibility case-studies and various low vision design typologies created by the experts in the field (see diagram p.17). Some visual accessibility design strategies employed ubiquitously are tactile flooring mats and linings on steps and kerb ramps, handrails, colourful wayfinding objects and contrasting utility items (door, door handles, phone booths, for example).



Tactile Flooring

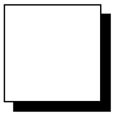


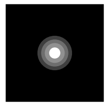
Guide Rails

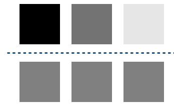


Wayfinding Objects

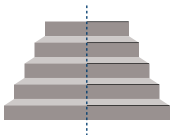
LUMINANCE CONTRAST


Silhouette

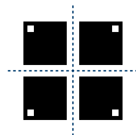

Sparkler

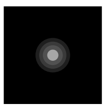

White Wash

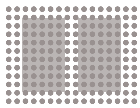
VALUE CONTRAST

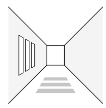

Detectable Warning

Ghost

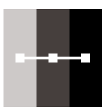

Mirror Mirror

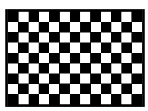

Mood Lighting

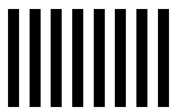

Camouflage


Deception

LUMINANCE PLACEMENT

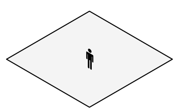

Transition Zone


Checker Board


Shadow Land

OBJECT PLACEMENT

Kissable Signage


Open Waters

Adapted from
Schambureck & Parkinson, 2018

ACCESSIBLE DESIGN CRITICISMS

Despite the admirable steps towards accessibility within New Zealand and internationally, there are still various criticisms and shortcomings in existing solutions. A 2012 report by the NZ human rights commission found a multitude of issues present in the existing urban infrastructure and surrounding regulations. Feedback from the disabled community suggested that the building standards and regulations were insufficient to meet their needs. Documented issues included: insufficient maintenance maintenance on items and areas such as tactile flooring, audible cues for crossing road and debris on footpaths crossing signals, all of which are necessary for blind pedestrians to navigate spaces safely. The most important issue raised was that large parts of the built environment were not designed to current standards and thus, remain inaccessible.

In addition to national-level issues, broad criticisms are applied to low-vision accessible design as a whole. The scope of accessible design often centres around physical impairment and related mobility issues, mostly leaving visual conditions out of its consideration (Jeffries, Gilroy, & Townshend, 2018). When visual conditions are addressed, the resulting designs often criticism from architects regarding their aesthetic qualities. Carolyn Ahmer (2014) argued that this aesthetic deficiency arises through the utilitarian focus of the existing guidelines, which leave the aesthetic as a mere by-product. These associated aesthetic fears are a substantial factor in the slow uptake of universal design principles into architectural praxis.

The effectiveness of the implemented accessible design is also challenged. Due to the reductionist nature of the solutions, there will inevitably be situations arising that are not covered by the guidelines or typologies (Jeffries, Gilroy, & Townshend, 2018). In specific reference to low vision design, the level of variance between conditions and their symptoms makes it very difficult to generate a comprehensive set of guidelines (Schambureck & Parkinson, 2018). This ensures that for successful, visually accessible environments to be created, expertise is required. However, this action is not mandated, meaning that the vast majority of new buildings fail to meet the needs of the community. The increasing presence of visual conditions poses serious public health and financial challenge. Even though the 'rehabilitative' approach lacks support within New Zealand, insufficiencies in the existing solutions provide a strong reason to investigate this approach in future design work.

UTILITARIAN

Criticised Universal design for being overly rule-based and lack aesthetic sensibility. "If the defintion of universal design does not include criteria for aesthetic design, the visual result is accepted as a by-product of utilitarian design."

Ahmer, 2014, p. 4-5

ONE-SIZE-FITS-ALL

Outlined that universal design often fails due to its creation of "one size fits all" solutions.

Jeffries, Gilroy, Townshend, 2018, p. 5

REDUCTIONIST

Argued that Low Vision Design typologies often fail due to their neccessarily reductionist nature which fails to account for the range of variation in visual conditions.

Schambureck & Parkinson, 2018

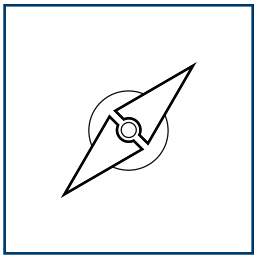
2.4 ASSISTIVE TECHNOLOGY

Assistive technology is an umbrella term applied to all rehabilitative, assistive or adaptive devices used by individuals with disabilities of different types. Available assistive technology is often used to supplement users understanding of an environment and can be considered an advocate for the 'rehabilitation' approach to the issues brought about by vision loss. The technology can be divided into three rough categories: Electronic travel aids (ETAs), Electronic Orientation Aids (EOAs) and Position Location Devices (PLD) (Elmannai & Elleithy, 2017). ETAs are devices that provide and gather information about the direct surrounding environment. This information may include obstacle identification, distances, user instructions to further sources of information (directions, braille signage). EOA devices are designed to give directions in unfamiliar locations; this process includes user location identification, route selection, and mobility instructions. These devices come in a variety of forms, including smartphone applications, clothing items, large mechanical devices, and small pocket-sized devices. Information necessary for their operation is predominantly gathered through the use of GPS positioning, gyroscopes, pre-loaded information, sonar, laser scanning and cameras. This information is then communicated through the use of haptic feedback, sonic cues, or verbal information. The devices are often designed to work harmoniously with conventional assistive methods such as guide dogs or white canes.

1.

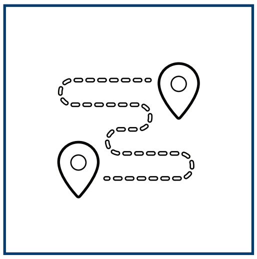
Position Location Devices

2.



Electronic Orientation Aids

3.



Electronic Navigation Aids

EXISTING DEVICES

Smart Canes:
Smart canes aim to employ newer technologies to improve upon the classic white cane used by many low vision individuals. The additions to the cane include sonar scanners which detect objects, cameras which are used alongside an algorithm to detect points of interest in the environment and laser scanners which can detect obstacles. This information is often communicated through haptic feedback to the hand or to the cane itself.

Haptic Wristbands:
Available haptic wristbands function as either obstacle recognition devices or as basic navigational tools. Obstacle recognition relies on sonar pulsing which triggers a haptic pattern when an object is detected. This pattern changes in frequency depending on how close an object is. Navigational devices work through the selection of a destination using a smartphone application. The user is then directed to this location via the use of directional haptic cues. Haptic wristbands integrate well with white canes and guide dogs, are generally affordable and largely successful in their use.

GPS navigation tools:
GPS navigation tools are readily available in the form of smartphone applications or separate GPS devices. An application such as 'overTHERE' combines the orientation of the user based upon their phone direction, with the desired destination set via GPS. A verbal cue will provide the name of the location; the clarity of this verbal cue is dependant upon the orientation of the user. If the orientation of the user points directly towards the desired location, then the verbalisation is clear, the further the user orientation rotates away from the desired location, the less clear the verbalisation is. Some variants of the haptic wristbands also provide similar functionality.

Image recognition tools:
Image recognition tools rely on cameras, algorithms, and image databases to analyse an image and provide information about what is in the image. Smartphone applications such as 'TapTapSee' or the 'ARIANNA' App fall under this category. 'TapTapSee' allows the users to take a photograph by pressing anywhere on a screen. The image is then processed, and a verbal cue is played, which identifies the object. The 'ARIANNA' application uses phone cameras and coloured stripes on the ground to provide basic navigational information. When the phone camera identifies one of these coloured stripes, a vibration is triggered. QR codes can be used to reveal more information about particular items of interest. The usage of cameras on smart canes also fall under this category; there are several unique tools, including cameras worn in a neck pouch which achieve a similar effect.

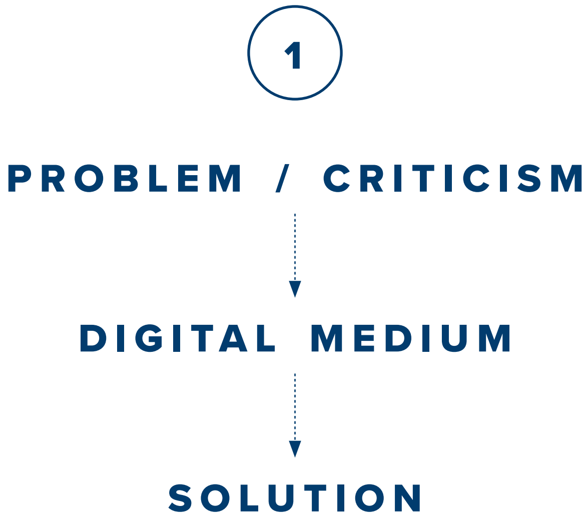
Criticism
The range of available assistive technologies is subject to various shortcomings and limitations in their application. Elmannai & Elleithy (2017) conducted a review of existing sensor-based assistive technology devices. The researchers evaluated the devices through the use of five criteria, the analysis type (real-time/static), coverage (Indoor/Outdoor), time (day/night), range, object type (dynamic/static). Of the twenty-five devices that were reviewed, only seven of them scored above 75/100, two of which are related to reading text and thus are not relevant to this thesis. The five remaining devices all failed to meet at least one of the crucial requirements. The limitations present in these devices outline the present insufficiencies in the technological approaches to the issue. The researchers outline further parameters for success which were, performance (meeting all of the criteria mentioned above), wireless connectivity with a database to ensure data exchanges, reliability, wearability, and economic accessibility.

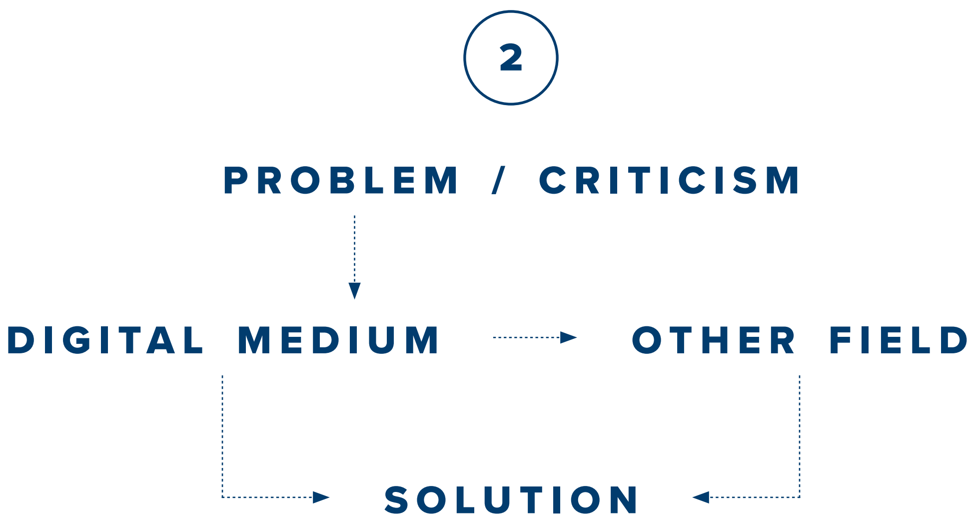
2.5 DIGITAL TECHNOLOGIES

This project takes part in the recent developments in virtual technologies, which have seen increasing availability over recent years due to the commercialised nature and newfound affordability. These virtual technologies have seen widespread integration with society and academia, becoming commonplace in research fields and as vital tools for stakeholder engagement in commercial enterprises (Cipresso, Giglioli, Raya, & Riva, 2018). Consumer tier virtual and augmented reality products allow for exploration free from the physical and monetary constraints of the physical world. The inbuilt tracking capabilities and multi-sensory outputs enable immersive user engagement with digital creations. These capabilities allow the creation of mixed reality spaces which as described by Peter Anders "incorporate the material presence of sensory objects with the capacities of virtual ones" (2008, p. 21). These mixed reality spaces blur the boundary between the virtual and the physical. Within the thesis, the features of these digital tools are used to expand upon the qualities of both accessible design and assistive technology; and to explore modes of interactions that are unique to the digital platform.

Both fields of existing solutions are plagued by numerous shortcomings that prevent them from adequately addressing the issues posed by vision loss. The inherent qualities of digital technologies provide an opportunity for the amelioration of these aforementioned shortcomings. This solution operates through two distinct dynamics. The first is a direct solution, a scenario in which an issue associated with a product, strategy, or feature of either assistive technology or accessible design is solved by recreating it within the digital realm. For an example, let us use a standard accessible design feature, tactile flooring. The goal of this product is to provide environmental information to users through tactile changes on the floor. This solution is effective, but unfortunately, the architectural community reject this feature due to its perceived lack of aesthetic consideration and thus, it receives uncommon use (Ahmer, 2014). The digital platform in this scenario can recreate the goal of tactile flooring through a combination of its tracking capabilities and haptic feedback functions. It simultaneously avoids the criticism, as the resulting creation is virtual and therefore can be made invisible and unobtrusive on a design aesthetic.

The second dynamic is an indirect solution, where the issue of one field is not solved by digital technology directly but is solved by borrowing and integrating a principle from the opposing field. As an example, assistive technologies are often criticised for providing insufficient information regarding the environment (Elmannai & Elleithy, 2017). In contrast, accessible design excels in this area. The digital platform, in this scenario, allows for the creation of an assistive technology-like response that borrows heavily from the placement strategies, sensory format, and general function of accessible design features. This scenario relies on 'borrowing' from universal design and using this to solve an issue with assistive technology.


1
PROBLEM / CRITICISM
DIGITAL MEDIUM
SOLUTION


2
PROBLEM / CRITICISM
DIGITAL MEDIUM
OTHER FIELD
SOLUTION

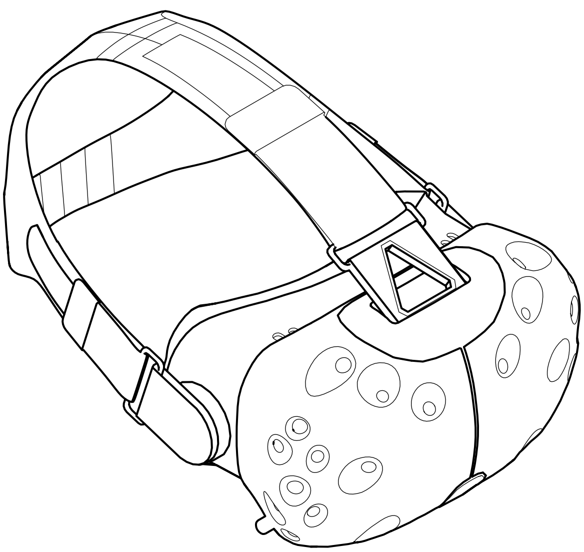
SENSORY 3.0

3.1 INTRODUCTION

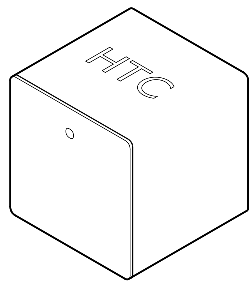
The sensory phase explored initial design possibilities related to digital space and sensory simulation through a closer examination of the native capabilities of the VIVE equipment and the Unity game engine. This phase constitutes a period of personal learning and familiarisation with the selected software and hardware. A series of iterative tests established formal parameters regarding haptic feedback, sound cues and virtual interaction.

VIVE EQUIPMENT

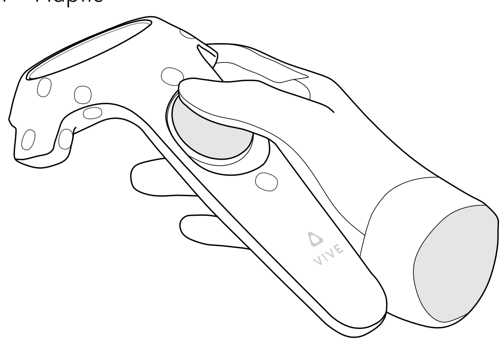
Headset
Input - Orientation
Output - Visual Display, Sound



Base Station
Input - Position
Output - Virtual Position



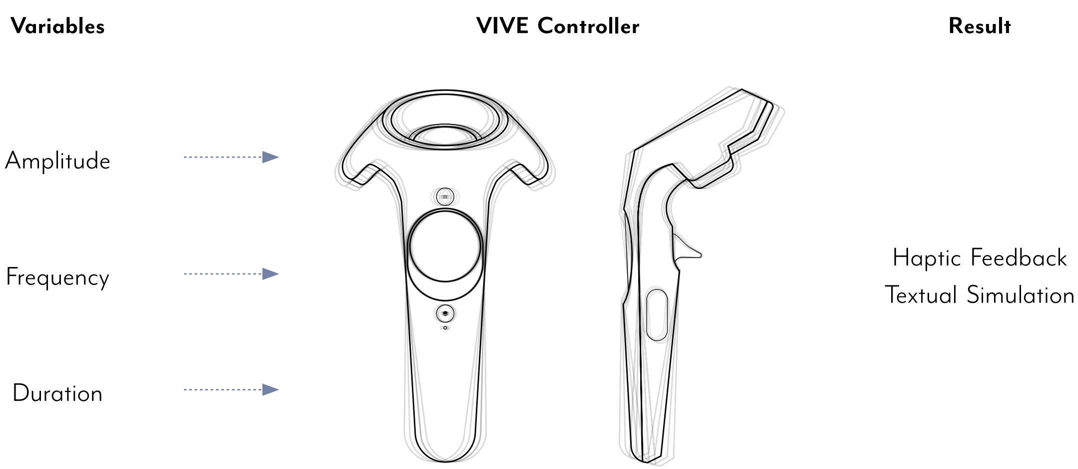
Controller
Input - Orientation, Button Input
Output - Haptic

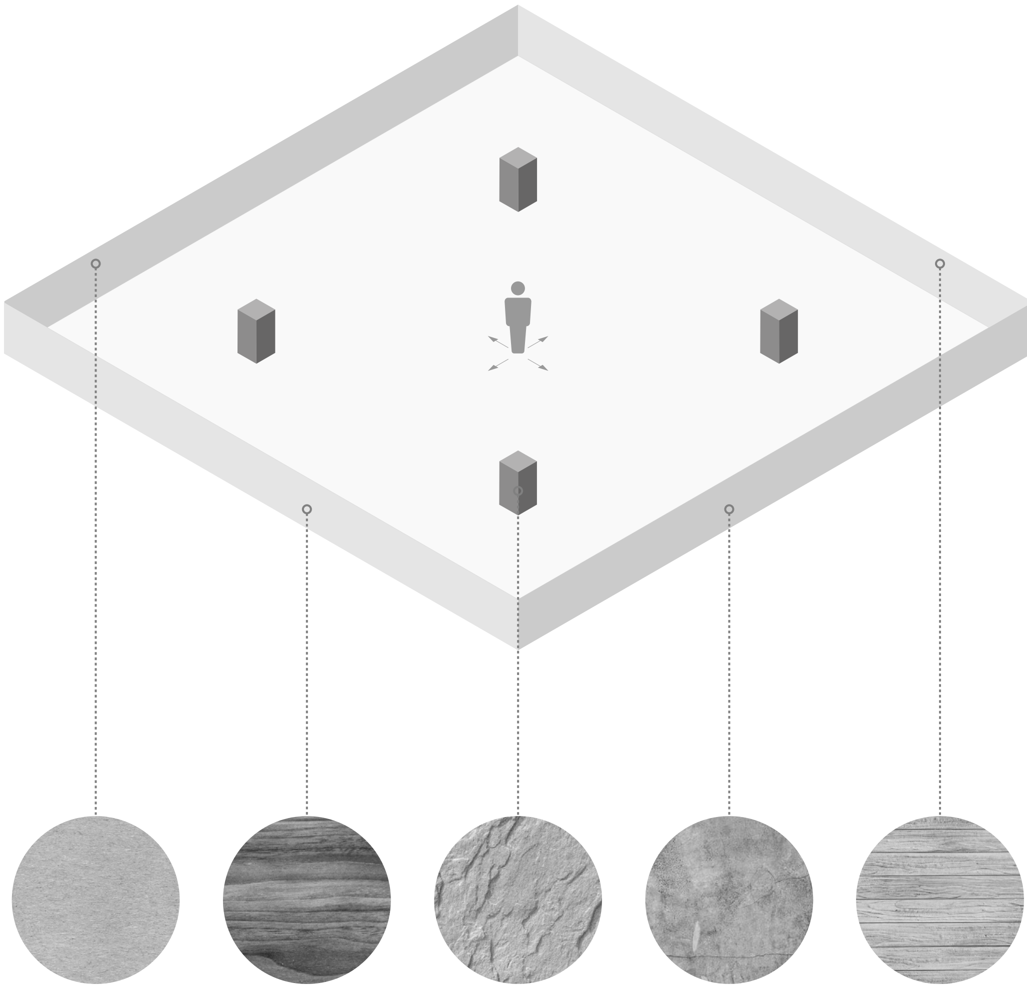


3.2 HAPTIC

Texture is a vital source of spatial information for the blind and visually impaired. Variances in material/textural qualities may indicate one's position within a space, potential uses of an area and are fundamental in the wayfinding process. Few studies have investigated the role of haptically enhanced virtual environments for visually impaired wayfinding. Lahav & Mioduser (2004) showed that virtual haptic cues were successful tools for the creation of complex spatial maps and provided a significant benefit in the navigation processes of the visually impaired. These results were expanded upon by Nam, Whang, Liu, & Moore in 2015, who analysed how the haptic trigger layout, density and number impacted perceived task difficulty, user behaviour patterns and task performance.

An examination of the haptic capabilities of the Vive controllers revealed that three parameters for the controller's haptic feedback, the duration, frequency, and amplitude, could be adjusted. These parameters, used in conjunction with the Unity software capabilities, were manipulated and adjusted within the design experiment. The variation of the parameters means that the haptic functions of the VIVE controllers differ significantly from those present in the previous studies. This process aimed to establish the overall successes and limitations of the haptic feedback and the opportunities provided by the multiple variable parameters.





Smooth
Weak long vibrations

Textured Wood
Moderate short vibrations

Stone
Strong short vibrations

Concrete
Strong consistant vibration

Wood Planks
Moderate intermittent vibrations

EXPERIMENT RESULTS

The outcome of this design experiment was a large square room bordered by four perimeter walls; the internal space is inhabited by four large boxes. Five unique haptic triggers were allocated, one to each of the four walls and one to the boxes. The haptic signatures were designed to mimic the material conditions of wood, rough concrete, wood planks, stone and smooth concrete. Movement around the scene allowed users to 'touch' the various objects. Boundary Colliders were used to trigger haptic sequences upon a collision between the objects and the VIVE controller.

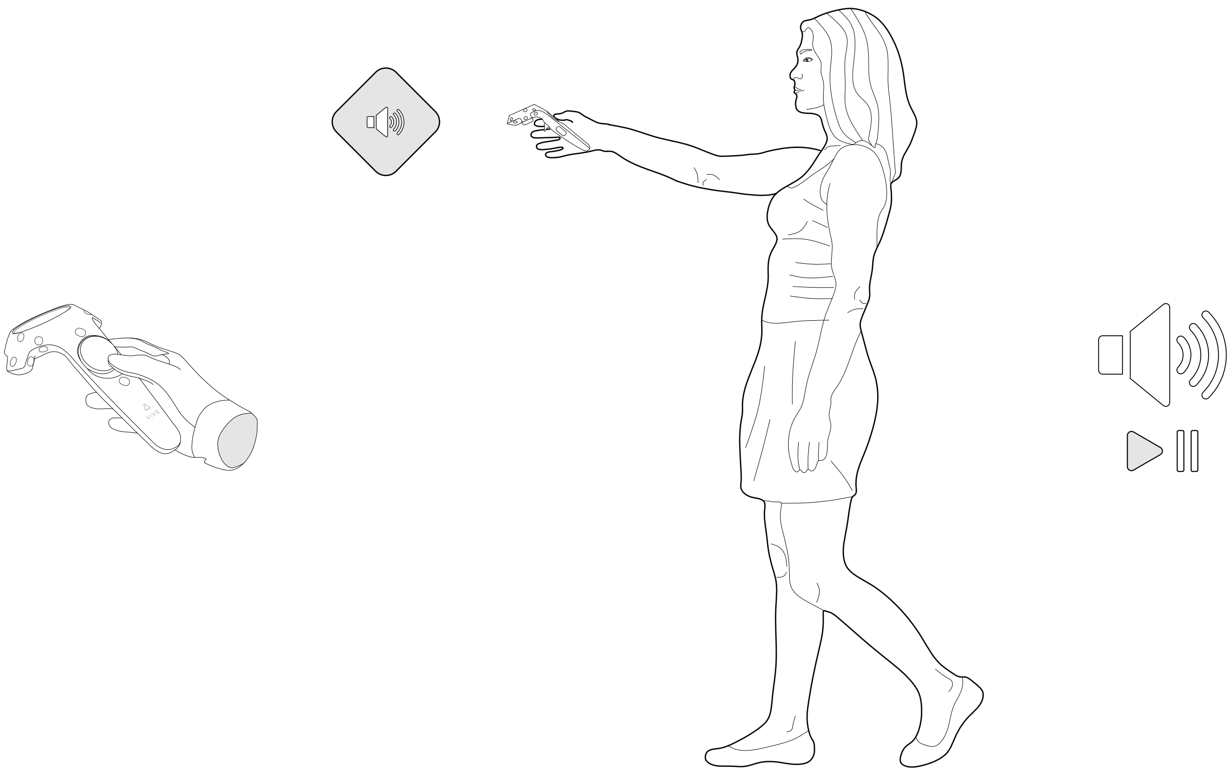
The preliminary experiment revealed a more extensive range of possibilities than expected, with the three control parameters providing a noticeable variation in the haptic result. A general notion of material texture was understandable. However, the lack of a physical object made understanding the shape of the object more difficult. The material palette would be significantly improved by restricting it to a small number; this would allow for a greater difference in each of the haptic profiles and would make each material easier to identify.

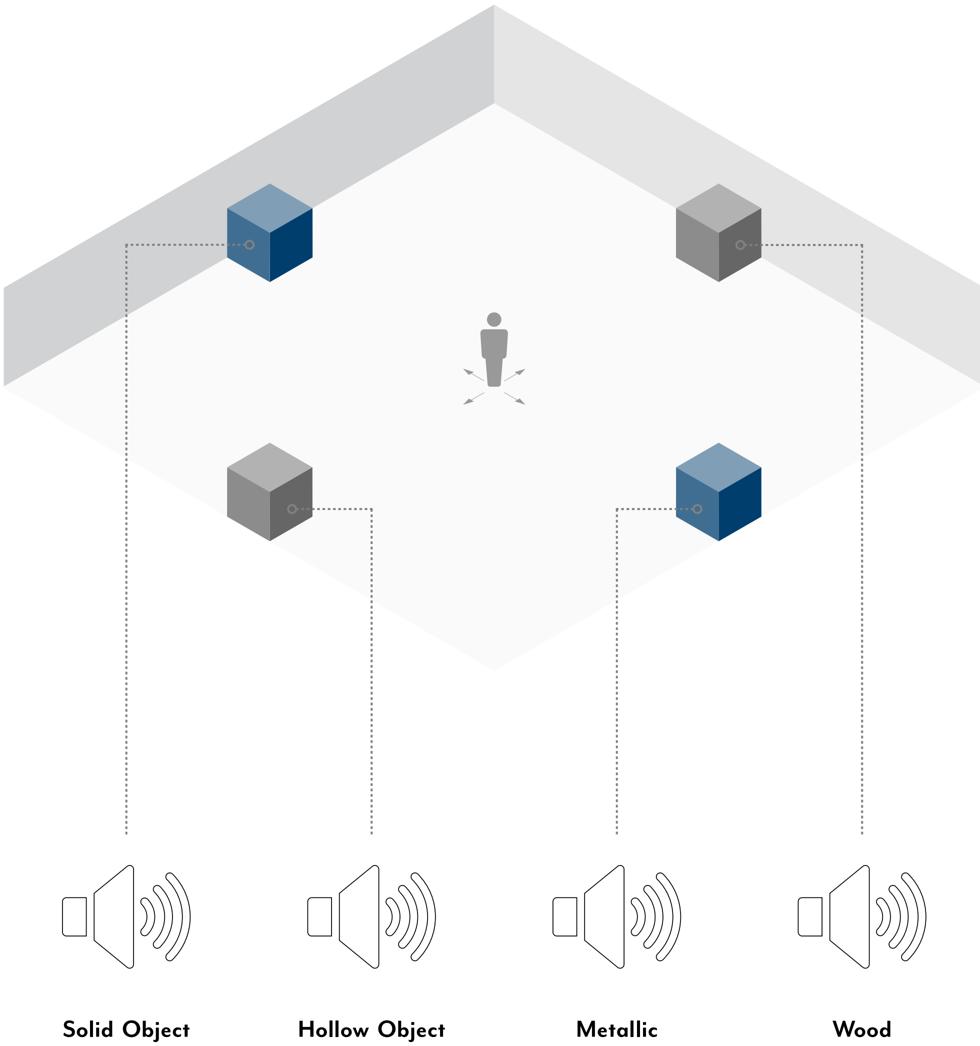
The early success in implementation and the results of this experiment suggest that the haptic component may provide a successful analogue to touch for the visually impaired. These results are further refined in the later design stages.

3.3 SONIC

Similarly to texture, sonic information is a crucial element of spatial information for the blind and visually impaired. A wide array of information is embedded within the sonic qualities of a space. Even simple sound cues may allow inferential judgements as to one's location, the programme of spaces, and potential items for interaction. Those with more advanced auditory abilities can use the reverberation of a space to establish the shape, scale and materials present within a room. Picinali, Afonso, Denis, & Katz (2014) showed that virtual sound cues could assist in the general cognitive mapping of blind individuals. The research also demonstrated that self-generated virtual sound cues could be successfully used for virtual echolocation.

The Unity game engine provides the opportunity for spatialised sound and sonic occlusion based on objects within a scene. The trigger functions allow users to generate sounds on command or through digital interaction. A potential shortcoming is the lack of material consideration in the Unity engine's sound simulation. The materiality present in space has an impact on the reverberation and perceived amplitude of sounds, making it necessary for accurate sound simulation. This setup differs significantly from the system of Picinali et al. (2014), providing lower quality sound simulations which could potentially alter the effectiveness of the cues.




Solid Object
Hollow Object
Metallic
Wood

EXPERIMENT RESULTS

The sonic experiment was similar to the haptic investigation, consisting of a large room with four coloured cubes. Each of these cubes had a distinct audio cue attached to it. As the user navigates the space, any collision between the controller and one of the cubes triggers a sound cue.

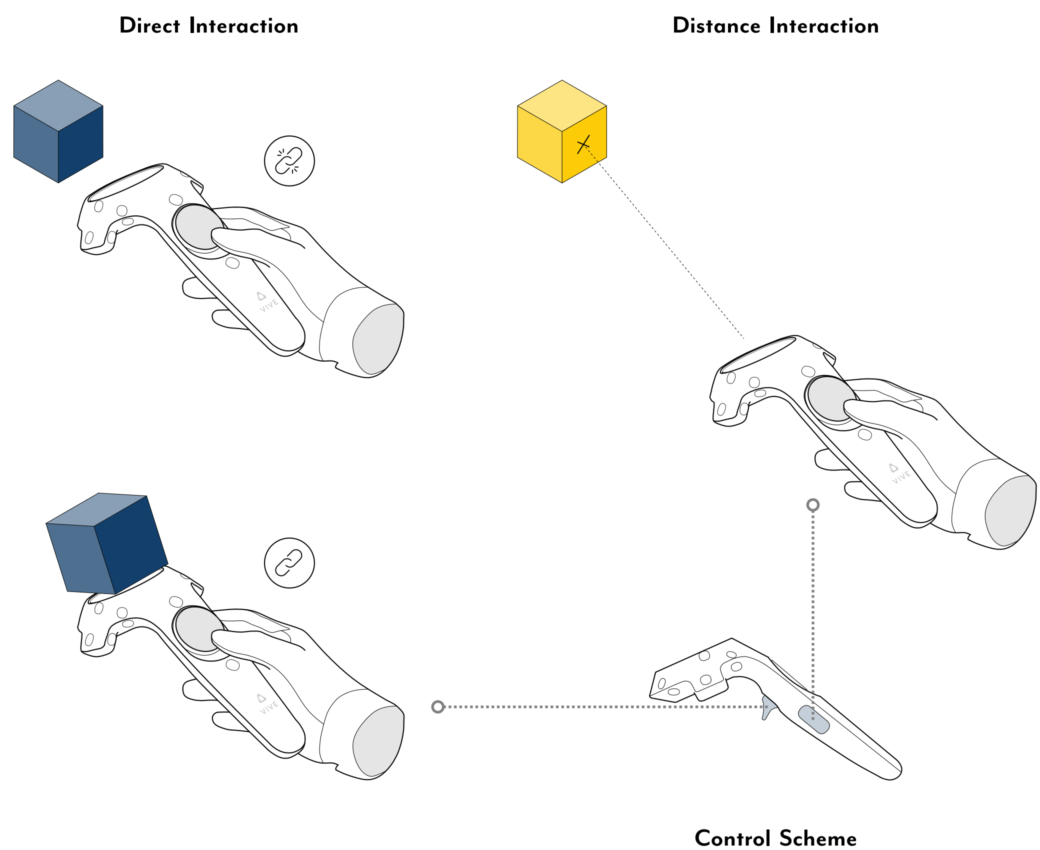
During testing, it was evident that there were many limitations in the generation and quality of the sound cues. When the sound cues of the object are triggered the sound will originate from the centre of the object that is touched, this feature has no implication for smaller objects as the central position is always close to the contact point. However, for objects of significant height or length, the centre point and the point of contact may be far removed from one another, meaning the sonic cue will originate from a different position than the collision. A future adjustment will see the sonic cues originate from the controller position; this will ensure that all sonic cues originate from the position of the collision, instead of the centre of the contact object. The second limitation is inherent in the sound cues themselves. The capturing of any sound biases the recording; this is due to various factors within the space it was recorded (Blesser & Salter, 2006). This includes the material properties, shape, scale, position of the recorder relative to the sound, quality of the recording device, and the way the sound is generated. For those with visual impairments, natural sounds are an excellent way to navigate and understand the environment, footsteps, doors closing, movement of other persons and even self-generated noises for the purpose of echolocation reveal information regarding, size, material and the position of the user. Thus, while the use of sound is intrinsic to the success of the project, the sound cues of the digital environment may prove less accurate than is ideal.

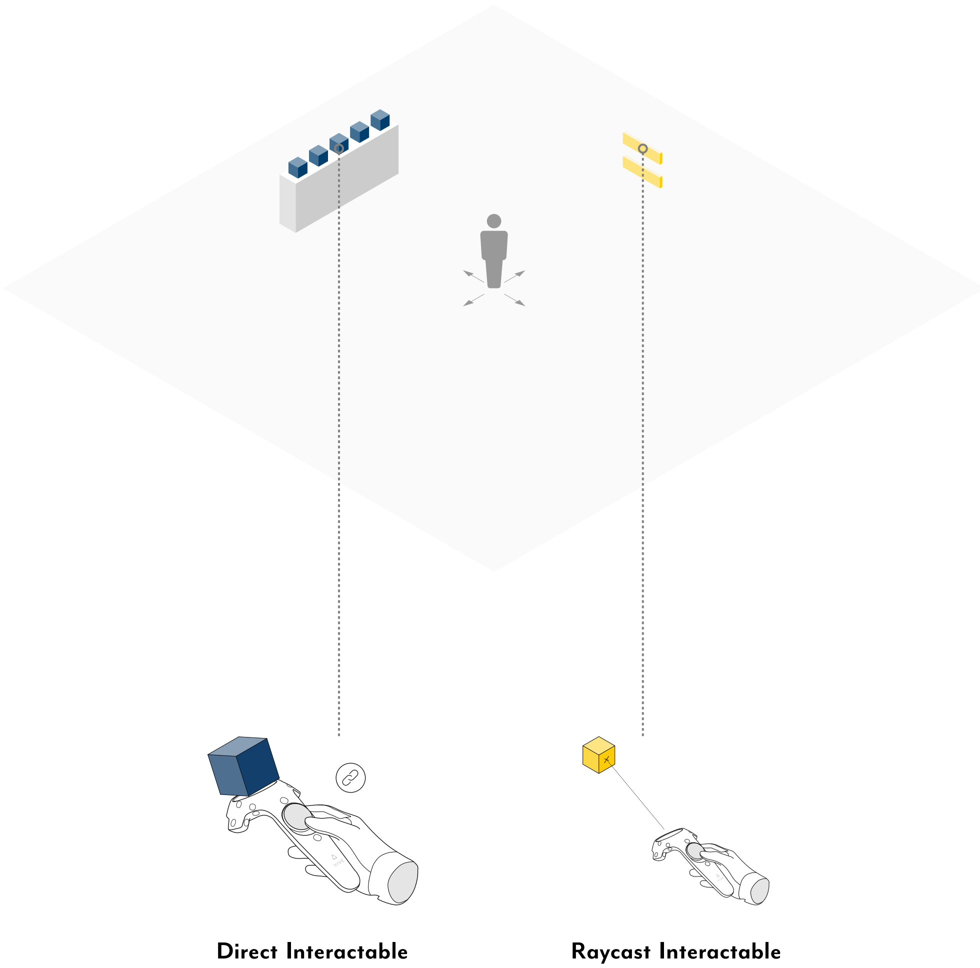
The experiment shows the successful implementation of sound cues embedded within a virtual environment. The Unity sound engine provides the opportunity for reasonably accurate sonic calculations, including reverberation and occlusion. However, some issues remain regarding the spatiality and accuracy of the sound cues themselves. The success of this exercise provides a basis for further sonic exploration. Greater accuracy with the acquisition of sound cues and the refinement of spatial qualities (3D sound) will improve the effectiveness of future designs.

3.4 INTERACTION

One of the essential functions of the Unity game engine is the ability to create interactive environments. The interactive opportunities of the visually impaired within a real-environment are restricted to the immediate human scale. The addition of virtual interactions allows the scale of interaction to be expanded, granting more functional opportunity and autonomy to the users.

The Unity game engine provides a plethora of opportunities for interaction; the previous experiments exhibit some of the basic capabilities. Options explored in this experiment include raycasting, trigger functions, and interactable objects.




Direct Interactable
Raycast Interactable

EXPERIMENT RESULTS

This experiment consisted of many small interactable components. A large room was once again used for the experiment. A small bench was set up with five small cubes placed on top of it. Each of these cubes can be picked up with the controller by pulling and holding the trigger. This enables the user to move them, stack them, and throw them. The raycasting functionality enables the user to manipulate objects from a distance, also allowing for the ranged execution of the same haptic and sound functions as the prior experiments. A potential limitation is that distance interaction with objects may prove quite difficult for those with impaired vision. As the distance between the user and the object increases, greater accuracy with the controller orientation (and henceforth, the raycast) is required for object interaction. For those with visual impairments, identification of the target object may be significantly more challenging and thus aligning the controller will prove more difficult. This issue may be alleviated through the use of strong colours or contrasting materials which will enable easier identification.

The results showed the potential for interaction with the virtual environment. Specifically, the raycasting aspects are of great importance as they successfully expand the realm of spatial understanding, and allow for interactions not limited by the physical constraints of the real-world.

3.5 CONCLUSION

The use of haptics, sound, and interaction in the sensory design experiments outlined a broad range of potential for their use as well as some significant limitations. Future design work integrates each of these elements in order to provide successful spatial comprehension.

The haptic feedback available with the VIVE controller is at a lower level of specificity than what would be ideal. An initial design idea for the use of haptics was that a unique kinetic signature that could be applied to different objects, allowing users to infer object identity through their materiality. Unfortunately, the haptic feedback did not provide enough variation for more than a few different signatures to be created. While it was initially thought that haptics would play an important role in virtual sensory experience, the information provided was not substantial enough for any meaningful sensory stimulation to be created. However, there was still potential for the use of haptics in object identification, navigation and task-oriented experiments.

The sound experiment showed potential for use in the functional experience of users. The initial design ideas regarding contact sound cues and spatial sound information were successfully implemented. There were some remaining issues regarding the choice of sounds, the quality of sound recordings and the origin of the sound cues when triggered.

Interaction experiments proved widely successful and carried the important task of expanding the scale of spatial understanding for those without vision. Initial design ideas in pursuit of this objective proved very successful. A potential limitation is the use of interactive tools that require orientational accuracy; this would need to be rectified in future design outcomes in order to be successfully utilised.

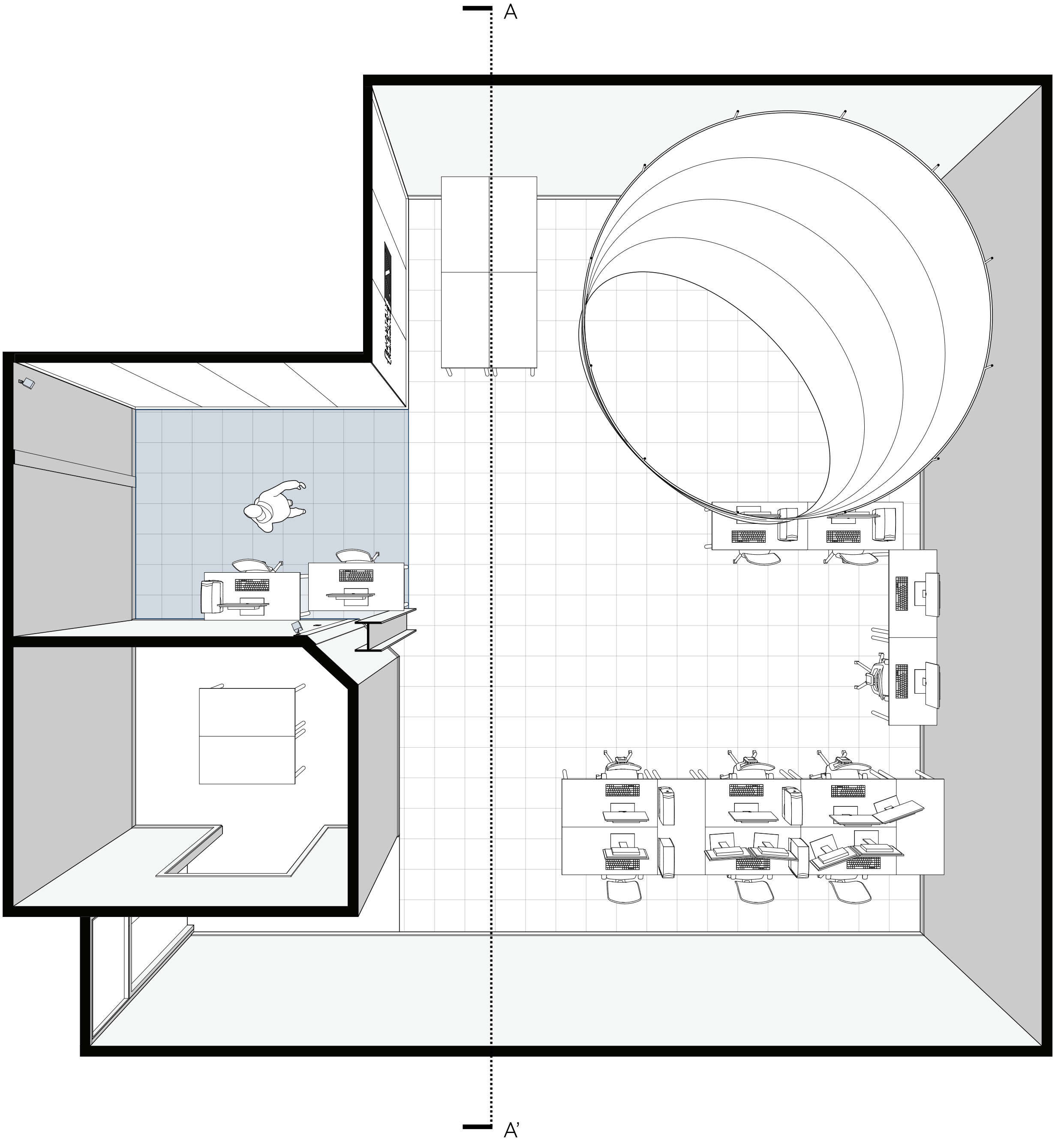
DESIGN 4.0

4.1 INTRODUCTION

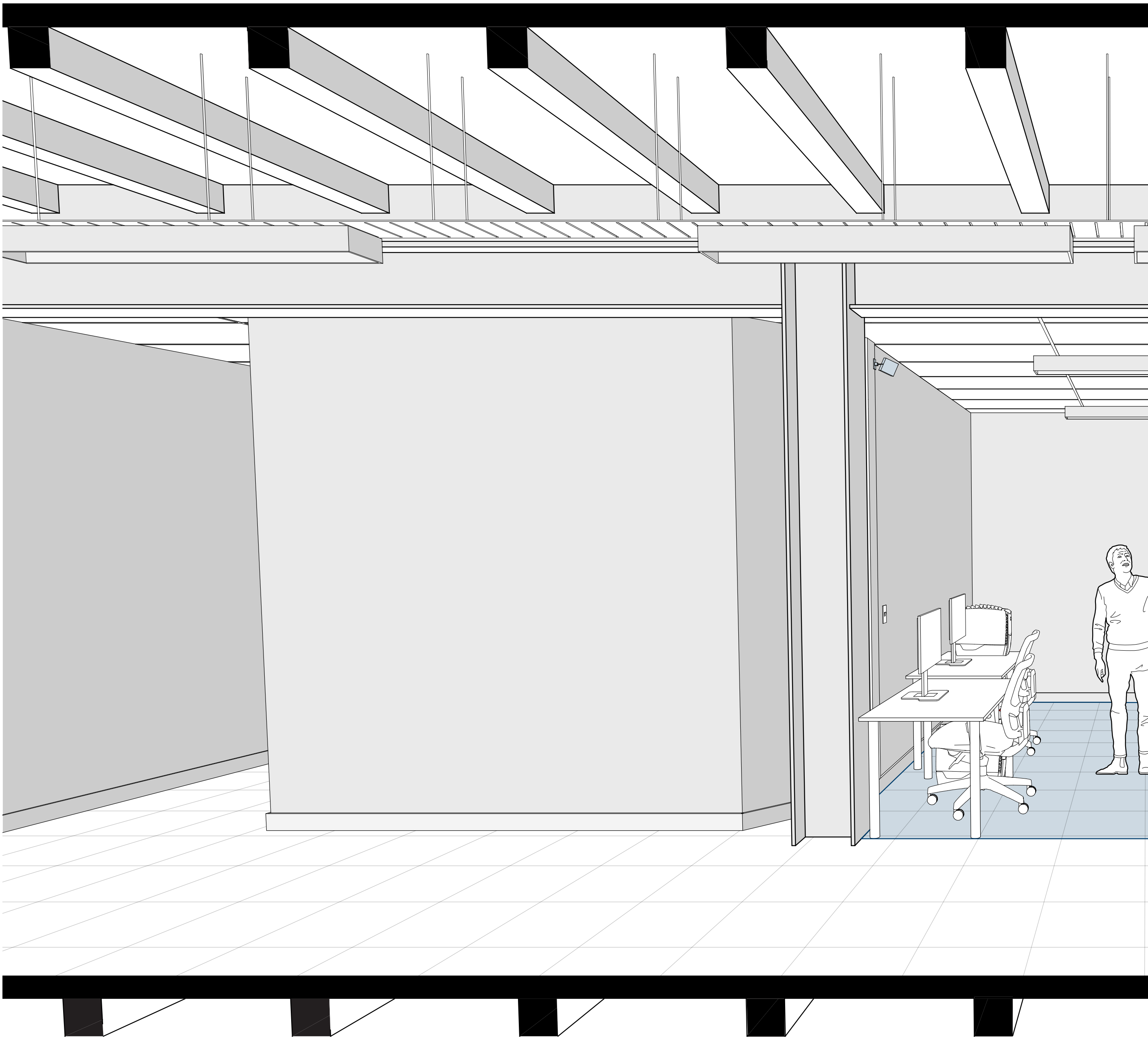
The design section integrates the previous findings of the sensory phase with the relevant literature through design experimentation within a Mixed-Reality (XR) environment. The continued experimentation further refined the scope of the design research and built upon the ideas explored within the sensory phase.

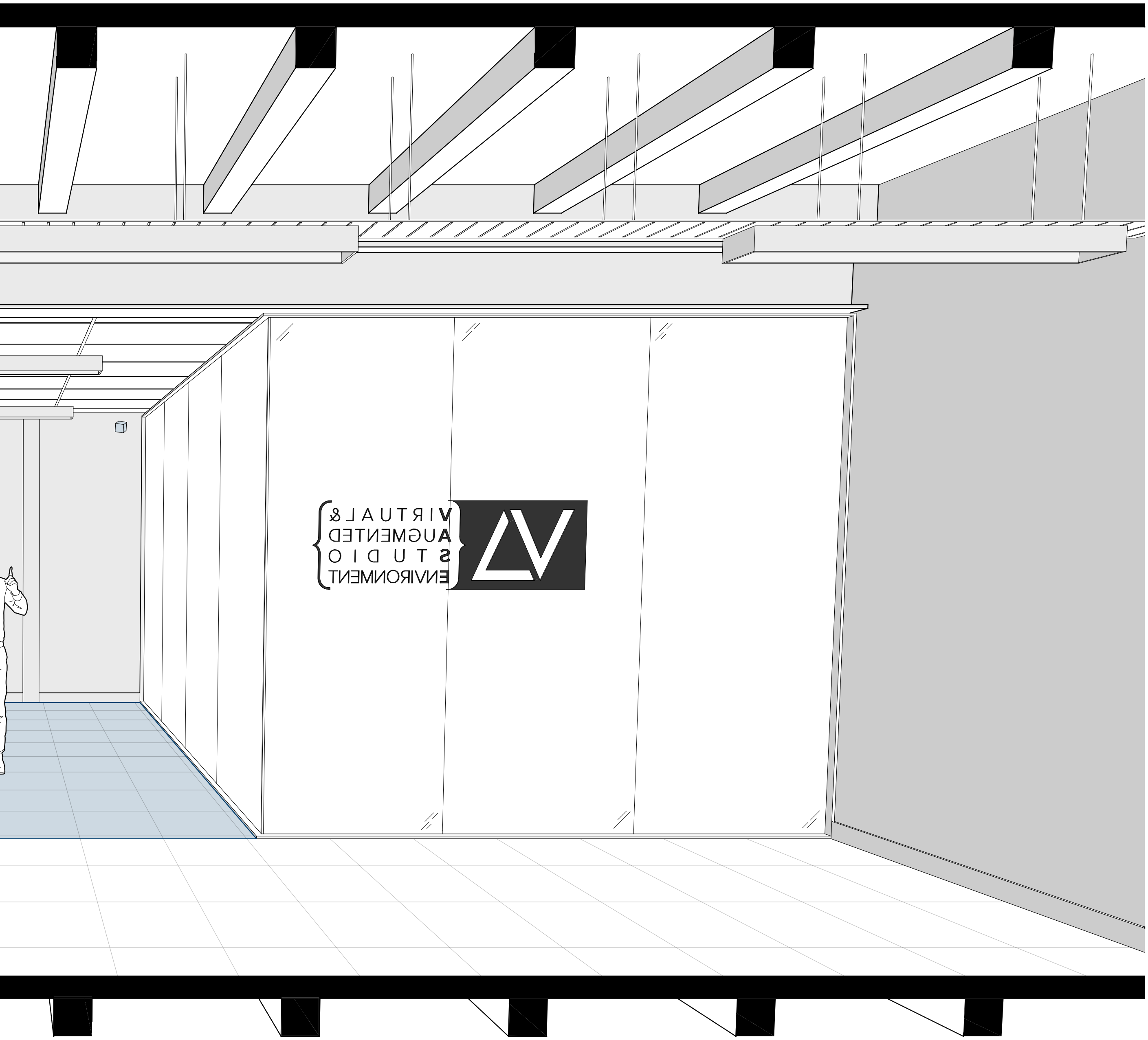
4.2 VASE

The VASE space(Virtual & Augmented Studio Environment) is the location in which the preliminary design scheme was developed. The VASE space is located within the School of Architecture's Te Aro Campus and is the location in which this thesis was completed. This design experiment resulted in the digital augmentation of the test area through the use of haptic and sonic cues, a previously created visual impairment simulation was used to assist in refining the detail aspects of the sensory cues.

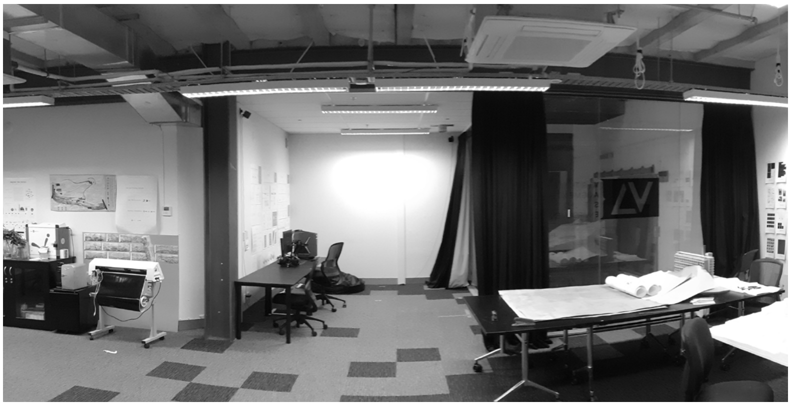

A
A'

VASE SECTION A-A'

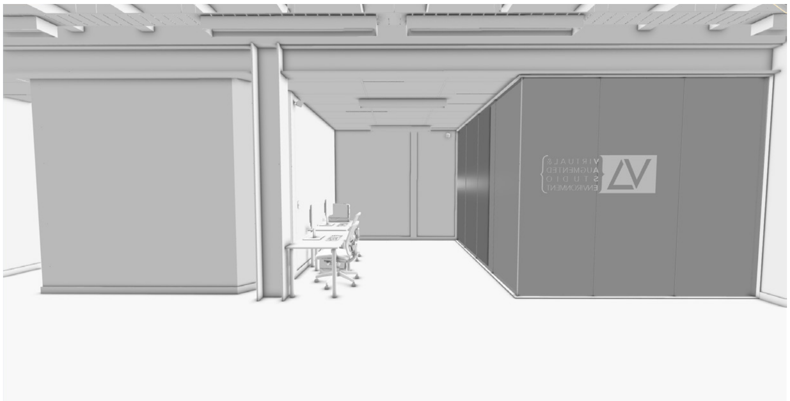



VIRTUAL &
AUGMENTED
STUDIO
ENVIRONMENT

Real VASE Room

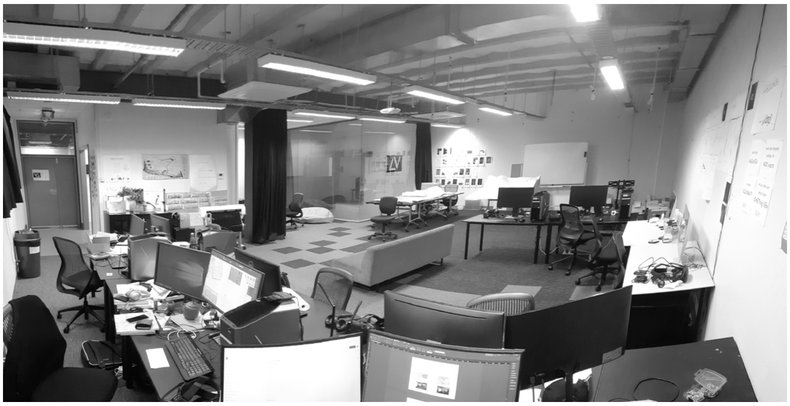


Rhino Recreation

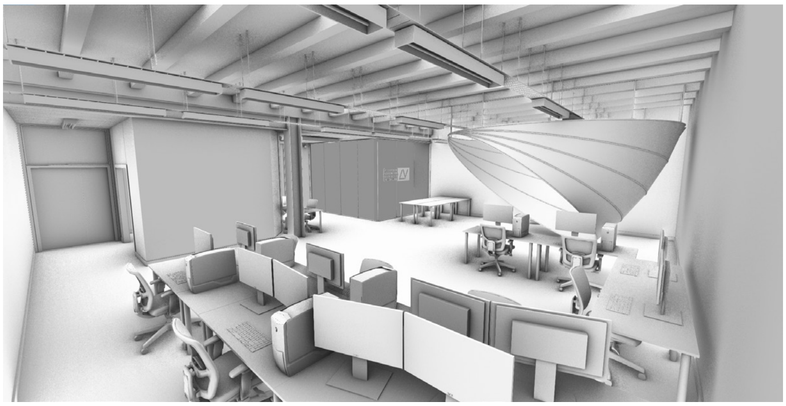


Unity

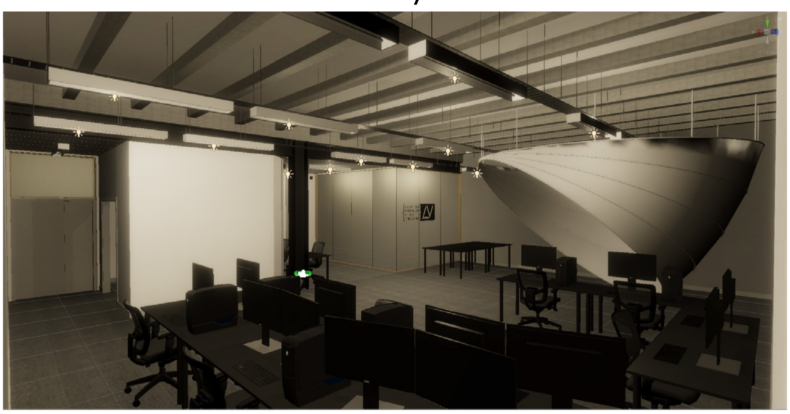
Real VASE Room



Rhino Recreation



Unity



4.3 PRELIMINARY DESIGN

This preliminary test examined the use of digital technologies for the augmentation of architectural spaces. A virtual model of the VASE space was created based on measurements of the room. The texturing of the model replicates the materiality of the room. These were created through the use of photographs of surfaces in the room. The resulting model is an accurate and immersive replica of the space, allowing users to suspend disbelief while interacting with the environment.

The preliminary design results placed a unique haptic signature upon each of the different objects in the room. Sonic cues were recorded that simulate the materiality of each of the objects. The haptic signature and sound cues are both instantiated on collision with an object.

Haptic Patterns

Glass
Strong Sharp Pulse, Followed By Strong Continuous Pulse

Wall
Moderate Strength Pulse, Followed By Moderate Intermittent Pulse

Desk
Moderate/Light Strength Pulse, Followed By Light Intermittent Pulse

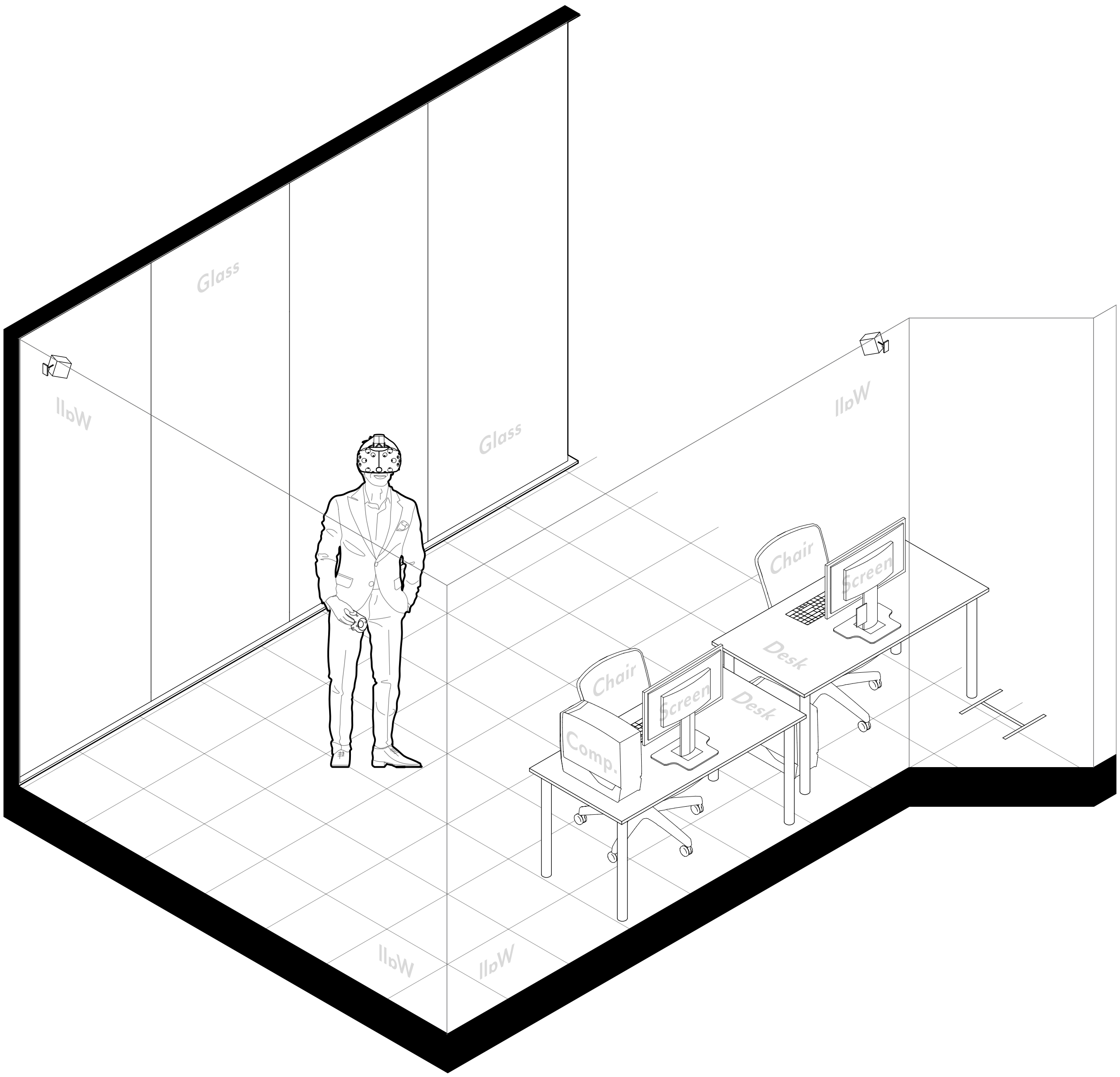
Screen / Computer
Light Intermittent Pulse Triggered

Chair
Light Intermittent Pulse Triggered

Sound Cues

Glass
Wall
Desk
Screen / Computer
Chair

SCENE SETUP



Glass
Glass
Wall
Wall
Chair
Screen
Desk
Chair
Screen
Desk
Comp.
Wall
Wall

EXPERIMENT RESULTS

The exploration of the augmented environment was done without vision and revealed a mixture of issues and successes. Despite the limitations of the earlier haptic experiments, it was possible that a re-investigation of haptic functionality with an improved skill-set and superior understanding of the Unity engine might uncover superior results. This assumption proved incorrect, and this experiment replicated the same limitations as prior design experiments. The unique haptic signature applied to each object proved confusing and ineffective. The lack of variation between the haptic cues ensures that identifying each object required a significant amount of time and effort. The sound cues proved hugely successful and helped identify the objects accurately; this was especially successful with the glass and metallic noises. However, it is doubtful that object identity could be inferred through its sound cue unless one was already familiar with the area.

While exploring the model and validating its accuracy, a high level of suspension of disbelief was present, which was highly unexpected. This allowed for a very immersive experience of the environment and the associated sensory information. Thus, while the experiment initially appeared to be underwhelming, it became evident that once trust was formed in the space, the sensory information allowed for a very accurate and detailed cognitive map of the space to be formed.

The results of the experiment suggest that at its current state, the project represents a unique method of digital sensory augmentation, which allows for very accurate and rich spatial understanding. The following experiment refines the existing sensory scheme and expands it by incorporating the previously established interaction techniques.

4.4 DEVELOPED TEST

For the developed experiment, the haptic cues were re-organised through the use of a two-category typology system, which grouped object into furniture and boundary items. The developed test integrated the previously developed raycasting techniques in the form of ranged mechanics. These allow users to gather information about objects from a distance, expanding the realm of spatial understanding.

The final control scheme is separated into passive and active mechanics. The split scheme allows for a reduction in cognitive load, only providing information when desired, or when necessary for personal/property safety. The passive mechanic is the object-detection scheme developed in the previous phase and automatically triggers when users collide with the boundaries of objects. The active scheme combines the raycasting techniques and the controls of the VIVE controller, enabling users to trigger a distance measurement function and an echolocation function. The two functions are newly developed methods of ranged spatial engagement.

Haptic Patterns

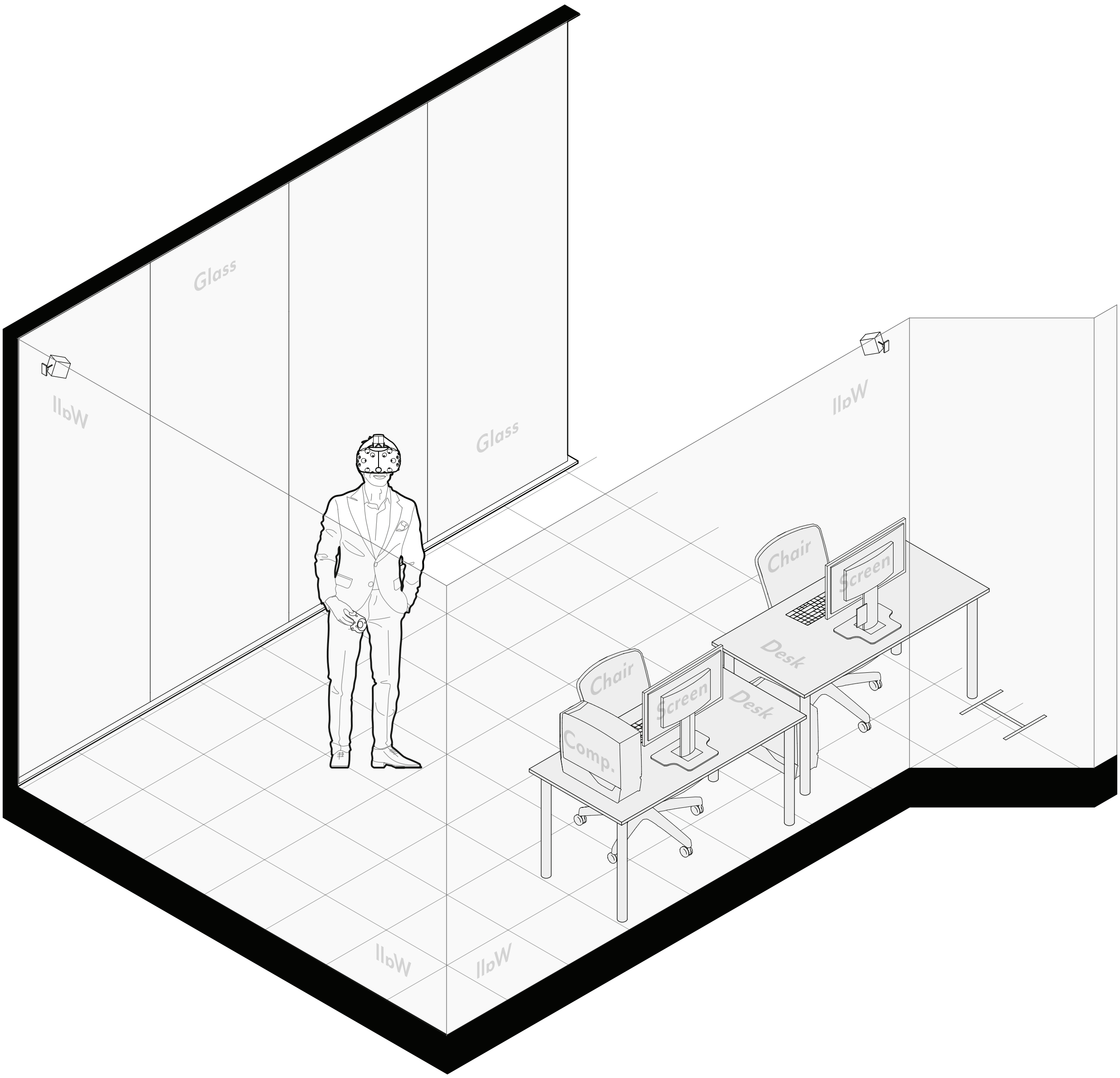
Boundary
Glass, Wall
Strong Sharp Pulse, Followed By Strong Continuous Pulse

Furniture
Screen, Computer, Desk, Chair
Moderate Strength Pulse, Followed By Moderate Intermittent Pulse

Sound Cues

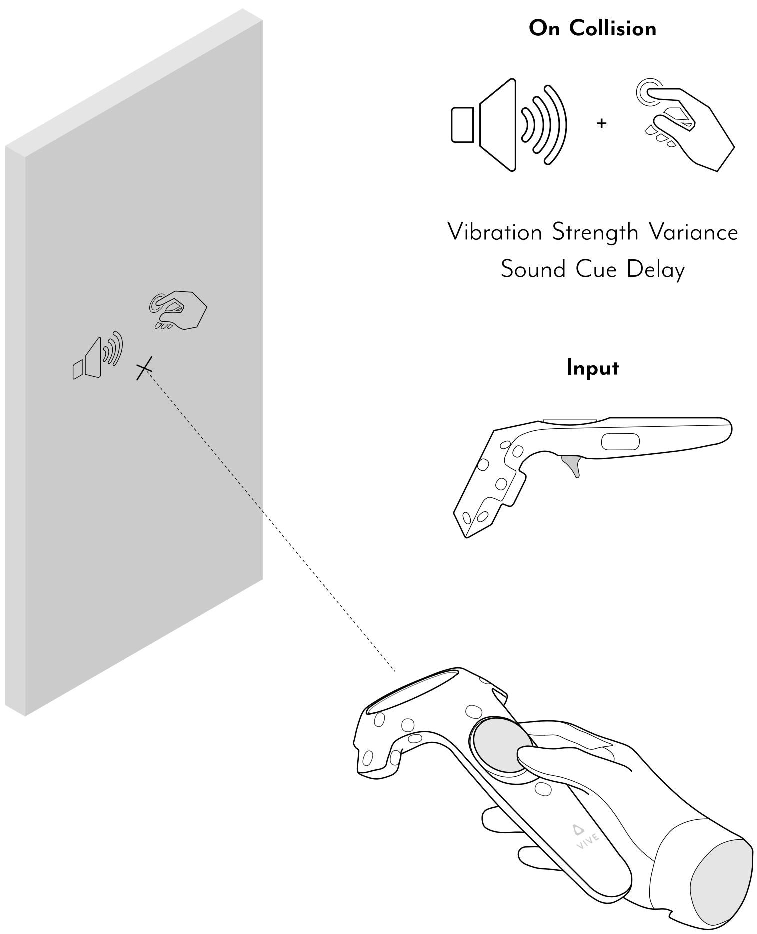
Glass
Wall
Desk
Screen / Computer
Chair

SCENE SETUP


Glass
Glass
Wall
Wall
Chair
Screen
Desk
Chair
Screen
Desk
Comp.
Wall
Wall

DISTANCE MEASUREMENT

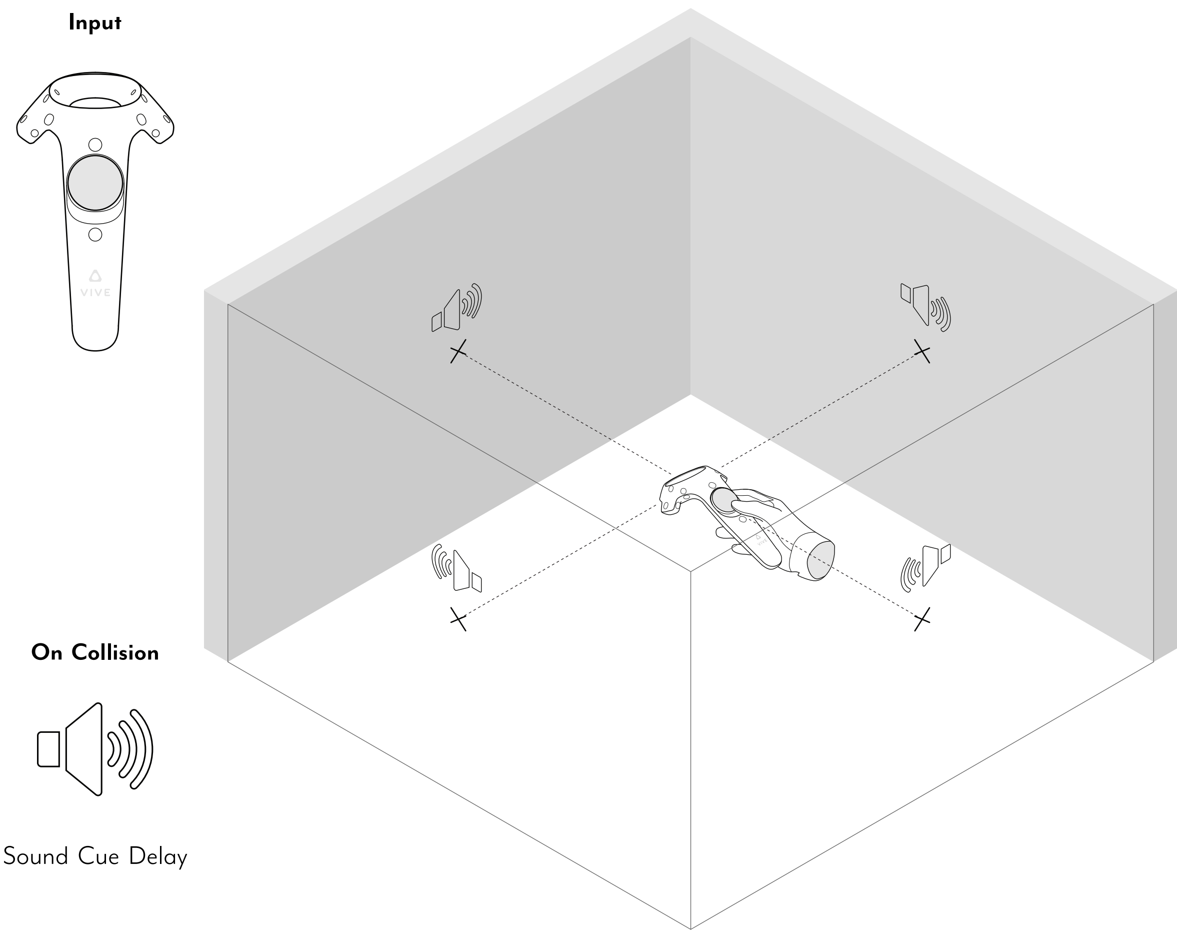
The distance measurement mechanic is used to gather information about a singular object in the scene. Upon pulling the trigger, a raycast is generated that follows the orientation of the controller. When an object is hit, the distance travelled by the ray determines the strength of the controller vibration. The object's assigned material will be used to select the material sound cue that is played. The Unity engine sound system allows the origin of the sound cue to be set at the location of the raycast collision. This feature allows for clear judgement of object distance and may allow for inferred spatial information.



4.4 Developed Test - Design

ECHOLOCATION

The echolocation mechanic is the second of the newly created active mechanics. This mechanic was developed to provide information about users surrounding, mainly through material properties. When a user presses the central pad of the controller, a four-directional raycast is generated. These raycasts enter the environment and upon hitting an object will trigger a sonic cue that reveals the materiality of the object. The distance that the ray travels is used to provide a delay to the instantiation of the sound cue. This allows users to establish the material of the objects surrounding them but also allows for judgement of distance.



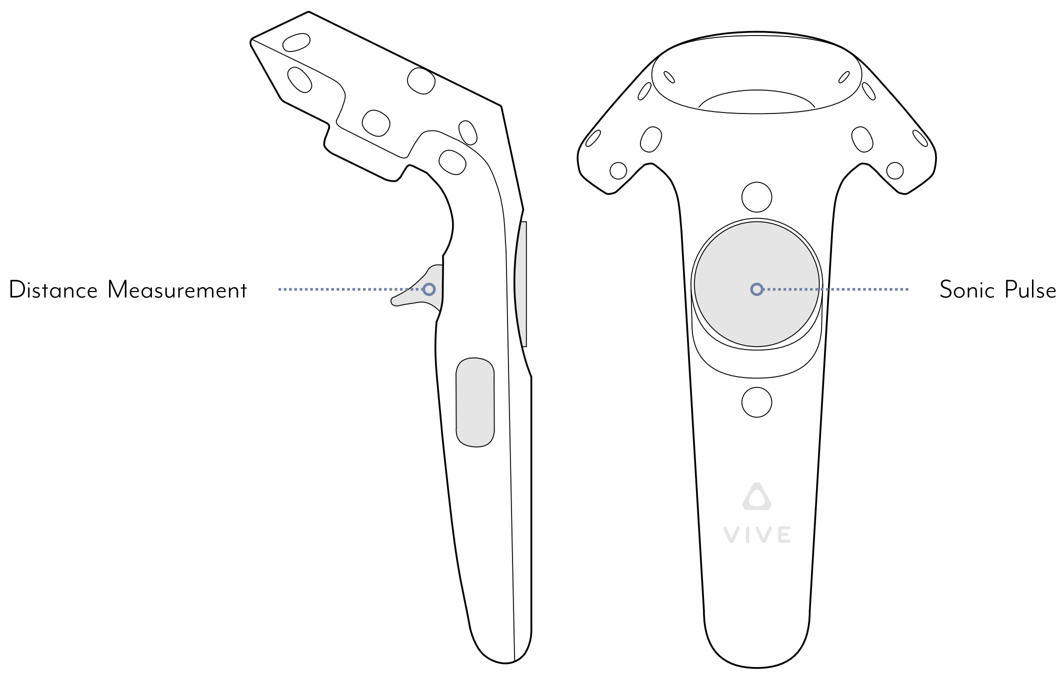
PASSIVE MECHANICS

The passive mechanics in this scheme will trigger regardless of user input. The passive mechanics summons a range of distinct haptic patterns and sound cues assigned through the typology-based organisation system. These cues are triggered once the VIVE controller collides with the extended boundary of objects in the scene. The typology system organises objects into two categories, boundaries and furniture. The boundaries of the room are marked with a strong, sharp haptic trigger, and a moderate continuous haptic pattern marks the furniture. The sound cues are assigned depending on the real-world material of the object.

ACTIVE MECHANICS

Active mechanics are functions that trigger upon user input. The VIVE controller has three buttons for which functions may be assigned, the trigger, pad and grip. The ‘distance mechanic’ is assigned to the trigger function, and the ‘echolocation’ mechanic is assigned to the pad.

Active Mechanics



REFLECTIONS

The developed augmented environment is a significant improvement over the initial experiment. The refinements of the spatial engagement system proved successful, allowing understanding of the human-scale and larger-scale aspects of the environment. This system is broken into two schemes, the passive (automatic) and active (user input) schemes. A previously created visual impairment simulation and closed eyes were employed to ensure an accurate spatial experience.

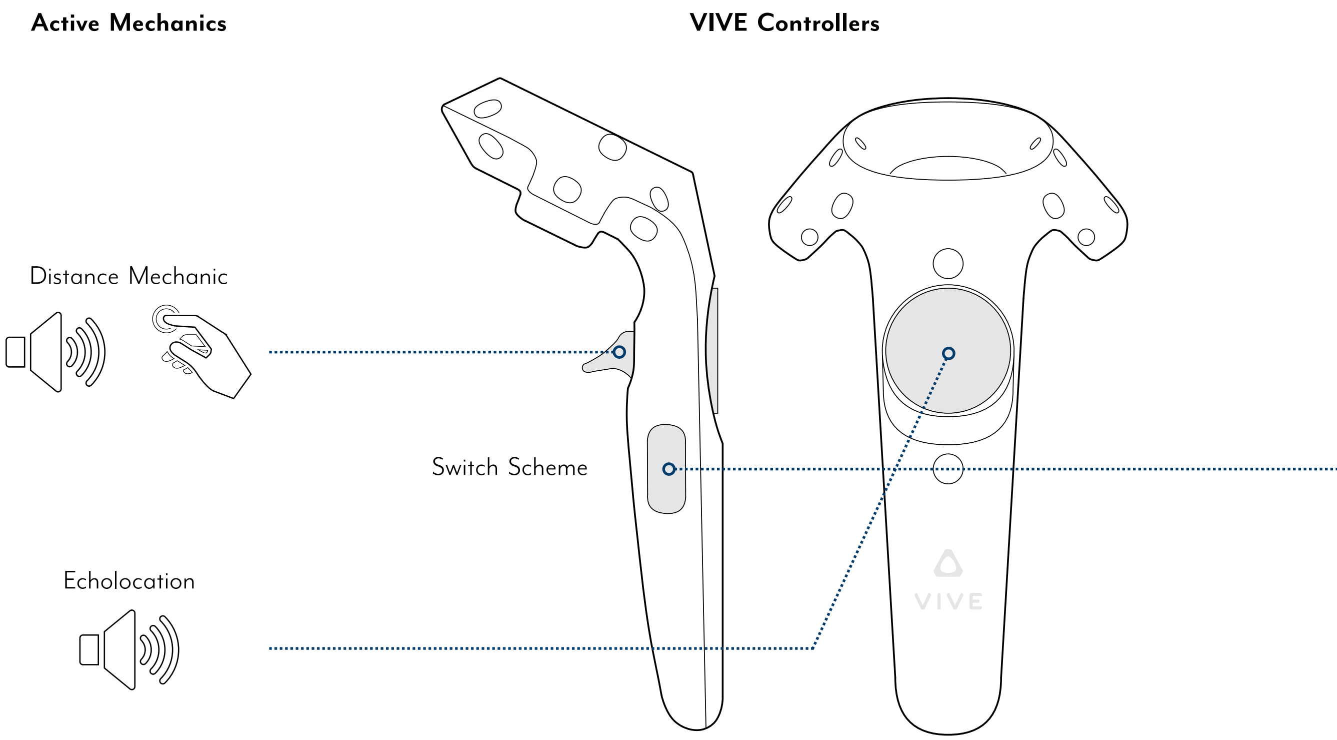
The haptic signatures assigned in the previous experiment allowed for a general notion of object location and size but using them to identify object types proved difficult. The new, simplified typology-based scheme proved very successful and allowed for clear differentiation between the boundaries of the room and the furniture of the room. The sound cues have consistently proved valuable in the communication of spatial information. Their use in this experiment replicated the previous findings, allowing for accurate material/object identification, this integrated successfully with the haptic signatures. The scheme functioned as follows: the haptic signature provided instant macro-level information as to the type of object and the simultaneous sound cue allowed for the identification of specific object features.

The addition of the raycasting based methods proved a useful addition to the scheme. These functions (Echolocation and Distance Measurement) extended the realm of spatial engagement significantly when compared to the primarily human-scale spatial understanding of vision-impaired individuals. Differentiating the methods into the active and passive sets allowed the mechanics to be added without the overall scheme becoming confusing or complicated.

The outcome of this experiment suggests that the method of digitally augmenting environments may prove to be very successful in aiding the spatial understanding of the blind and visually impaired. While the experiment was a resounding success in terms of spatial understanding, there is still room for the expansion of the active mechanic set and further validation of the existing mechanic's effectiveness.

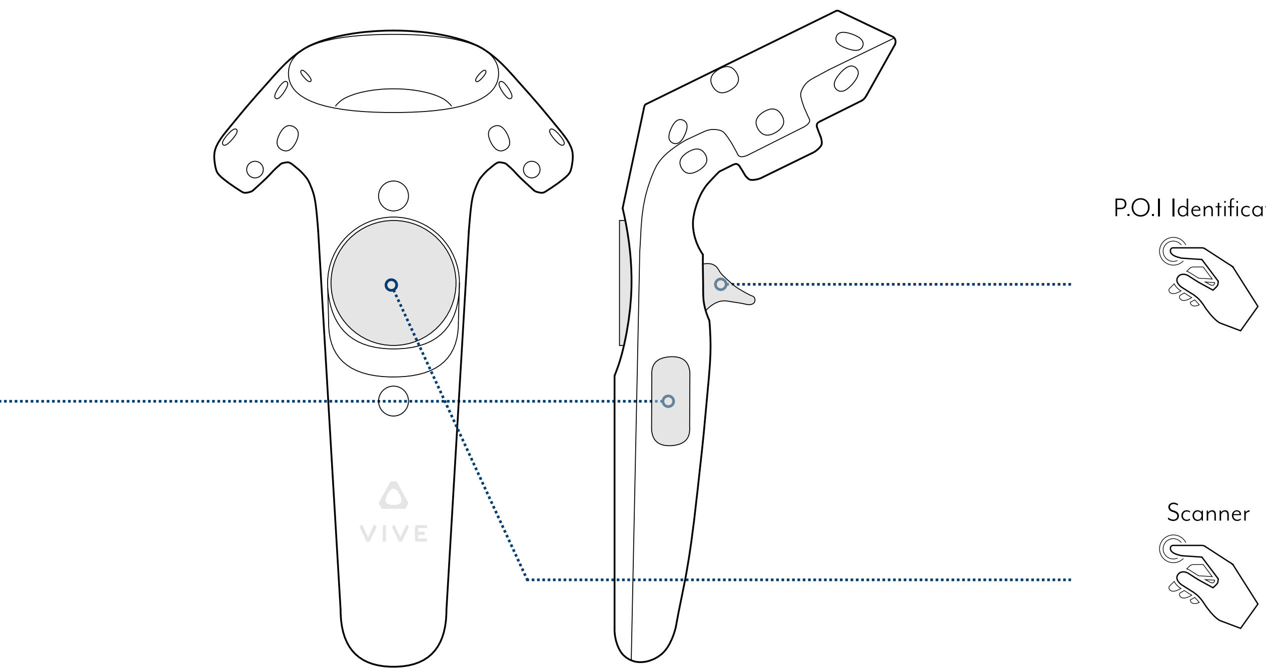
4.5 EXPANSION

In order to add new active mechanics, the control scheme required adjustment. Using the grip button on the side of the VIVE controller the active mechanics assigned to the pad and trigger can be toggled, enabling expansion from two mechanics to four. The expansion allows users greater freedom in choosing how they wish to explore the environment and how they would like to receive information.



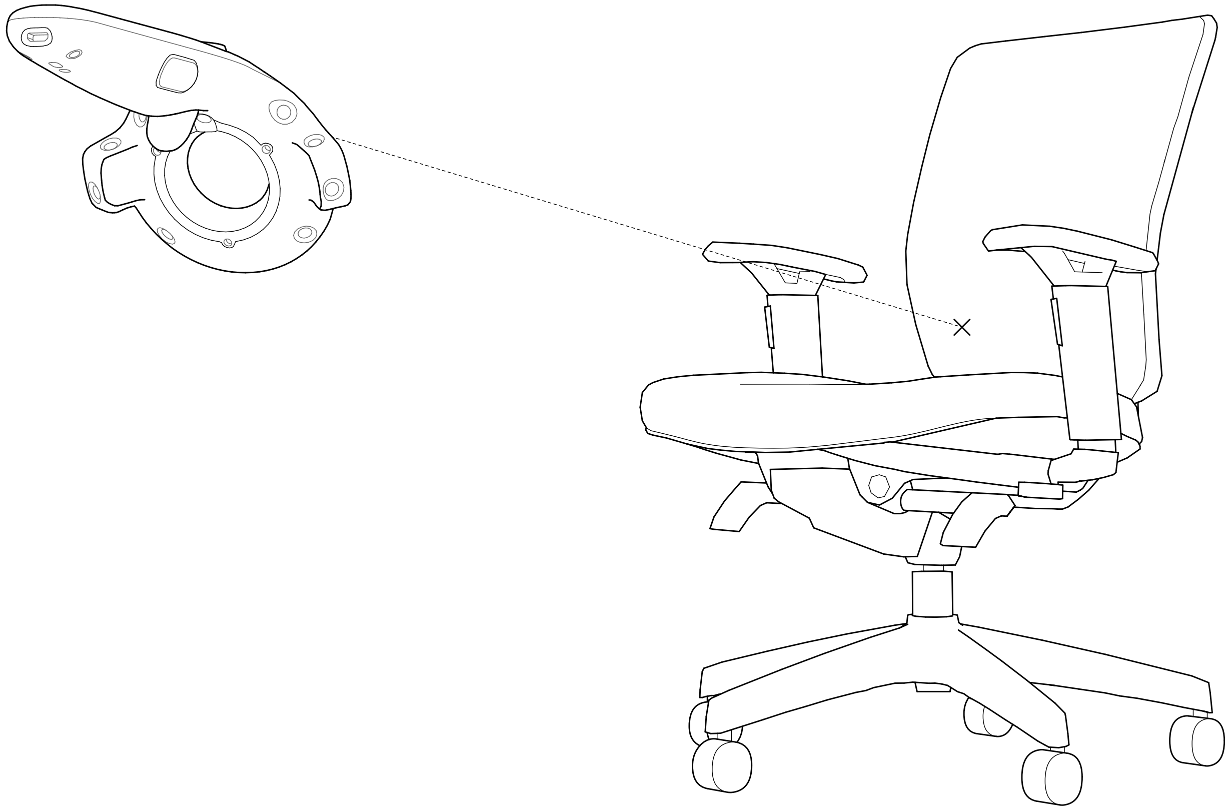
VIVE Controllers

Active Mechanics



4.6 POI MECHANIC

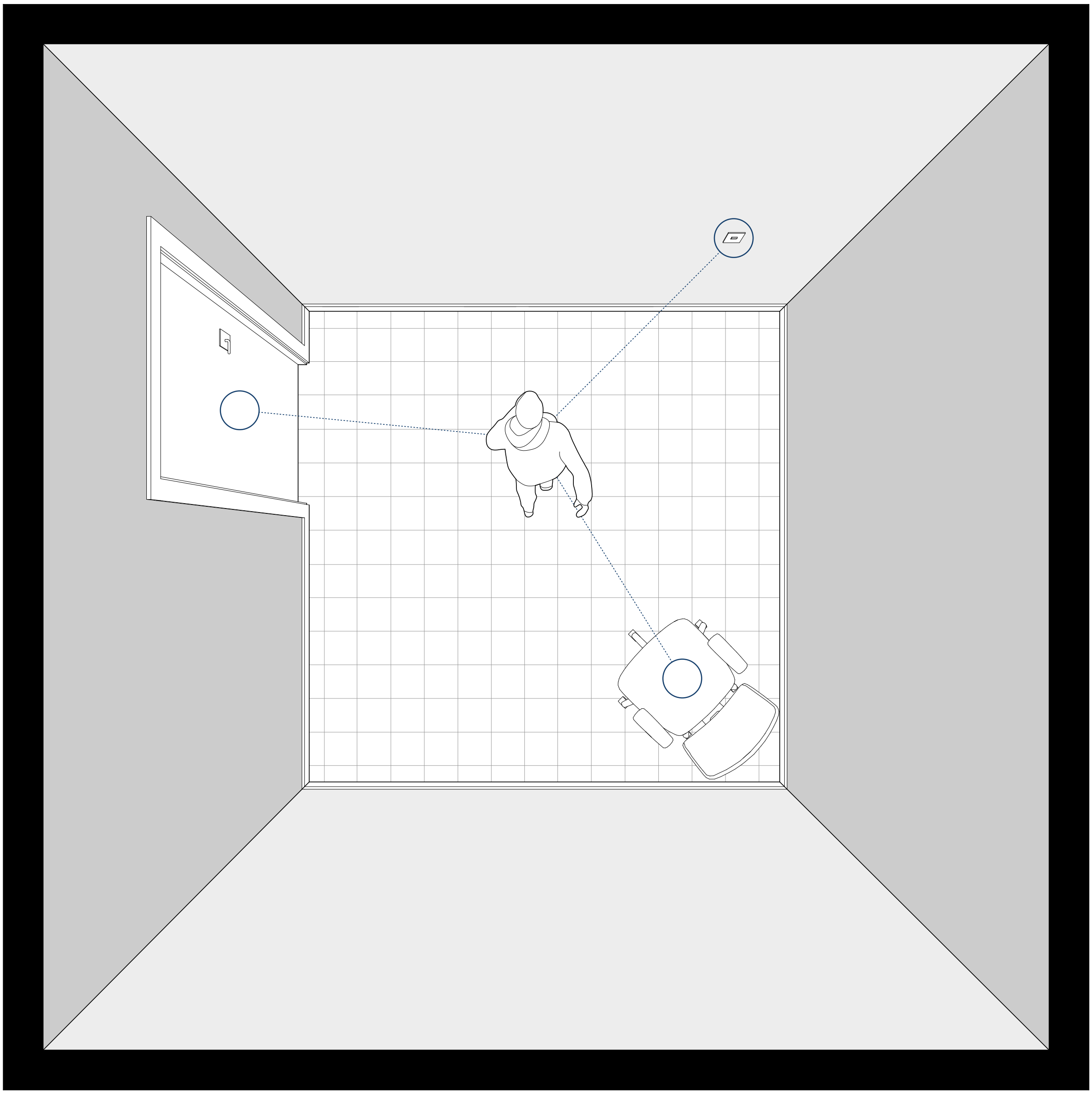
The POI (point-of-interest) mechanic is first in the second set of active mechanics. The function of the mechanic is to identify 'points-of-interest' in a space. These points of interest rely on the typology system and can be assigned by users, allowing them to decide what type of information they would like to receive. In this design experiment, the points of interest are set to be chairs, entrances and utilities. The haptic cues are single, double and triple pulses, differentiating these different points of interest. The design experiment aimed to validate the usability of the system and whether the pulse-based haptic system functioned as intended.

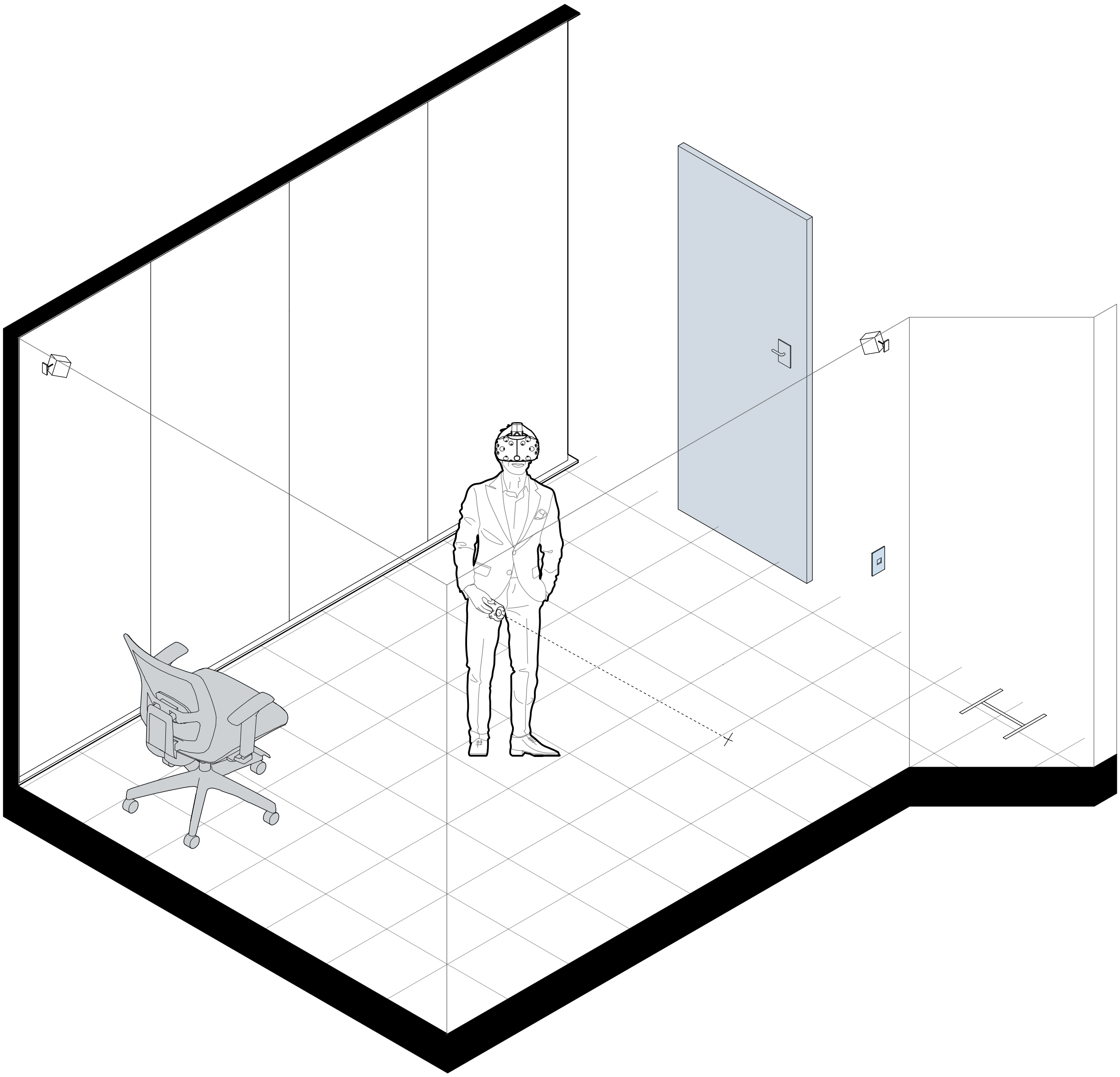


Utility / Taps

Entrances / Exits

Seating





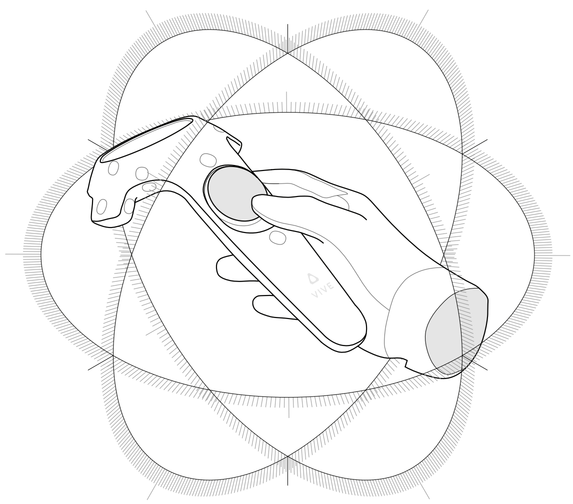
EXPERIMENT RESULTS

The design test revealed that a significant issue with the system was the reliance on accurate raycasting; this meant that the orientation of the controller must point directly towards the object for the haptic cue to trigger. This feature is acceptable when the objects are large, but once they get below a certain size or are at a distance, it becomes much more difficult to orient the controller towards them. An alternative method of ranged engagement was necessary for the mechanic to function as intended.

4.7 POI DEVELOPED

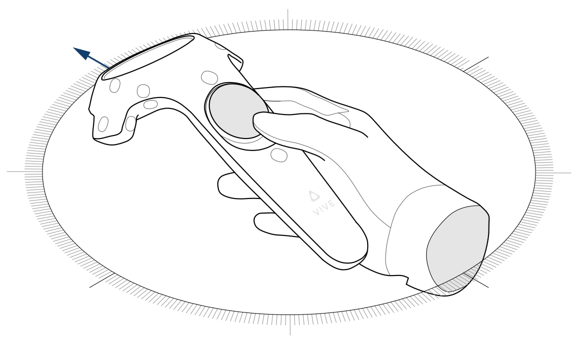
The developed mechanic relies on a different raycasting technique but otherwise retains much of the infrastructure of the preliminary mechanic. The development utilises the orientation of the controller. While previously the orientation of the controller is measured on three axes, this development reduces this to a single axis, removing the need for precision. The angles between the user and the points of interest within the scene are measured. If the trigger is pulled and the orientation of the controller matches these angles, then the associated haptic cue will be triggered.

Three Axis Raycast



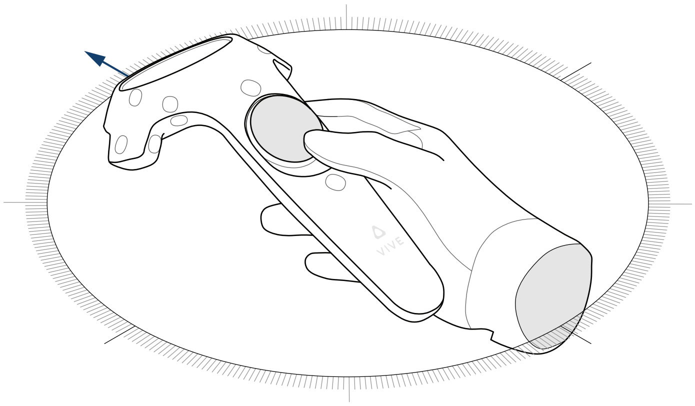
-Requires orientation to align exact with object
-Difficult to use for those with low vision

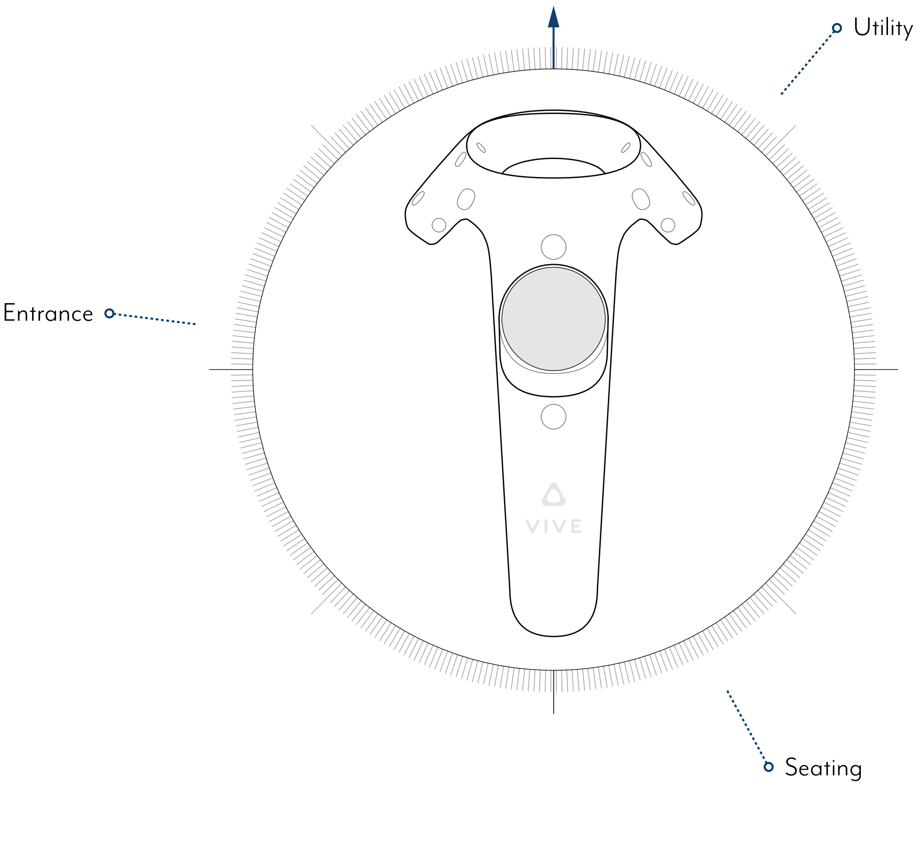
One Axis Raycast



-Based on bodily and controller rotation
-Reduces need for accuracy

One Axis Raycast

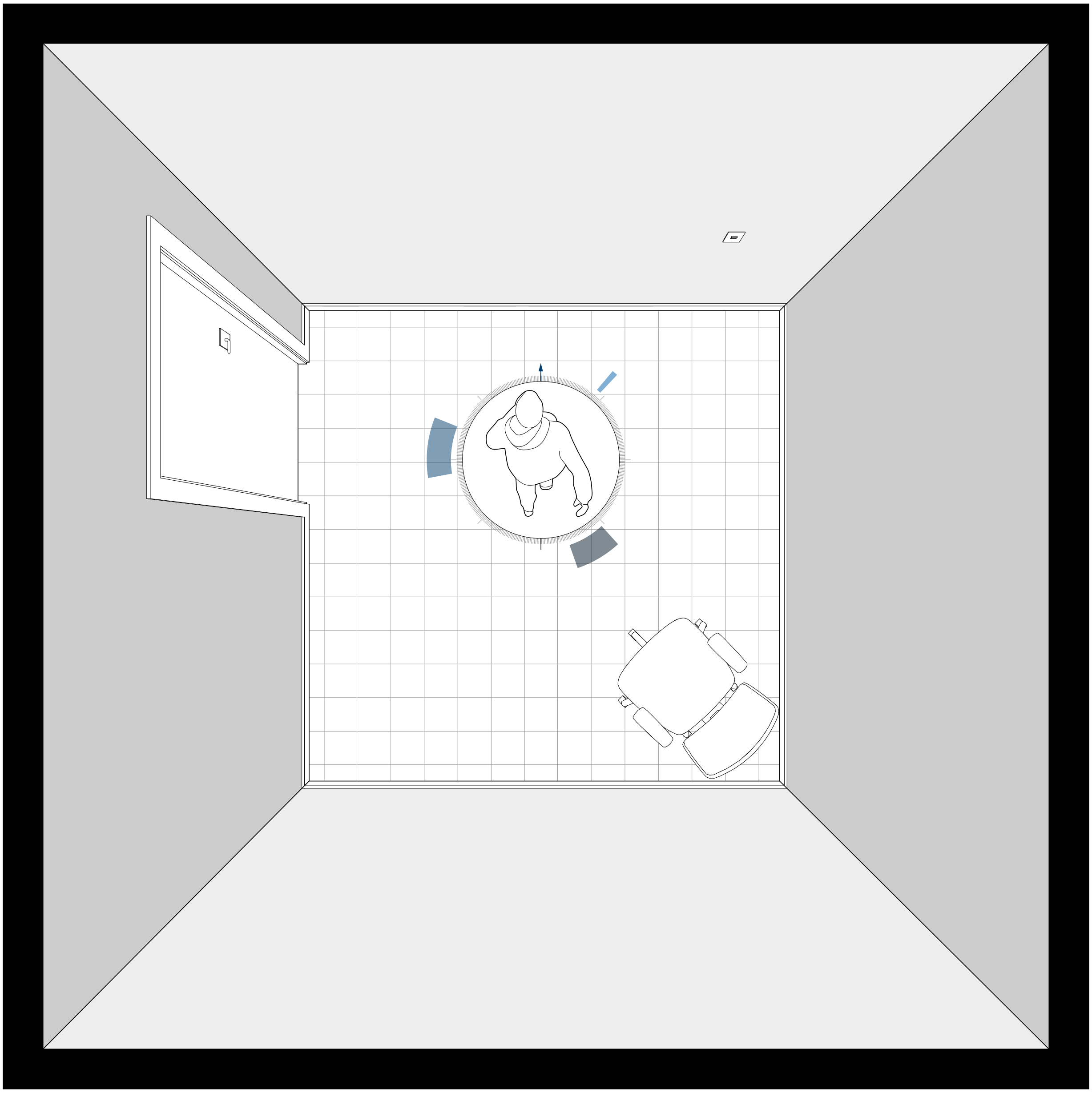




Utility / Taps

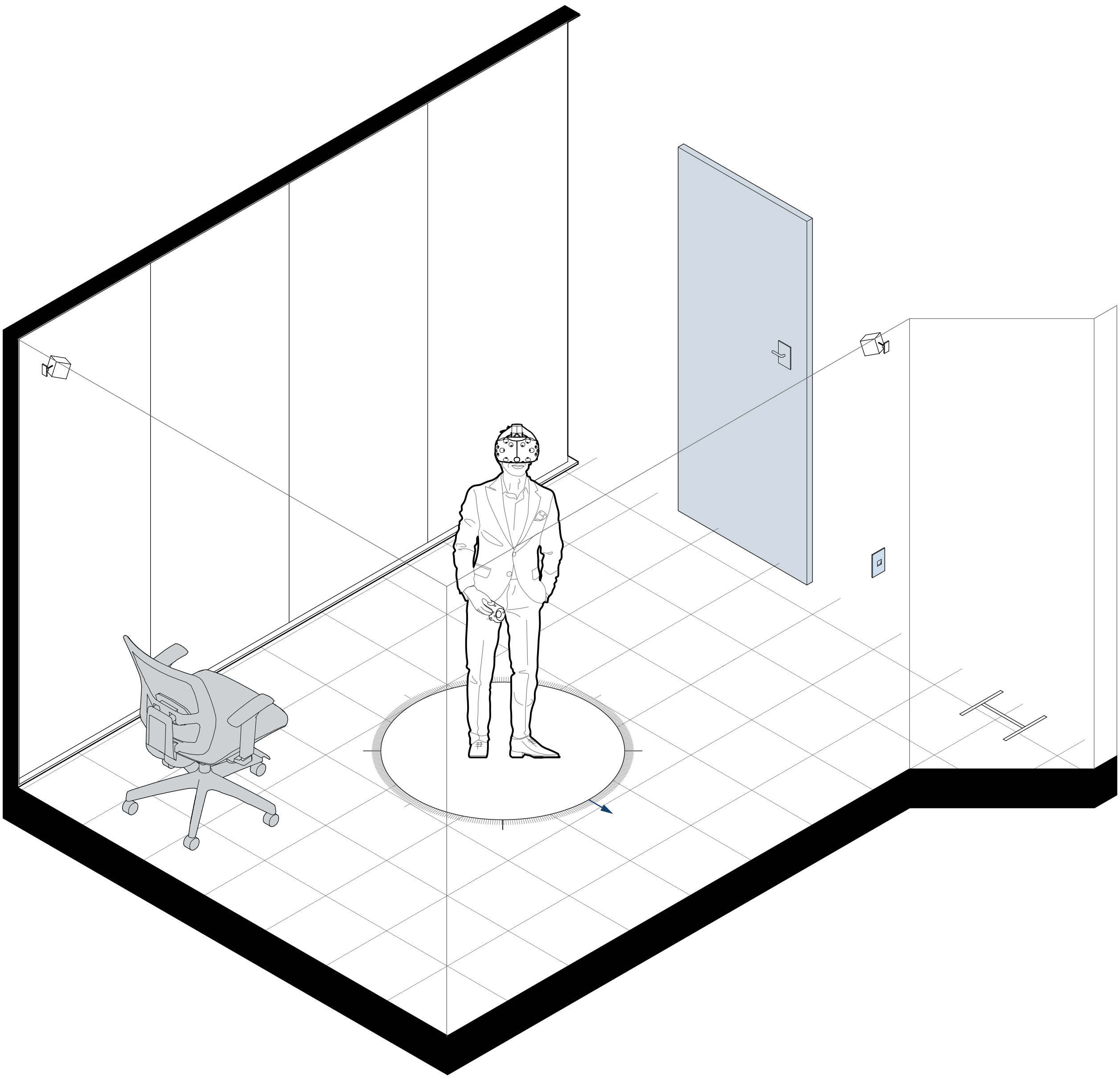
Entrances / Exits

Seating



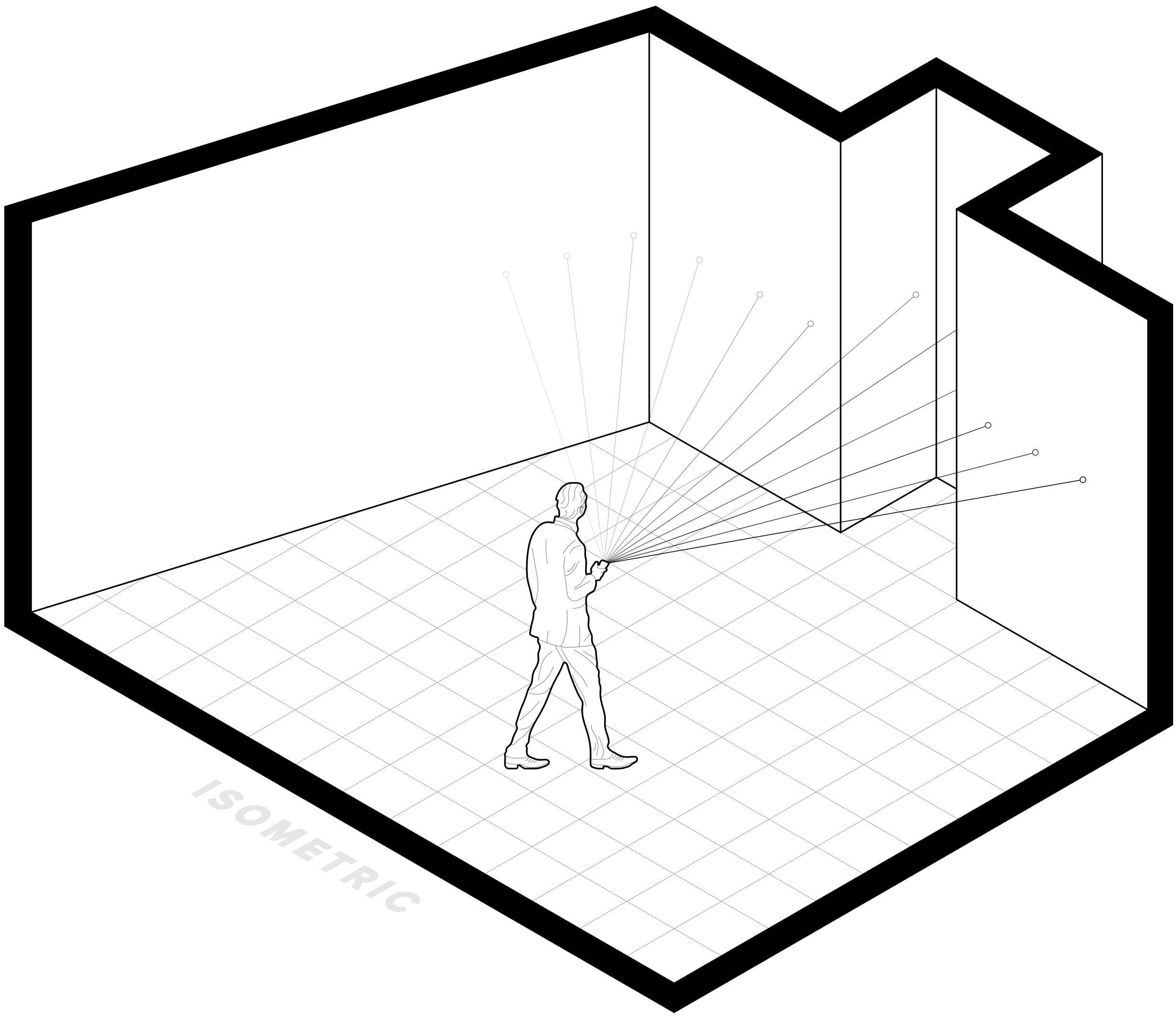
RESULTS

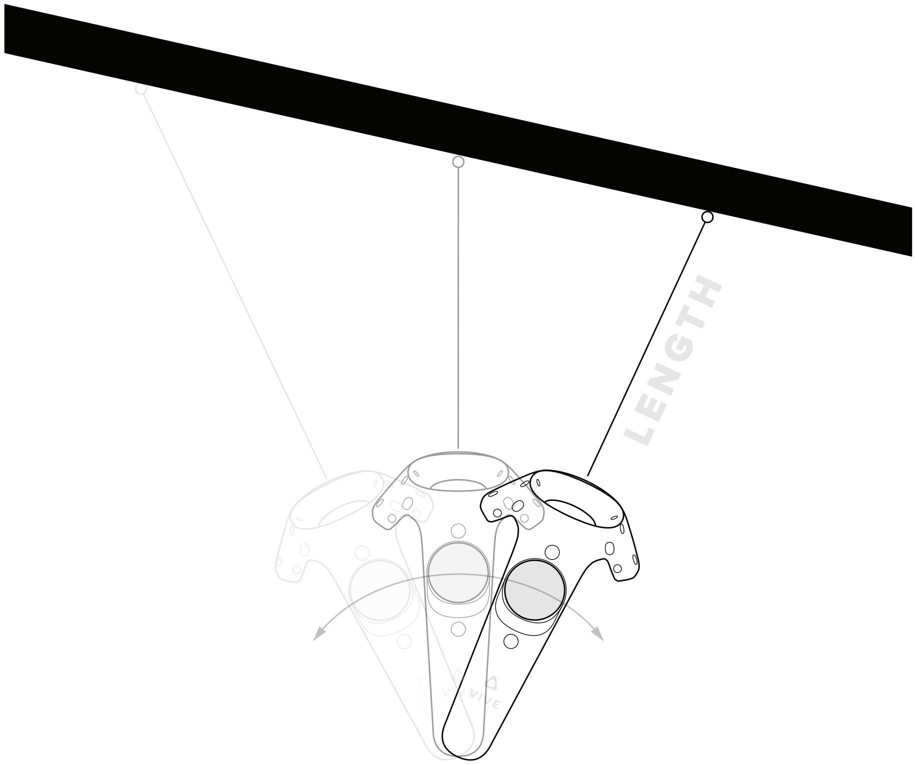
The angular based system proved vastly superior to the ray-casting methods, allowing easy scanning of a room and identification of the relevant objects within.

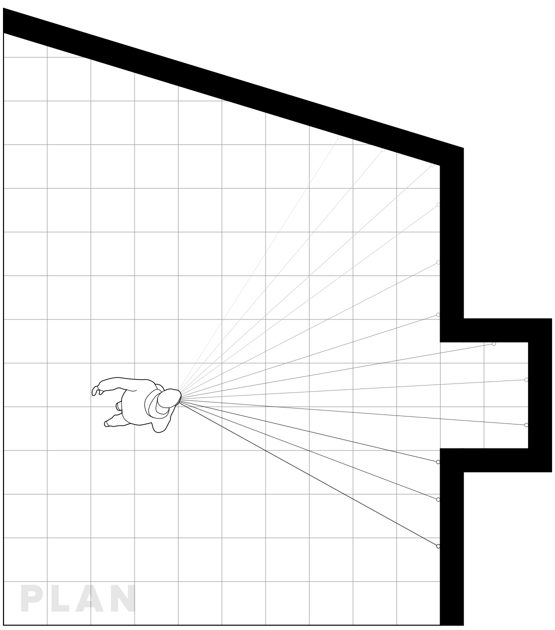


4.8 SCANNER MECHANIC

The scanner mechanic is designed to provide users with continuous information regarding the distance to objects in the environment. Upon pulling the trigger, a continuous series of raycasts are generated and sent into the environment. The direction of these raycasts is based on the orientation of the controller. An average, based on the distance travelled by the most recent raycasts, will dictate the strength of the haptic vibration.







RESULTS

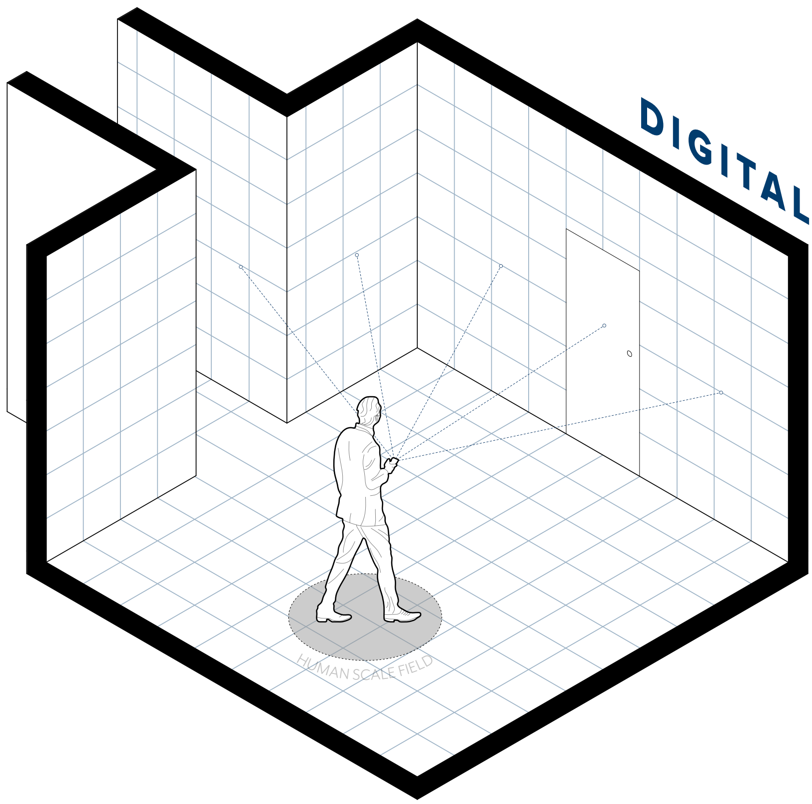
Preliminary exploration with the scanner mechanic showed definite promise. The continuous provision of haptic information provided a powerful method for building a spatial understanding. This worked particularly well for walls and other long continuous objects. The frequency of haptic information and the strength/distance relationship needed further resolution, but overall the mechanic worked as intended.

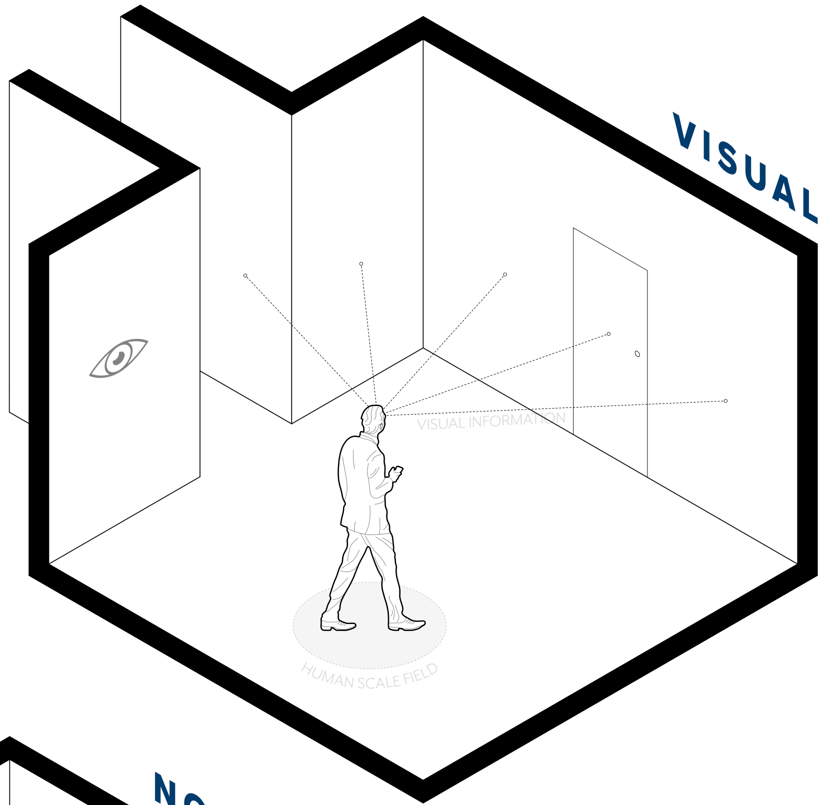
4.9 CONCLUSION

The early stages of the section explore the possibility of mixed reality environments from a perspective akin to sensory design, where the associated haptic and sound cues are understood as aesthetic design features. The early failures in these more artistic experiments, in conjunction with practical utility found in the ranged mechanics significantly altered the course of the development. Throughout a single section, the thesis rapidly shifted into a technical exploration of digital tools and their relevance to architectural/spatial understanding. This is evidenced by the expansion of the passive scheme and in the design of the new ranged mechanics. The analytical approach to organising, categorising and delivering information in the active mechanics, most notably the POI mechanic, are perhaps the best examples of the emerging technical slant to the project.

The success of the five formalised mechanics appeared to represent a step into understanding the methods through which digital tools may help the visually impaired interact with architecture, and how this interaction may aid in their spatial knowledge acquisition. Analysis and summary of the progress thus far would be best described as a spatial understanding scheme that bolsters the local-scale perception of the user, while enabling ranged engagement with the environment.

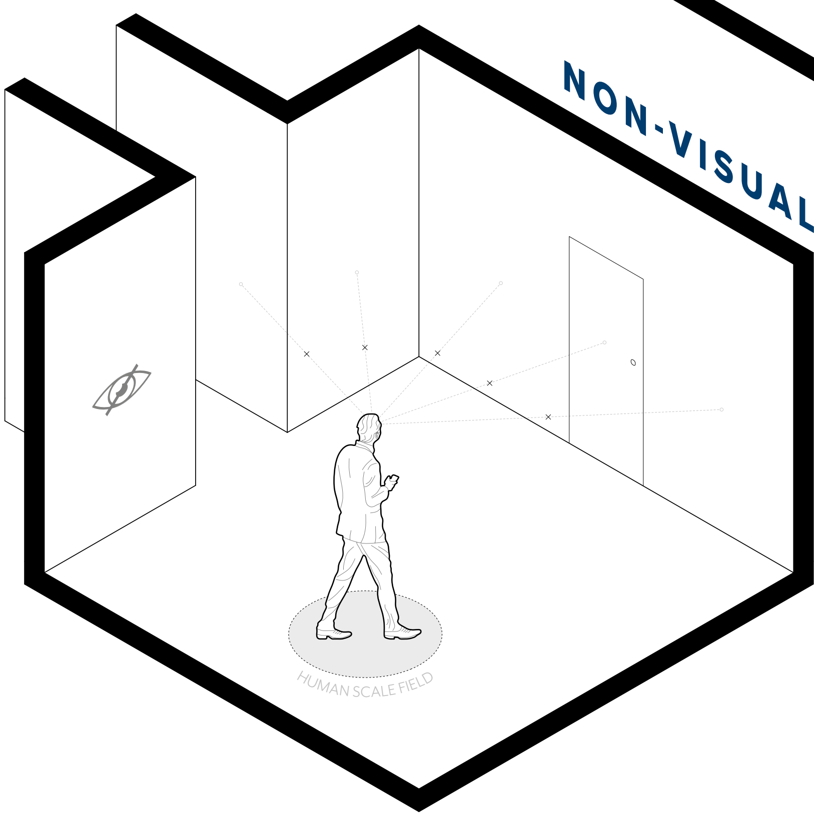
A digital platform is used to bolster the human scale attributes of the user and allow for distance-based engagement with environments. Information is communicated through haptic and sound cues.





Gathering Information
Primary: Vision
Secondary: Sound, Touch

Vision used to gather information, human-scale touch and sound cues play a secondary role.



Gathering Information
Primary: Sound, Touch
Secondary: Vision

Without vision, human-scale touch and sound cues become paramount, they are supplemented by memorised and inferred information.

4.10 CRITICAL REFLECTIONS

The assistive technologies field faces a significant technological hurdle. Because of this, the research and production in the field are primarily concerned with answering for the difficult problem of analysing a real-world environment and providing non-visual information regarding it. This difficulty means that 'an' outcome itself, rather than the performance of the outcome is the primary goal. This is evidenced by the convoluted nature of some results in the field (referred to as niche devices in the literature summary) and the consistent failure of the assistive technology products in the real-world (Elmannai & Elleithy, 2017). The design work of this thesis so far has mostly followed the procedure set by the assistive technology field, where a method for providing environmental information is created and then later assessed for its performance. However, the chosen digital technologies, as a result of their inherent qualities, do not face the same technological hurdle as the assistive technology field. So while the design work in this thesis follows the procedures of the field, it does not face the same difficulties required to justify this type of approach. The lack of this technological hurdle, while harming the quality of the completed design material, does allow a profound opportunity for development. The digital platform's capabilities can be used to explore questions that cannot be answered by assistive technologies. Thus, a far more exciting direction for the research is investigating how the visually impaired may engage with and understand architecture through the digital medium. This is a broader research interest, but one that may provide substantially more important results.

There is very little existing work that explores these questions, and even less that rely on modern digital technologies. Some examples previously cited in this thesis are Nam et al., 2015, Lahav & Mioduser, 2004, and Picinali et al., 2014. Each of these studies employs the potential of virtual reality to establish a more foundational understanding of virtually-based spatial engagement. The authors achieved this through the careful investigation of the intricacies of sound and haptics in virtual environments. Unfortunately, the virtual reality tools used throughout these studies are significantly outdated desktop versions, uncomparable to modern, high-fidelity HMD's. The four most prolific authors in this field were, Amandine Afonso Jaco, Lorenzo Picinali, Michael Denis, and Brian Katz (who all frequently collaborated). None of these authors has published a study relevant to this field in over five years. This suggests that this field of research has been left mostly unexplored through the lens of modern digital technologies and represents an important opportunity for the direction of this design research.

PHYSICAL WORLD

Features

Dynamic

Difficult to analyse

Restricted Development

DIGITAL ENVIRONMENT

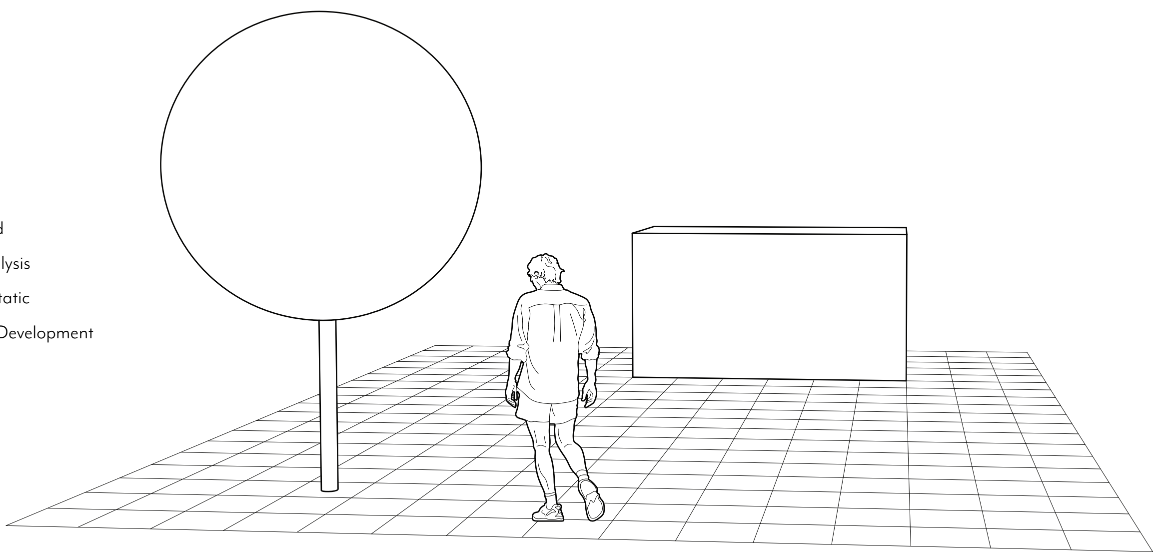
Features

Simplified

Easy analysis

Mostly Static

Greater Development



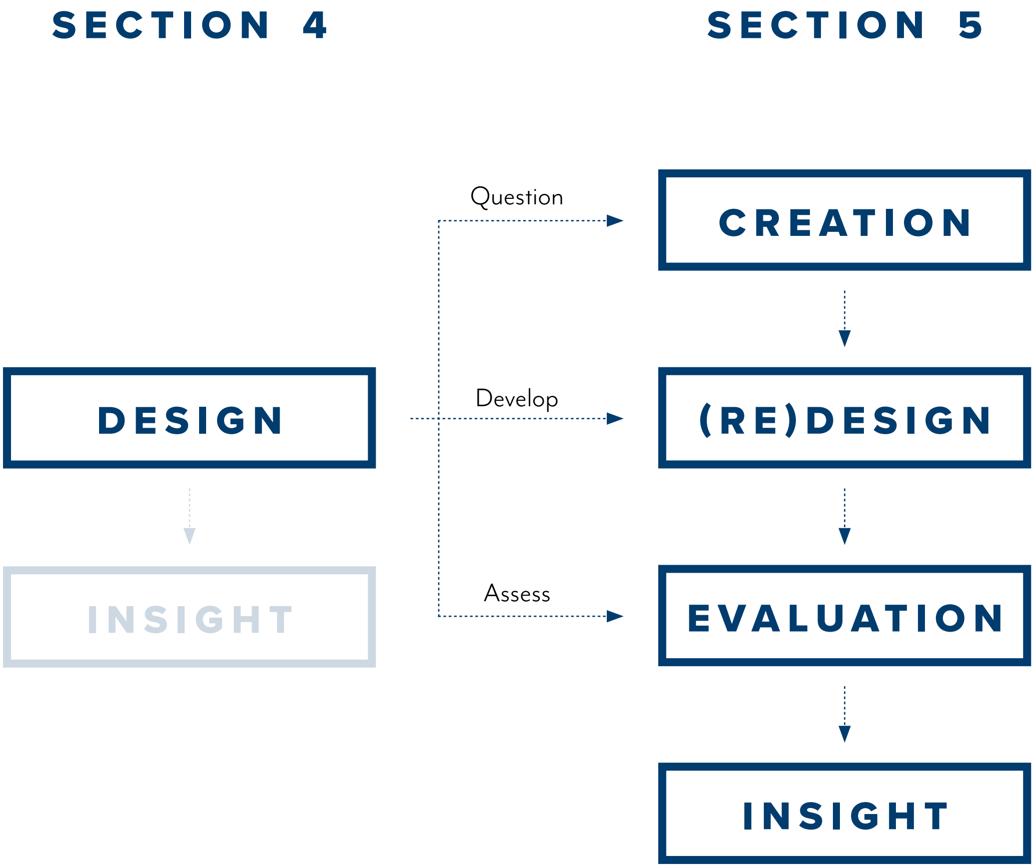
DEVELOP 5.0

5.1 INTRODUCTION

Identified in the previous section was the possibility for the technical shift of the project to be directed into understanding how digital technologies may be used to build non-visual spatial understanding. Following from this, a reinvestigation into the literature revealed very little work of this nature, particularly with modern-day digital technologies.

It appears that the work in this field is focused heavily on the (very significant) technological hurdle. Unfortunately, this means that much of the production relies merely upon delivering any information. This apparent focus is evidenced by the somewhat comical productions occasionally seen in assistive technology literature, and reviews of these devices which demonstrate their meagre success rates when held against practical criteria. The design work of this thesis has mostly fallen into this paradigm, where the focus is not on understanding the application of these tools, but the mere creation of them. The more substantial questions regarding this field of inquiry are not merely what these tools offer as design outcomes, but what do they reveal about how we can understand space and interact with space through a digital medium.

This section ameliorates the shortcomings of the previous section through the interrogation of its design outcomes. The underlying design ideas are questioned and developed, and a method evaluating their performance is created, which allows for broader conclusions to be drawn about their implications.


SECTION 4
SECTION 5
Question
CREATION
DESIGN
Develop
(RE)DESIGN
INSIGHT
Assess
EVALUATION
INSIGHT

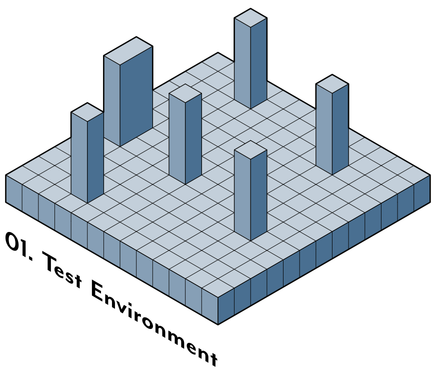
5.2 TEST PROTOCOL

The previous section relied heavily on the documentation of personal experience to examine the design outcomes. This proved successful for establishing the early success of the given active/passive mechanics. However, after the revelations noted in the prior section, this observational approach proved less useful as a way for evaluating the impact of the designs and gave little insight as to their broader implications for digitally-based spatial understanding. This gave cause to design and implement a method which would allow for the proper evaluation method for the effectiveness of design outcomes. This resulting outcome is a testing protocol, to be applied to specific testing environments which are tailored to evaluate each mechanic.

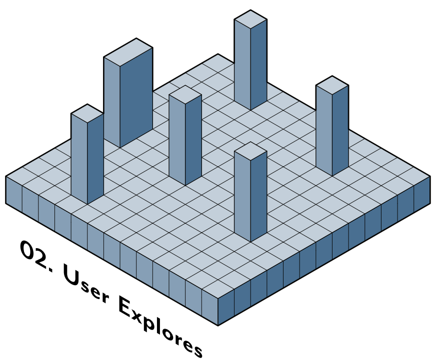
The resultant test protocol is as follows. A test environment size will be set, and objects will be generated within this environment. The user is free to explore the environment and 'perceive' these objects through the chosen mechanic. The user will then document where they believe the objects are located in the environment and what properties the objects possess. The results will then be cross-referenced with the scene to evaluate whether the documented information was correct. The objects within the scene will be aligned to a grid; this allows for simple quantification of the success rate for object identification. The randomisation of object placement ensures that there is no bias created through repeated testing and participants memorising the object layout. Finally, the objects are randomly assigned haptic and sound properties. The protocol is designed to evaluate the spatial comprehension accuracy provided by the scheme/mechanics, an element fundamental to wayfinding processes. The success rates of object and object property identification outline the effectiveness of the mechanics to provide usable and understandable spatial information.

The sizing of the grid on the test environment may be varied between 1m, 0.75m and 0.5m, dictating the spacing and size of the generated objects. This variation in the scale of the objects and the underlying grid will provide further insight as to the resolution of spatial comprehension achievable solely through the use of the mechanics. If the user can identify roughly where an object is located but is unable to identify its location at the specific grid sizing, then we can conclude that the resolution of spatial comprehension is larger than the current test size. To elaborate, let us imagine that the grid is set at 0.5m. This sets the size of objects to 0.5m2 and will mean that they will be placed at a random increment of 0.5m. If the user cannot differentiate between objects that are 3m away from those that are 2.5m or 3.5m away, then we can conclude that the resolution of the spatial comprehension is larger than 0.5m. If the users are successful when the size of the grid is increased to 1m, then we can conclude that the virtual space is understood through the mechanic at a resolution of 1m.

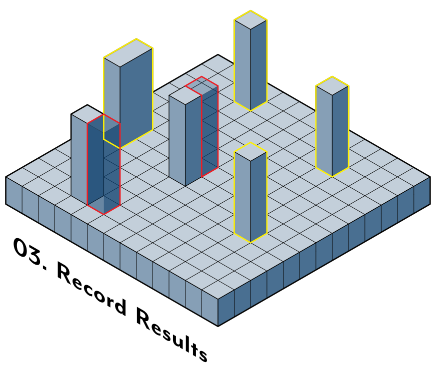
TEST PROTOCOL



Test environment with objects set at random locations.



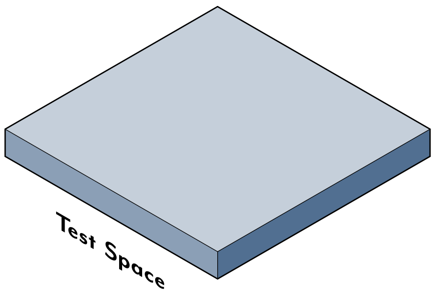
User explores the environment using the selected mechanic and attempts to build a spatial representation.



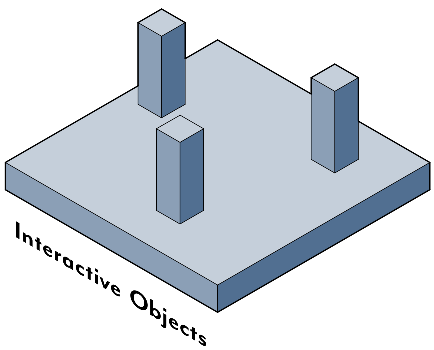
The user will document their best assumptions as to the exact location and properties of the objects. This will be cross-referenced with the actual locations.

TEST SETUP

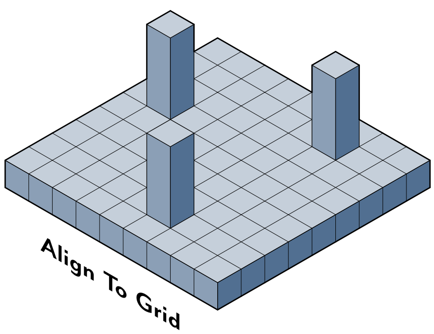
Overall test design



Set a test environment size.



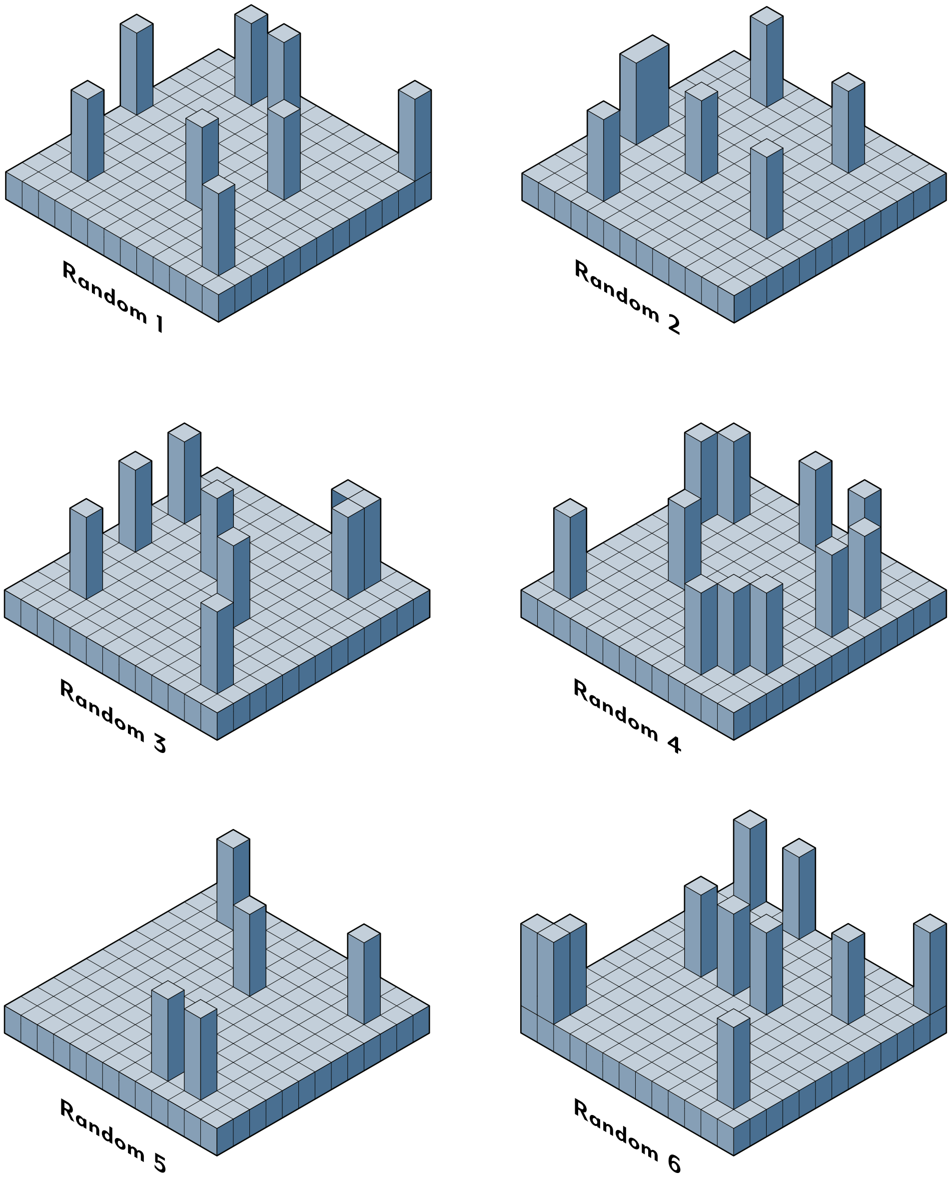
Provide simulated objects within the environment. These objects can be used to measure the success of the haptic and sound cues by testing whether they can be correctly idenitified.



Aligning the object to grids allows the success of the spatial engagment system to be quantified, documented and easily compared to other experiments.

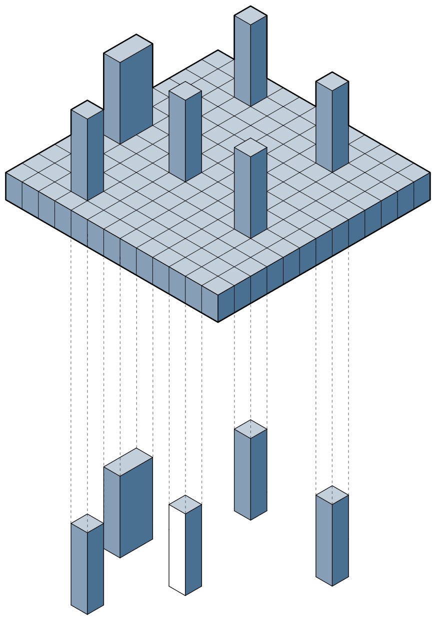
RANDOMISATION

Randomisation of testing objects to retain vailidity



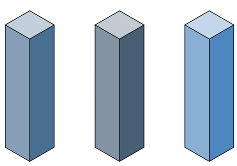
OBJECT ASSIGNMENT

Assigning properties to objects for testing purposes



Allows the success of the spatial engag-ment system to be quantified and easily compared to other experiments.

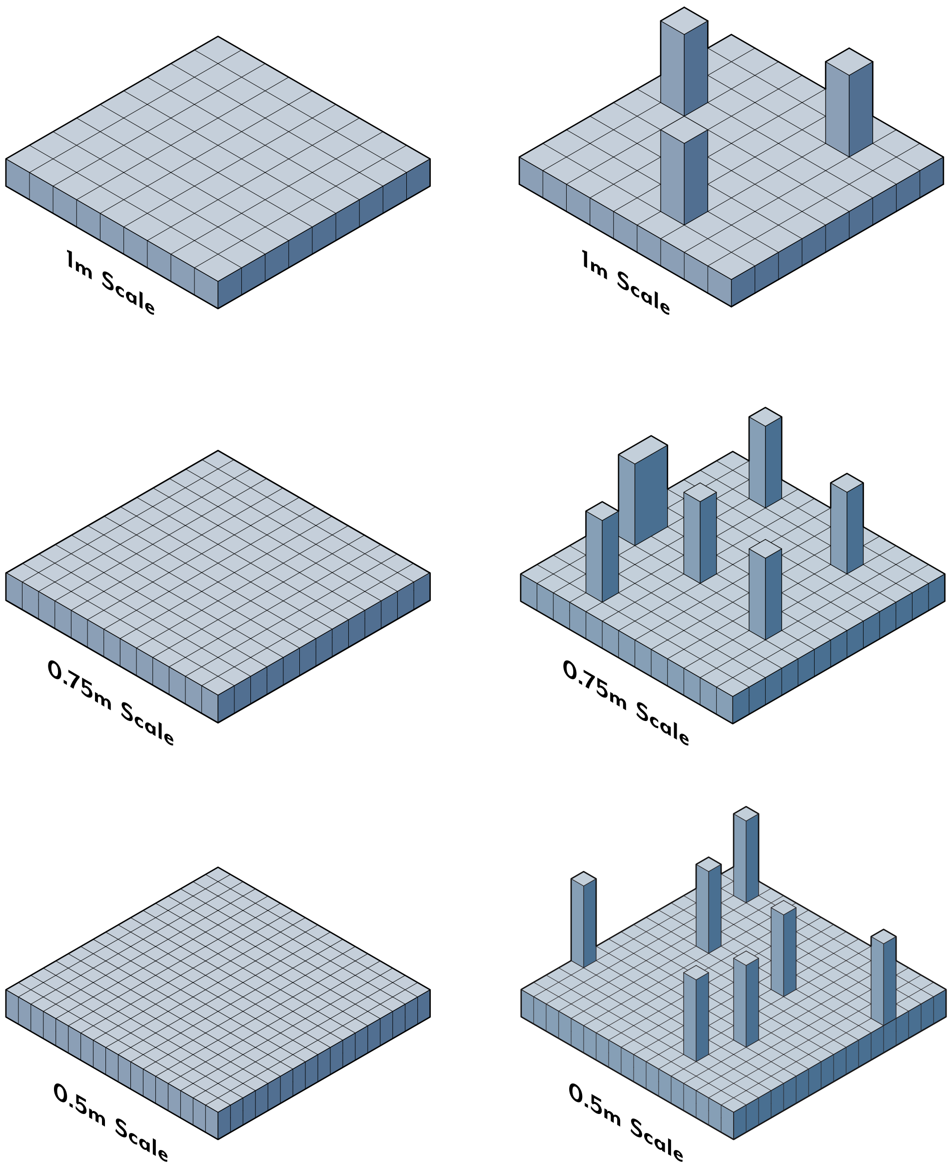
Isolation of interaction objects.



Haptic and sound properties assigned at random according to organisational typology.

TEST RESOLUTION

Establishing the resolution of spatial comprehension



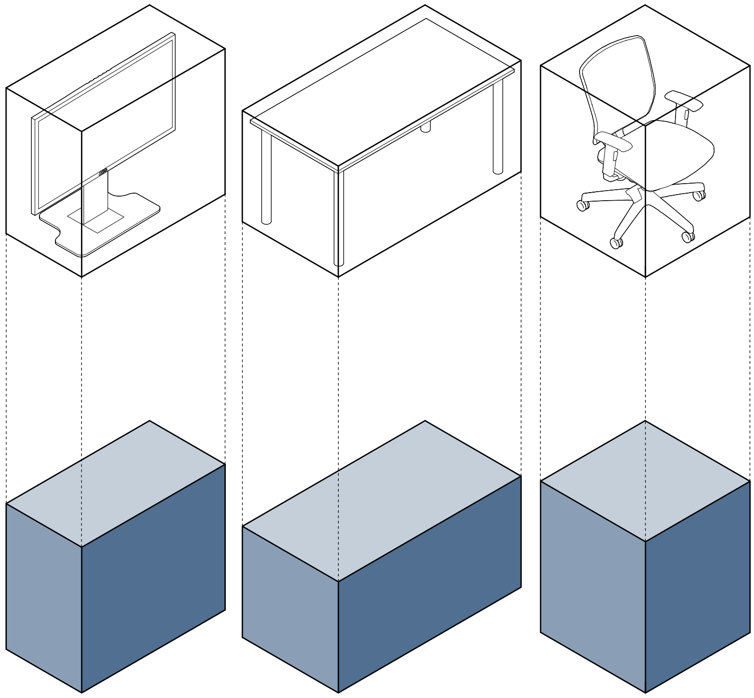
SIMPLIFICATIONS

There are several simplifications built into the testing protocol. The first involves reducing the complexity of real-world geometry into rectangular shapes. Real-world geometry rarely occupies an exact rectangular shape, however slight reductions on object shape often reveal a rectangular-like occupation of space. Everyday objects within a space have been diagrammed to elaborate upon this point. This reduction of object occupation is necessary for the simple quantification of data as well as enabling the efficient repurposing of the associated codes and virtual test environments. Furthermore, the only time where direct interaction with objects is required is in the testing of the passive scheme. Other mechanics do not attempt to provide detailed information about the shape of objects.

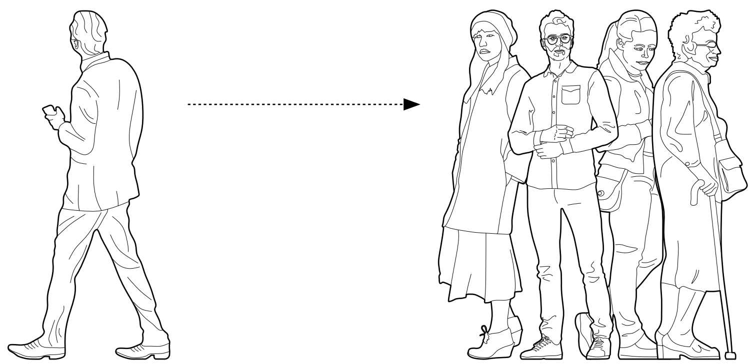
The second significant simplification is the use of the author as a test participant. Much has been written about the use of sighted participants in testing for technology and studies on non-visual wayfinding. The available research does not provide a determined conclusion on the matter. Some studies show that the wayfinding abilities are uncomparable (Rieser, Guth, & Hill, 1986) whereas other studies show that the use of blindfolded sighted participants performed worse than those with visual impairments/blindness (Loomis et al., 1993). The conclusions of the latter would suggest that test results are likely to be under-estimating the effectiveness of the created scheme. Due to the uncertainty associated with results generated from the preliminary tests, a series of experiments with members of the visually impaired community will prove whether the results are replicable or not. This testing is documented in Section 6 of the thesis.

SIMPLIFICATIONS

01.



02.



Preliminary (Self)

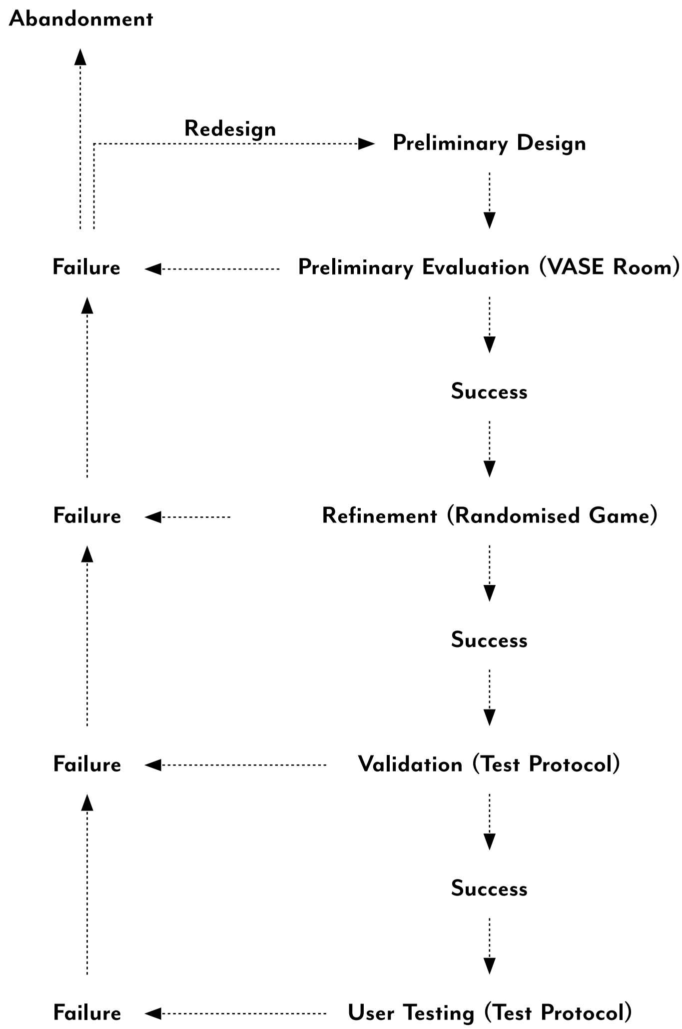
Developed (Users)

5.3 DEVELOPMENT PLAN

The addition of the testing protocol expands the mechanic design process into five stages. The first step was completed in the previous section and focused on the concept design and preliminary testing of particular mechanics. This involved the coding and creation of the appropriate virtual functionality, followed by an exploration of the VASE space. This experience is critically evaluated for any glaring errors and potential user-interfacing issues.

Following the significant critical reflection in the prior section, a following series of steps was conceived to further the exploration of the thesis. These steps rely on the previously created design material. The second step is the examination and reflection upon the functions and underlying assumptions of the previously created mechanics. Once these aspects have been identified, the third step is the development of a randomised game, this will allow for the systematic redevelopment of functions and sensory outputs. The fourth step is to employ the newly developed testing protocol in order to assess the effectiveness of a mechanic. This process involves the application of the test protocol to a specific virtual testing environment, followed by self-testing, result documentation and evaluation. The fifth step is the repetition of formal testing with members of the visually impaired community as the test participants. These experiments provide the validation or discrediting of earlier results gathered by self-testing. The formalisation of this development process demonstrates the shift in the primary concern of the project. The earlier stages, much like the fields it drew upon, focused heavily on designed products. This process provides far more credence to the process underlying the design and the final evaluation of the design, creating a more systematic method for the creation of these tools.

DEVELOPMENT PROCESS

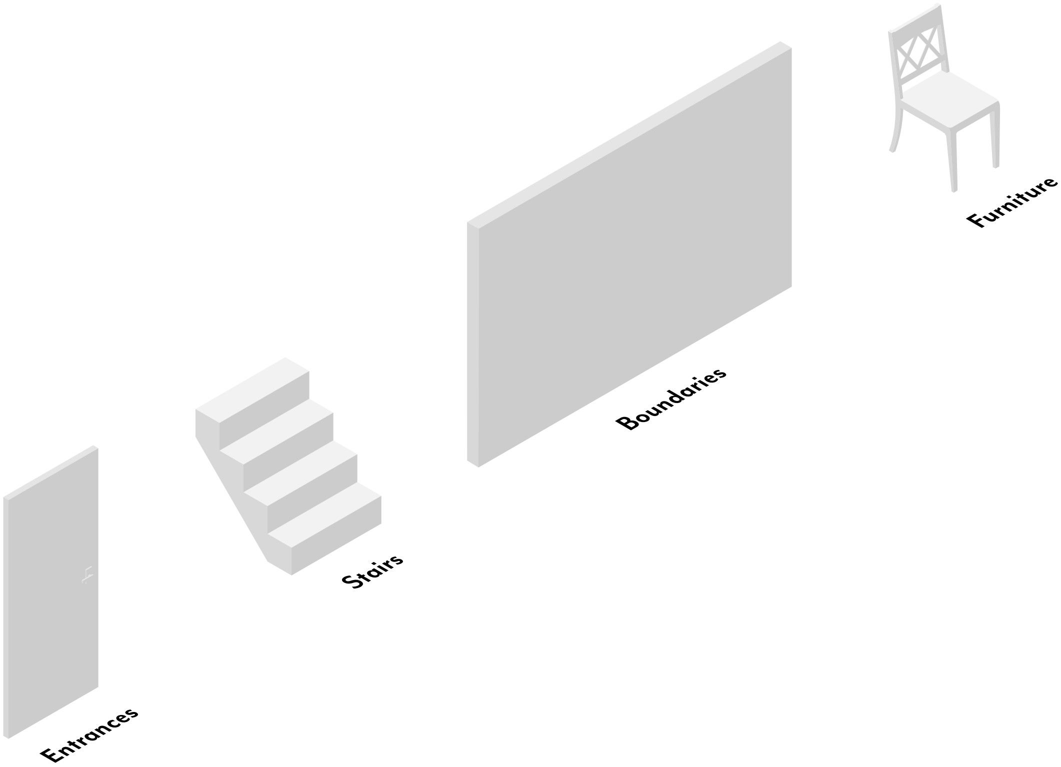


5.4 PASSIVE SCHEME DEVELOPMENT

The passive scheme is the first of the mechanics to be developed. The mechanic aims to provide human-scale information regarding the location and the typology of objects. This is achieved through an organisational typology system, which triggers particular haptic and sound cues depending on the type of the object. The boundary system enables these haptic and sound cues to warn users of surrounding objects before they make contact with them. There are three main areas for critique and development; these are the existing typology system, the boundary diameters, and haptic cues.

For the design response to function as a holistic spatial comprehension scheme, numerous aspects could be expanded upon and improved. The main developments were the expansion of the sonic and haptic cues within the passive scheme to enable the recognition and use of stairs and doorways. The preliminary system does not distinguish doors from the boundaries, as entrances/exits are crucial for operating within a building; this needed to be rectified. Meanwhile, staircases represent not only an essential navigational feature but also a significant danger to those with visual impairments.

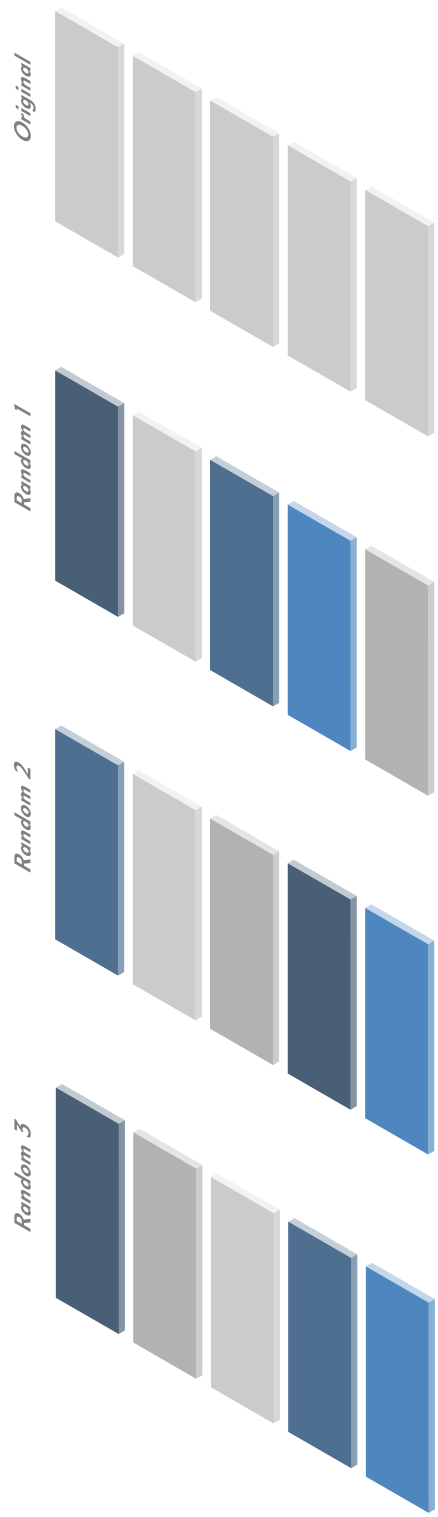
TYPOLOGY OVERVIEW



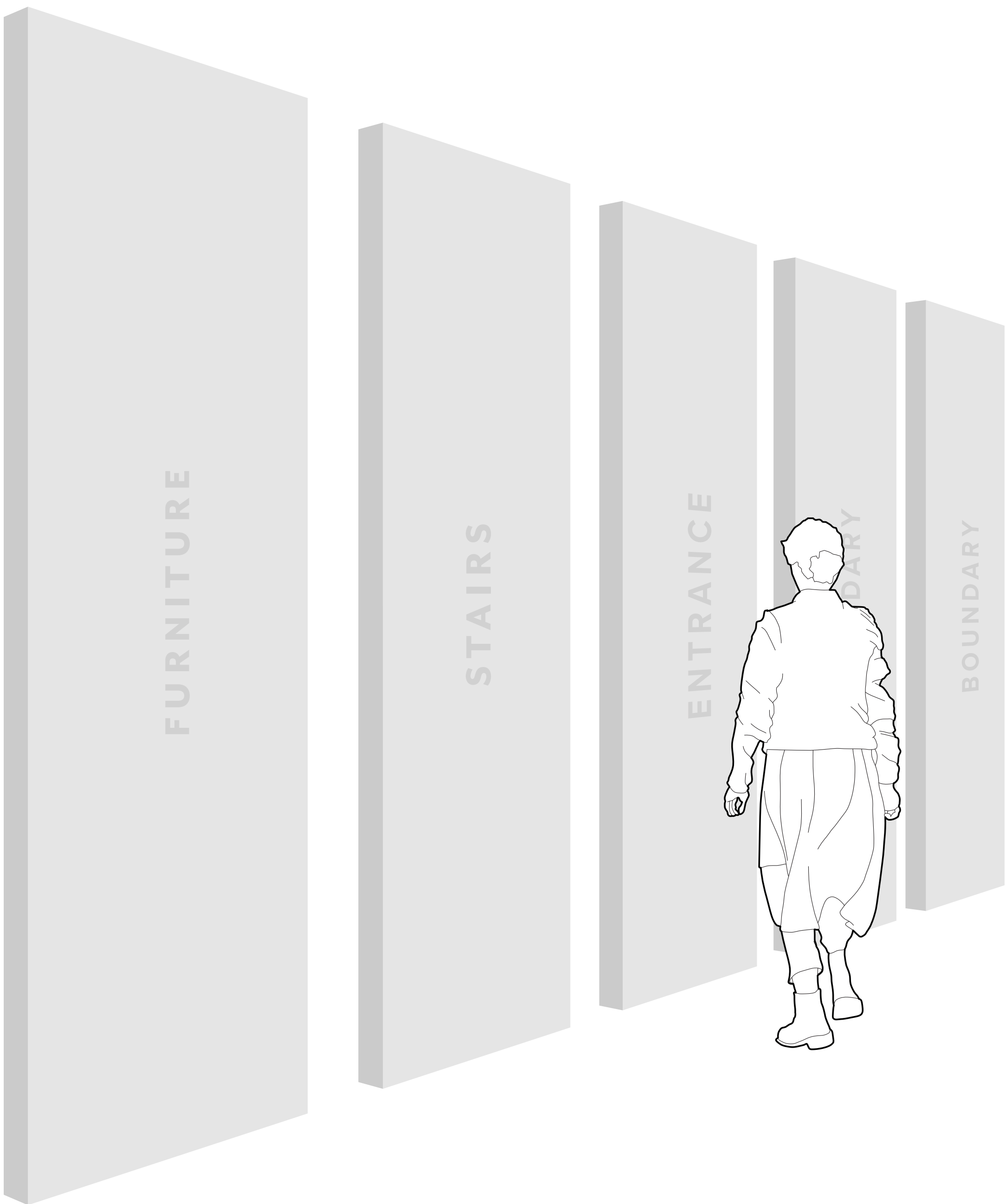
HAPTIC REFINEMENT

This experiment expands the typology organisational system - underlying the passive mechanic of the scheme - to include haptic cues for the identification of entrances and stairs. This will enable the users of a space to successfully identify the entrances/exits and the location of steps and level changes within a space.

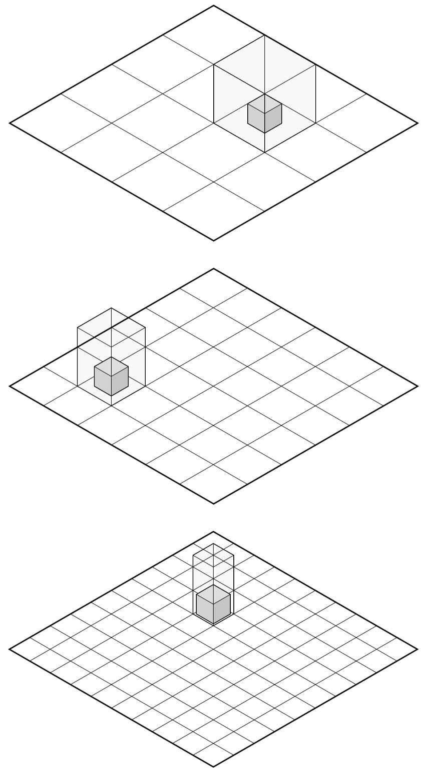
A randomised design experiment was created to assist in the refinement and expansion of the haptic palette. The experiment allows for the refinement of the haptic palette, assuring that each is recognisable and that one can infer the object types successfully. The design experiment consists of five panels. Each panel generated upon the commencement of the Unity scene and is assigned one of four possible haptic cues. An identification notifies the user as to which of the cues is to be identified. The user to 'touch' each of the panels and establish which of the five corresponds to the notification. Once one believes the right panel has been identified, the trigger is pulled. If the panel was correct, the panels are regenerated, and the process repeats.



EXPERIMENT OVERVIEW

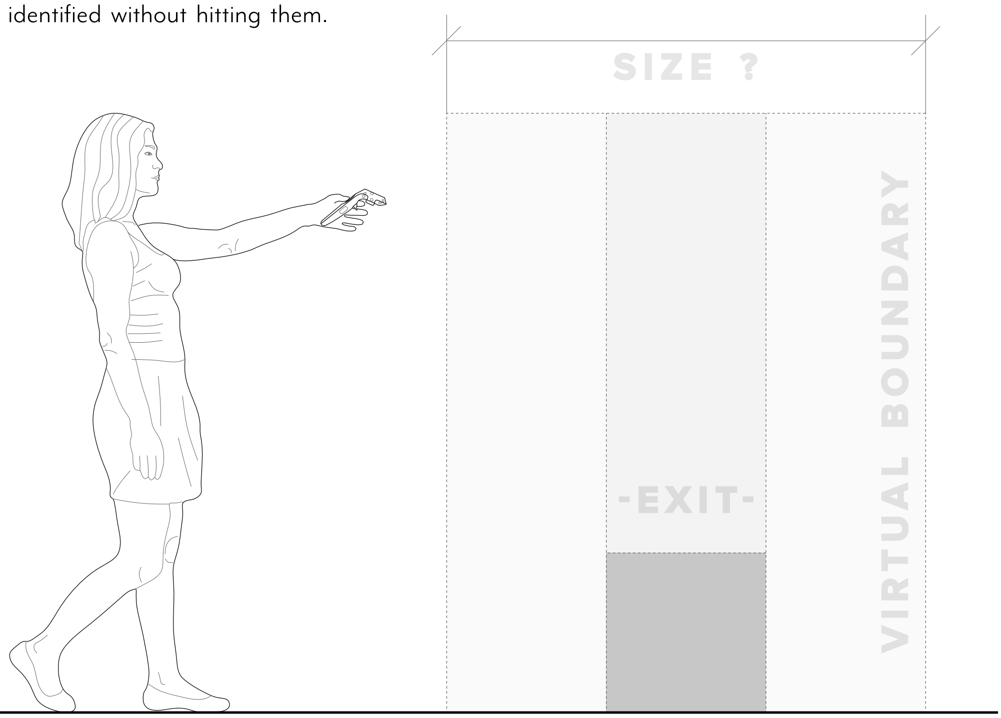


BOUNDARIES

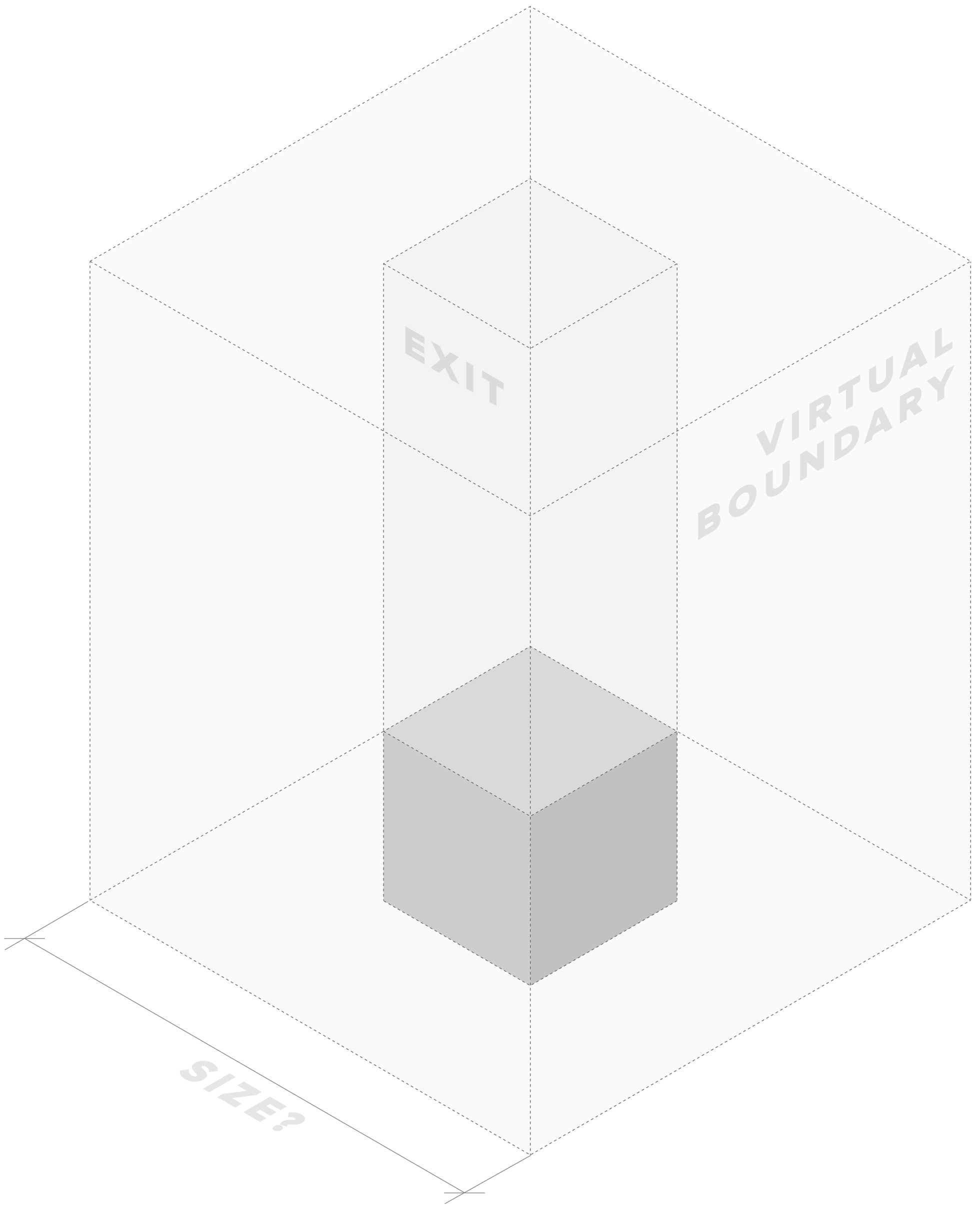


This experiment is the second response to the analysis of the passive scheme. One identified issue was the setting of the perimeter boundaries, which were previously made an arbitrary size. This design experiment was established to aid in the refinement of the boundary size.

A small invisible box will appear at a random location in the scene. This box is assigned one of the four haptic cues and two separate boundary colliders, one which matches the length and width of the box but extends upwards by 2 metres. The second collider is the same height as the first but is larger in length and width than the original box. The dual colliders serve two different purposes. The larger of the two is used to dictate at what distance the haptic cue should be triggered. The smaller cue is used to alert the user if the theoretical 'object' is hit, representing the user colliding with the object. The experiment allows the trigger boundary sizing to be refined, ensuring that users have enough time to react to objects when identified without hitting them.



EXPERIMENT OVERVIEW



PASSIVE SCHEME TEST (EXPANDED)

Following the redevelopment of the passive scheme, a test environment was created. This experiment, derived from the test protocol, uses a 4x4m testing space (aligned with the VASE room) with objects generated and assigned one of the four typology classifications - boundary, furniture, stairs, or entrance. This experiment verifies whether the developed mechanic provides useful spatial information regarding the location, and type of object.

Key >

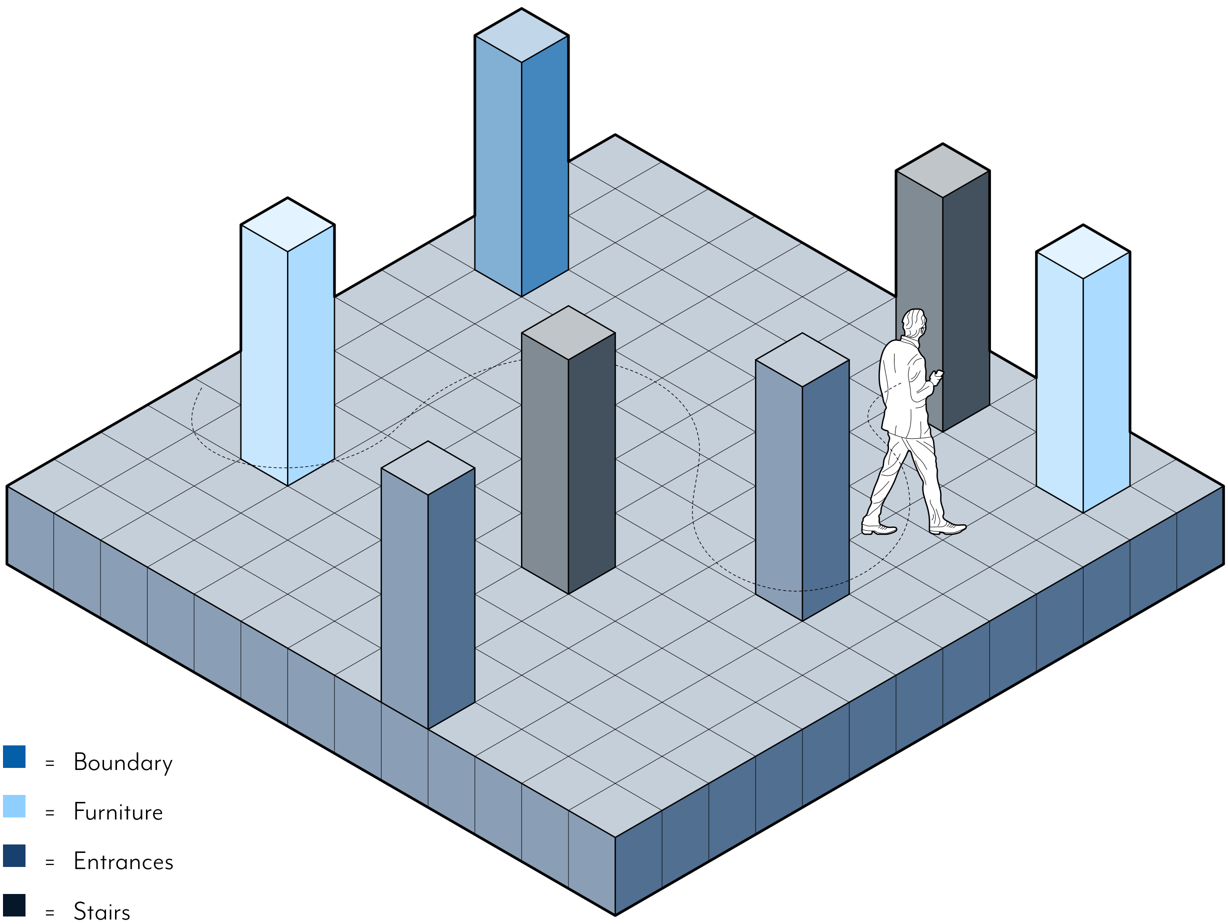
User Choice (Both Correct) = ■

User Choice (Location Correct & Type Incorrect) = ▣

User Choice (Location Incorrect & Type Correct) = ■

User Choice (If Both Incorrect) = ■

Object Location (If Incorrect) = □



■ = Boundary

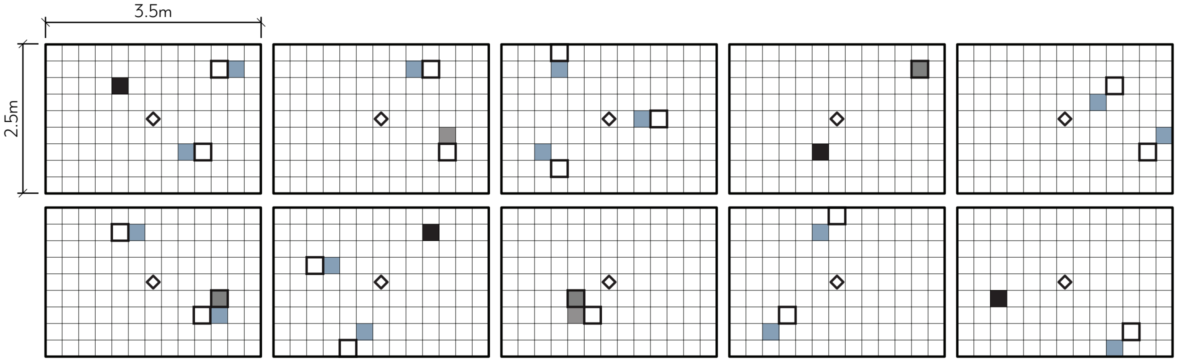
■ = Furniture

■ = Entrances

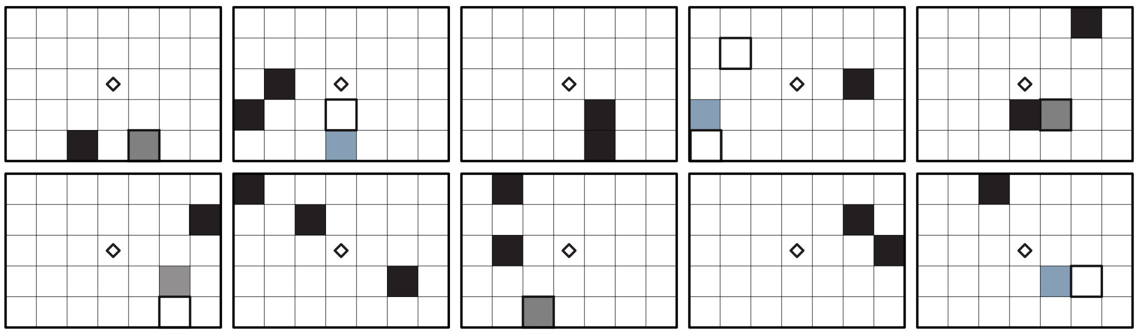
■ = Stairs

FULL RESULTS

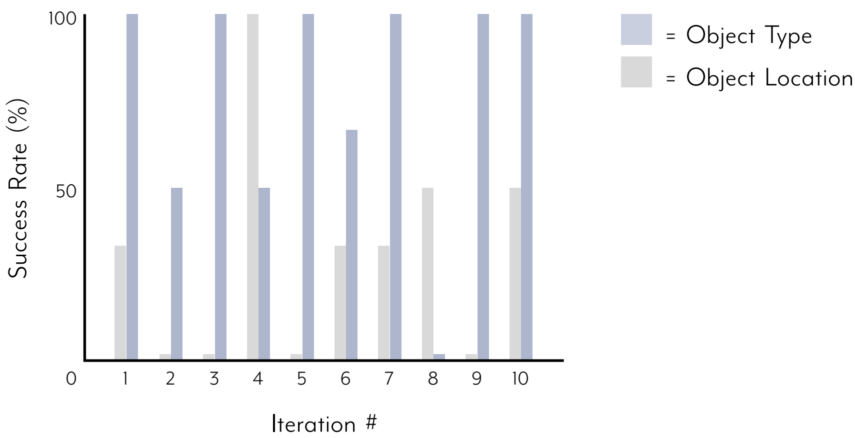
SMALL



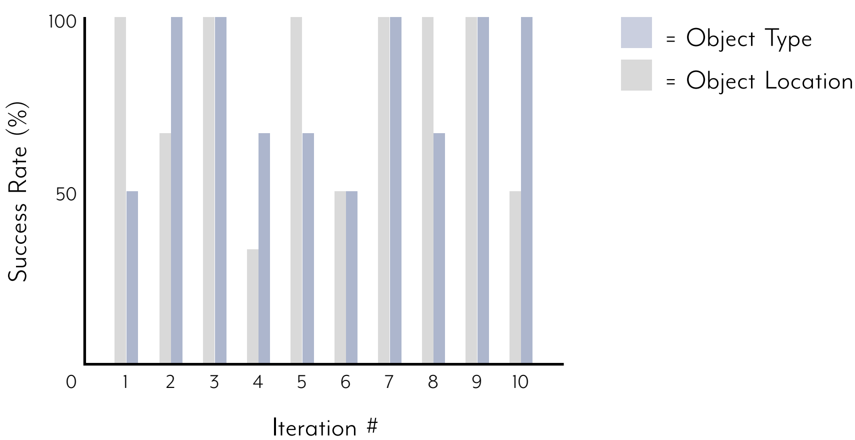
MID



Success rate of object location and type identification - Small resolution



Success rate of object location and type identification - Mid resolution



RESULTS

The passive scheme (expanded) experiment assessed the mechanic's ability to provide accurate information regarding local objects location, and materiality.

The results show that the mechanic performs excellently for materiality identification. At the small scale, the results show a 92% success rate, this slightly decreases for the medium scale, averaging at 88%. The small difference between the two results suggests that this may be a result of the small data size rather than a true difference in performance.

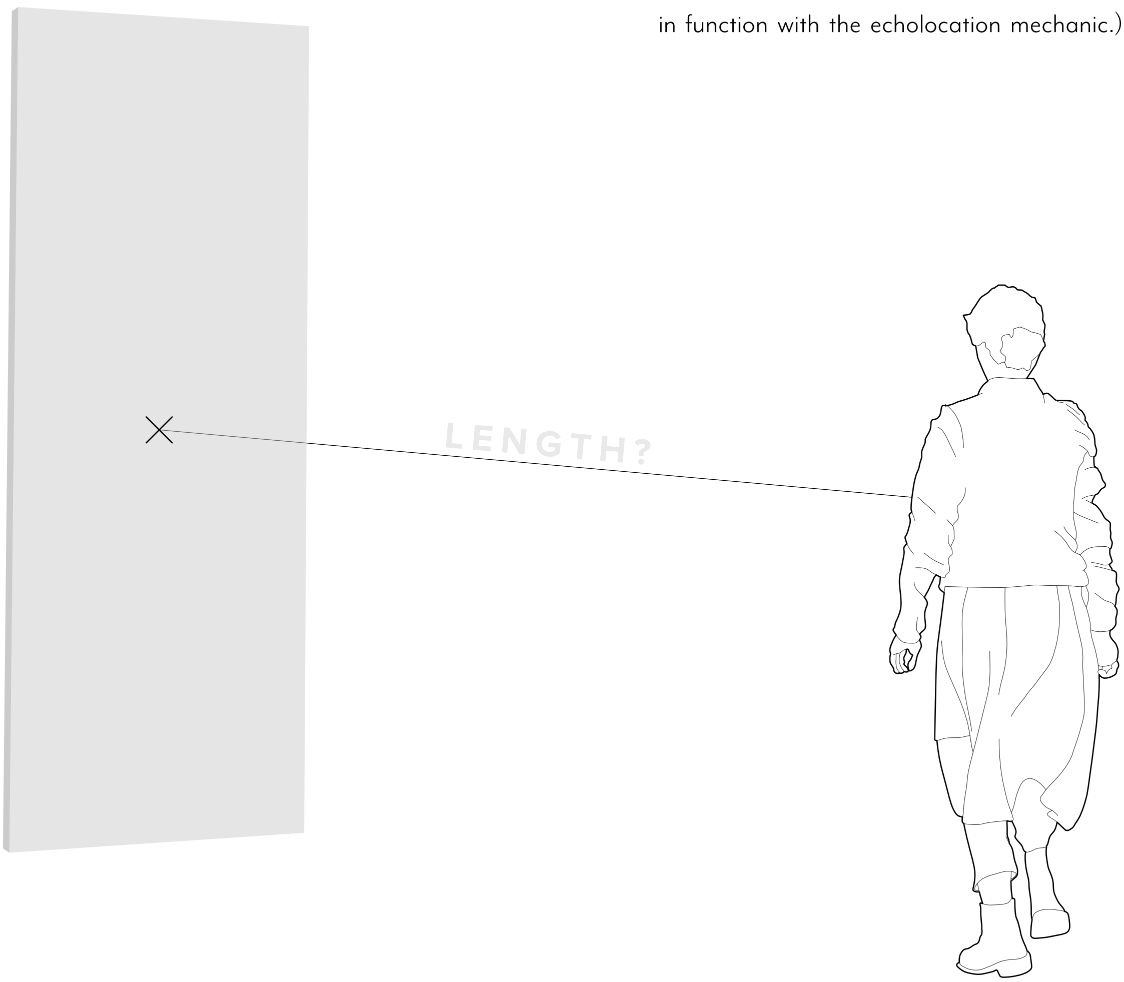
As for object location identification, there is a sharp difference in performance between the two scales. The small-scale testing shows only a 17% success rate for location identification. This rose substantially for the medium-scale testing where the success rate averaged at 79%.

The results show a reasonable success rate for object location identification and an excellent success rate for object materiality identification. Due to the high rates of success in this evaluation, further testing of the mechanic was conducted in section 6.

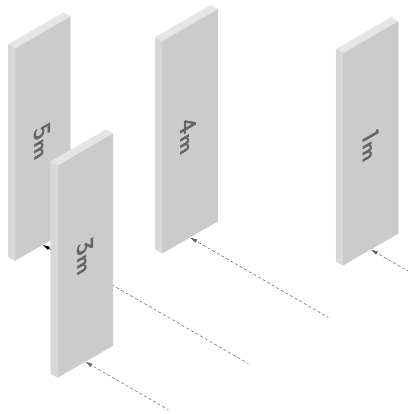
5.5 DISTANCE TOOL DEVELOPMENT

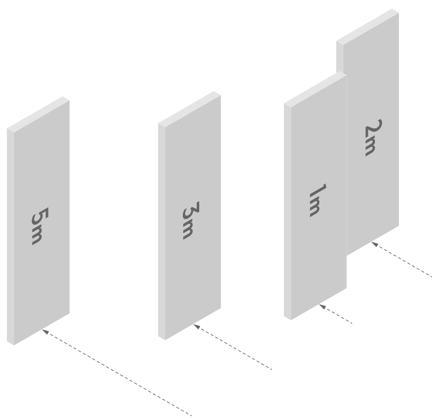
The distance measurement mechanic's primary task is to provide information regarding the distance between a user and an object, allowing inferences as to object location. This is achieved through a haptic and sound cue which vary in strength/volume depending upon the distance to the object. The following developments aim to refine the relationship between object distance and haptic strength.

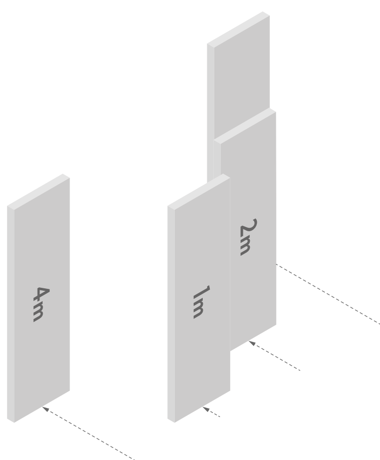
A randomised game was created that allowed for the fine-tuning of the haptic. In this game, four walls are created and are set randomly at different distances from the user (between 1 - 6m). The user is to select the walls in a sequence of ascending distances (closer to further away). Failure to identify the correct order would result in the game restarting. Repeat experimentation with this game enabled the haptic cues to be tuned for the fastest and highest accuracy when identifying distances of objects. (The sound cue associated with this mechanic has been removed, due to the similarity in function with the echolocation mechanic.)



EXPERIMENT OVERVIEW







FORMAL TESTING

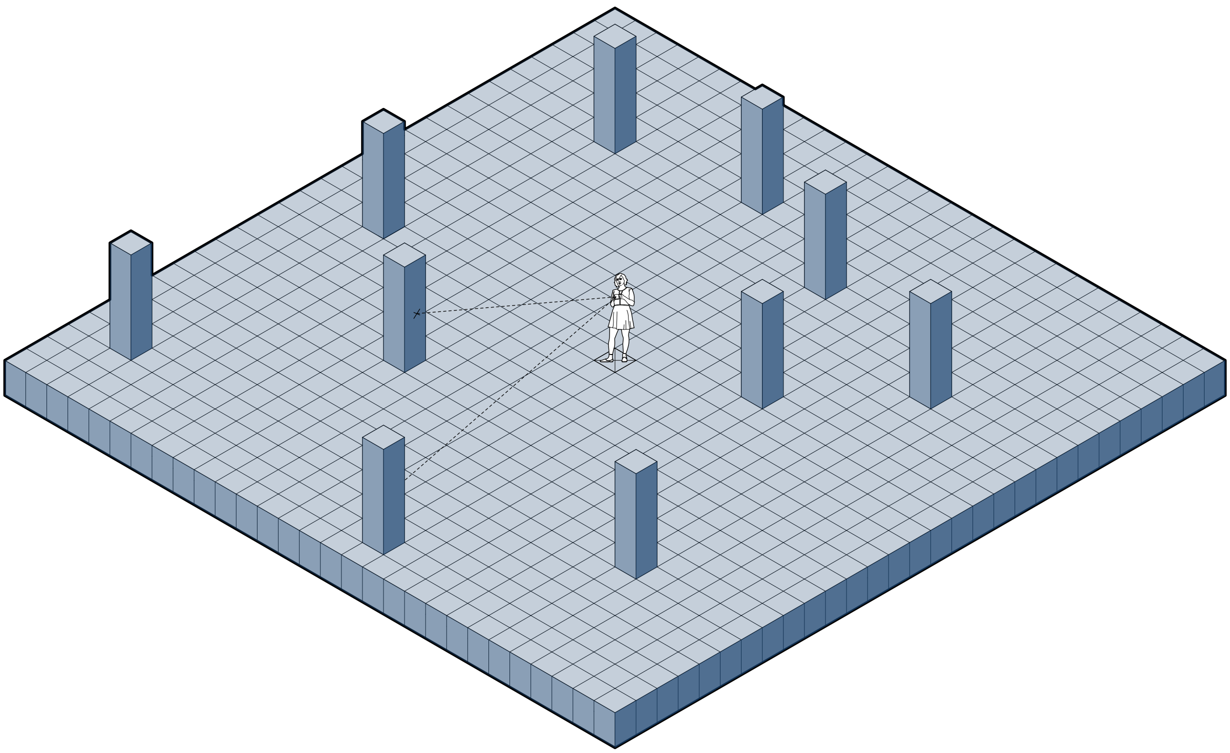
The distance measurement experiment establishes the effectiveness of the mechanic in providing information regarding the distance, position and materiality of the objects. The test setup involves the generation of randomly placed cube objects within a 9x9m space. These objects are assigned the material property of either metal, wood, plastic or glass.

Key >

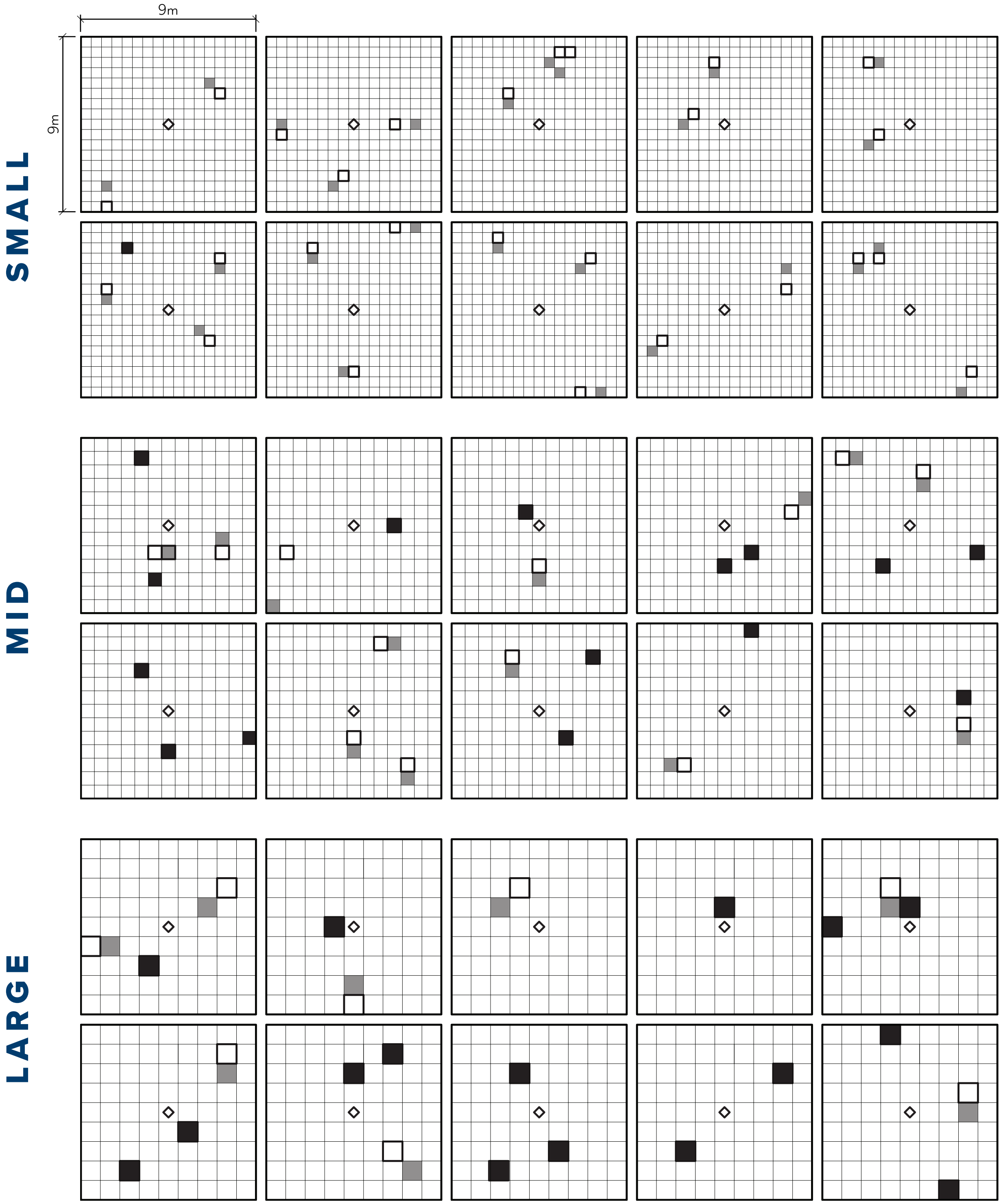
User Choice (Correct) = ■

User Choice (If Incorrect) = ■

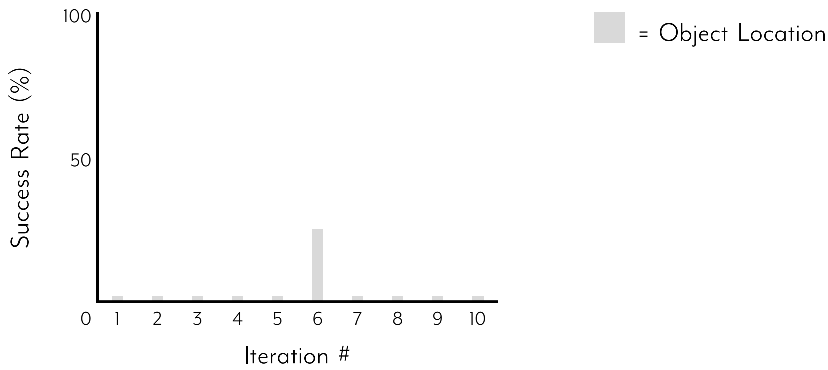
Object Location (If Incorrect) = □



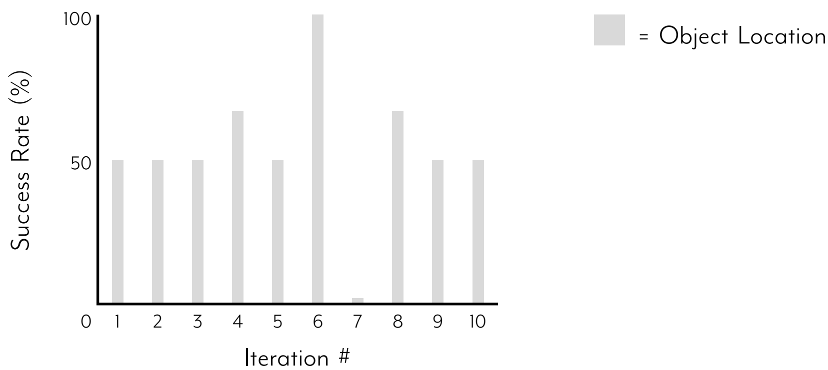
FULL RESULTS



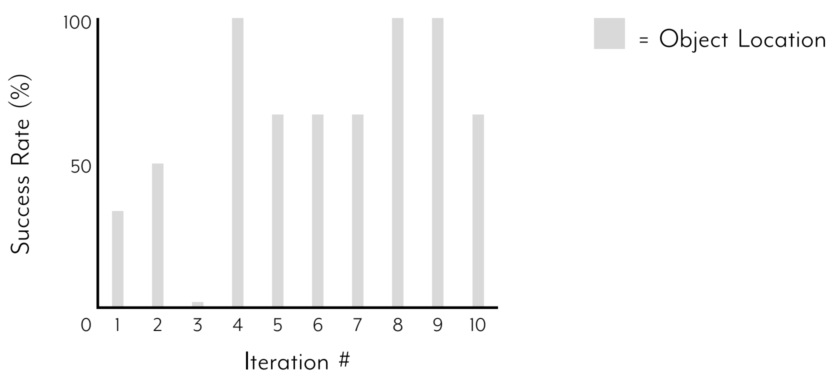
Success rate of object location identification - Small resolution



Success rate of object location identification - Mid resolution



Success rate of object location identification - Large resolution



RESULTS

The distance measurement experiment assessed the mechanic's ability to provide accurate information regarding object distance, and therefore location.

At the small scale, the scheme had a success rate of 0.04% with only 1/27 objects having their position identified correctly. This scale, which was tested first, showed that the mechanic did provide some indication as to direction and most objects actual position were within 1m of the users choice. This suggested that the spatial resolution was too fine for correct identification. The second set of tests at the mid-scale showed a much higher success rate of 53%, a 49% increase from the small-scale. The slight increase in the spatial resolution made it significantly easier to identify the distances of the objects. The final test at a large scale showed an 11% increase in success location identification, resulting in a 64% success rate.

The results show, at best a moderate - good performance by the mechanic. The disparity in success rate increase between the spatial resolutions (53% increase vs. 11% increase) suggests that the higher two spatial resolutions are the best choices for building spatial comprehension. The development question that remains is how to balance the effectiveness of location identification and the amount of information that is accessible (success rate vs. spatial resolution).

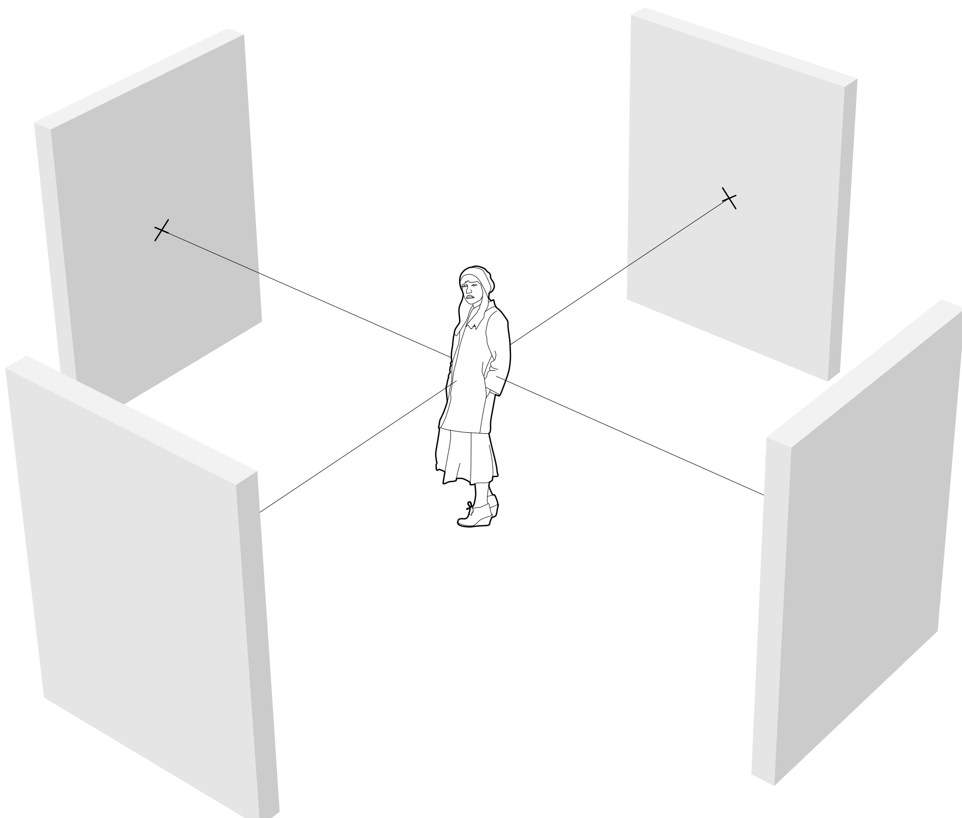
5.6 ECHOLOCATION DEVELOPMENT

The echolocation mechanic was the third mechanic to undergo redevelopment. Similarly to the distance measurement, the objective of the echolocation mechanic is to provide information regarding the surrounding object's distance and thus their positions. This is achieved through the use of sound cues, which vary in volume and initialisation time, based upon the distance of objects.

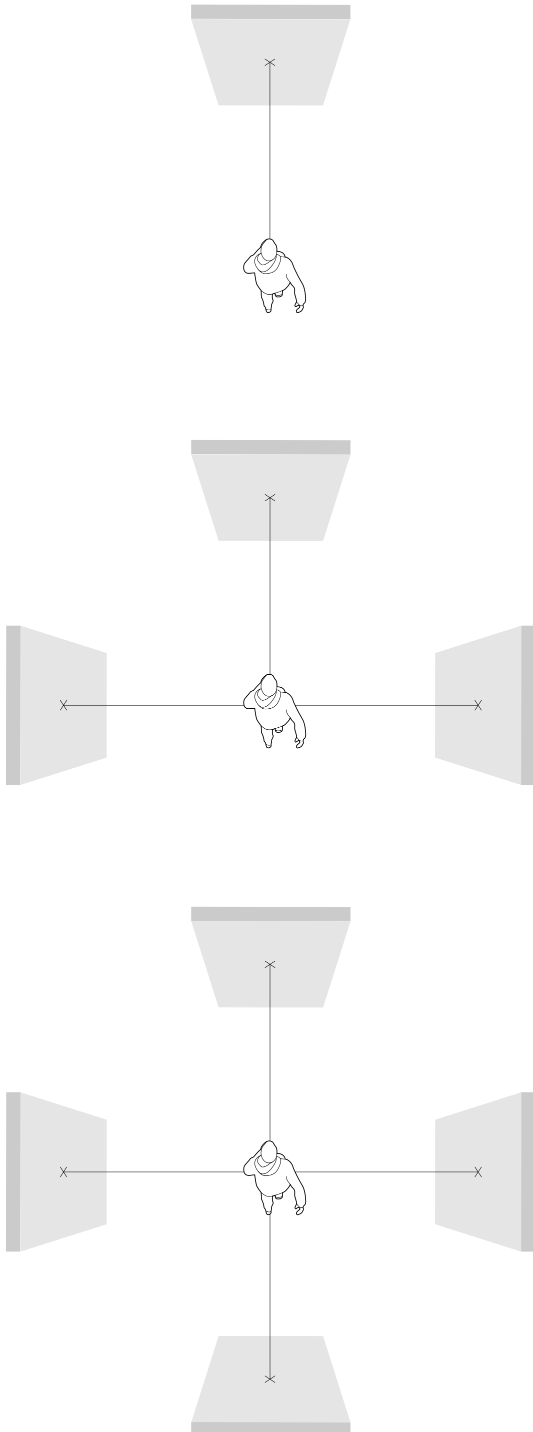
The items for reflection and analysis were: the relationship between the distance of the objects and the volume of the sound cues; the distance-based delay of the sound cues, and the multi-directional nature of the raycasting.

A randomised game was created that questioned the directional nature of the sound cues. This game varies between a single forward raycast, a three directional raycast, and the original four directional raycast.

The experimentation revealed no significant changes in the perception of space. Correct identification of object materiality and direction remained consistent with the original setup.

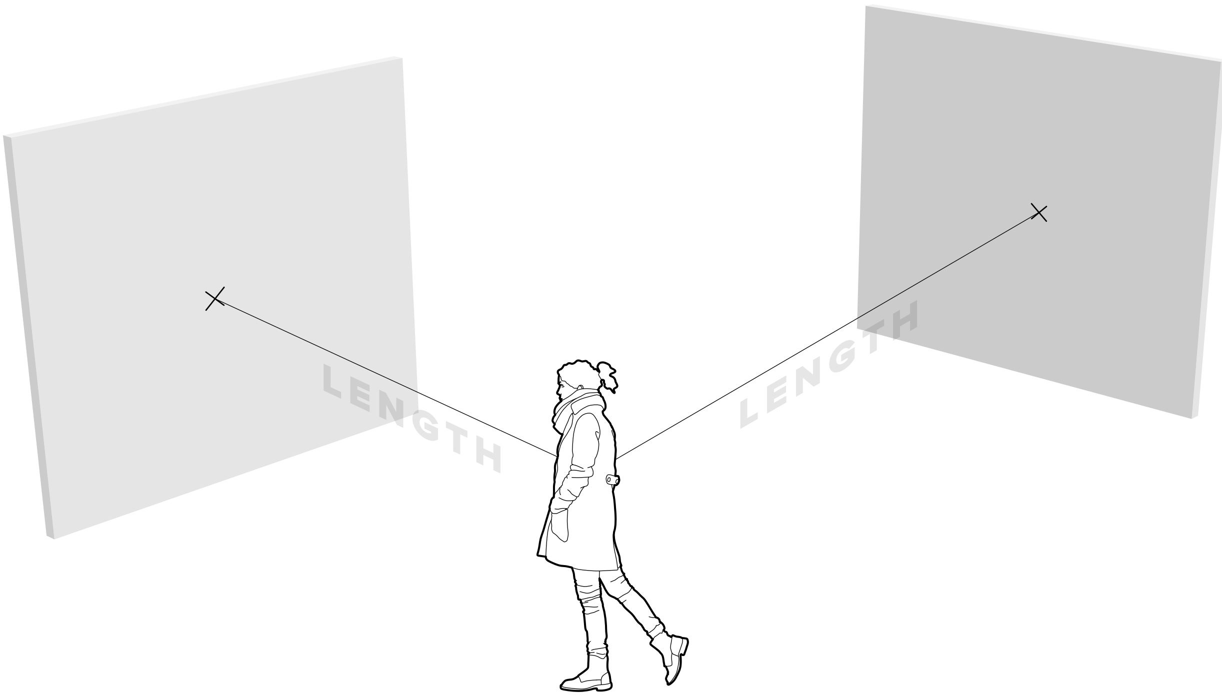


EXPERIMENT OVERVIEW

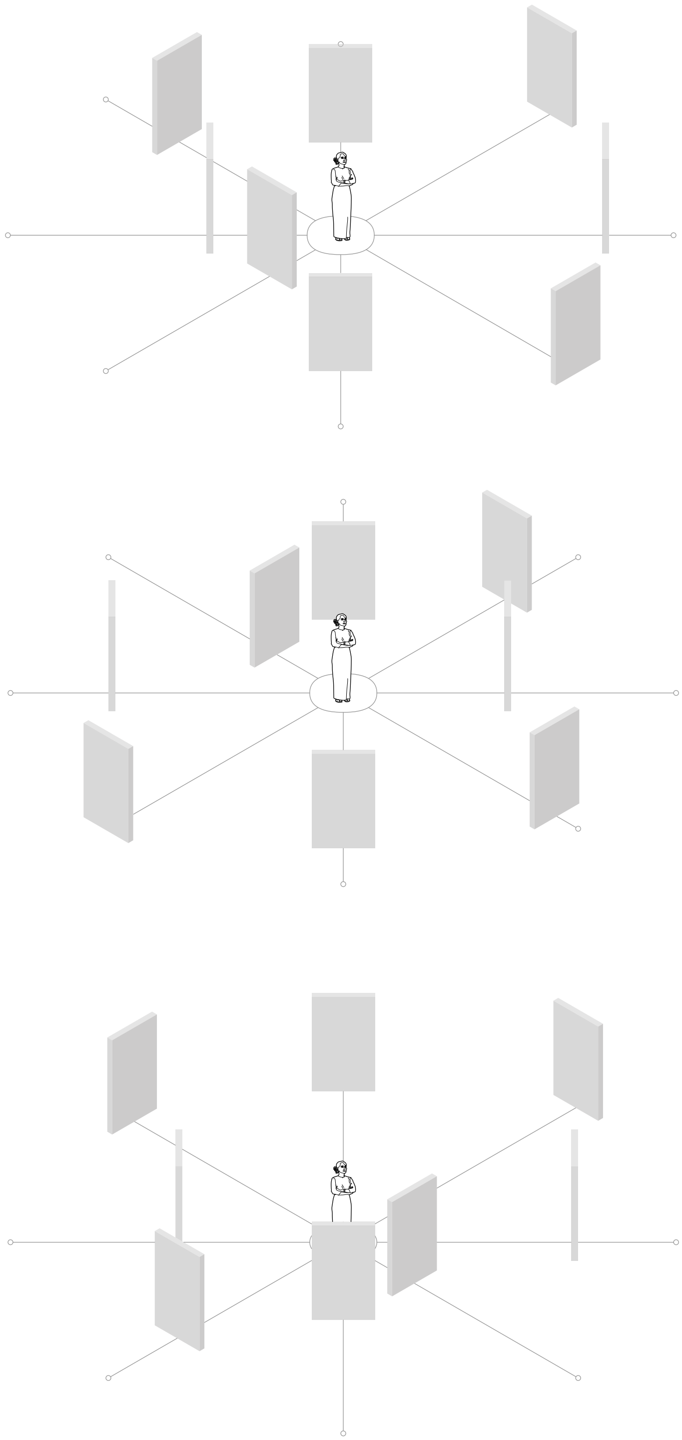


DISTANCE EXPRESSION

A second randomised game was created that allowed for the development of the sound outputs. Particular items of focus are, the relationship between the distance of the object and the sound delay. Similarly to the previous game, users are to correctly identify - in ascending order - the distance of walls which are randomly set at a distance between 1 - 6m. Failure to identify objects in the correct order would restart the scene.



EXPERIMENT OVERVIEW



FORMAL TESTING

The echolocation experiment tests the ability of the mechanic to use sonic information to provide the user with an understanding of object distance and materiality. For this experiment, objects are randomly generated along four axes, originating from the user origin point. These objects are then assigned the same material property as the prior experiment - either metal, wood, plastic or glass.

Key >

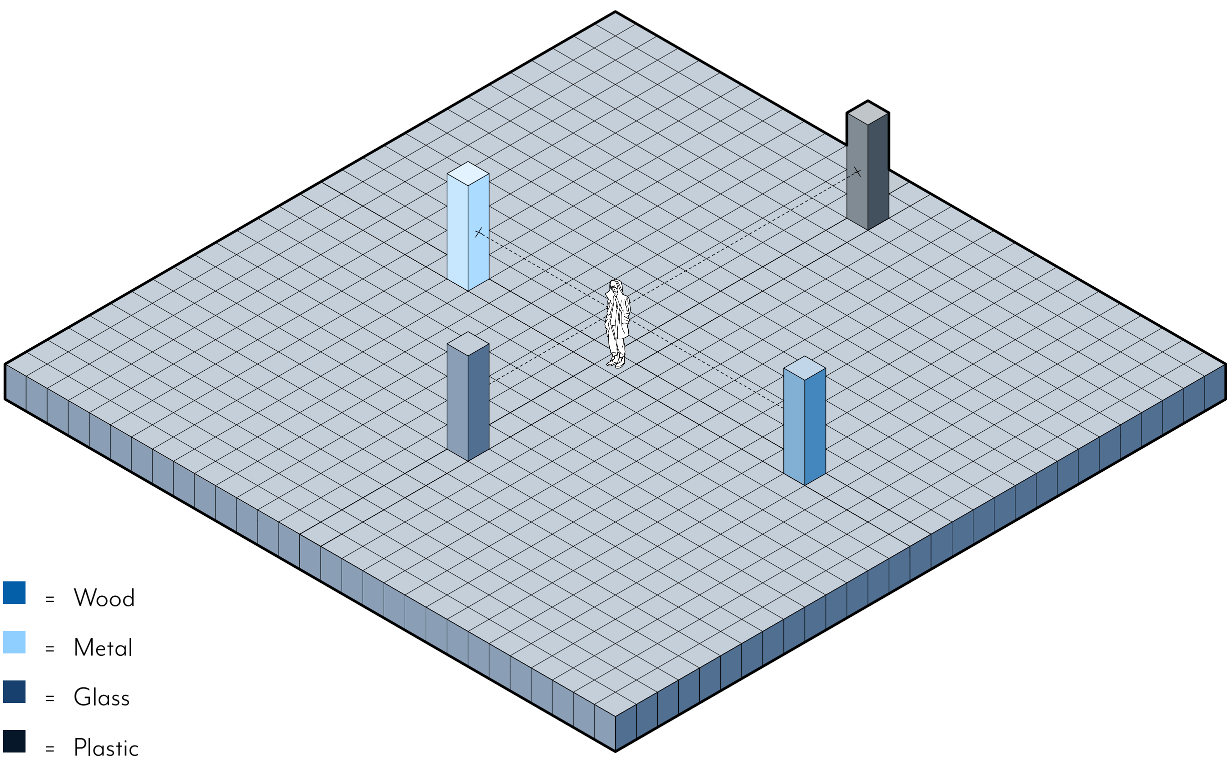
User Choice (Both Correct) = ■

User Choice (Location Correct & Type Incorrect) = ■

User Choice (Location Incorrect & Type Correct) = ■

User Choice (If Both Incorrect) = ■

Object Location (If Incorrect) = □



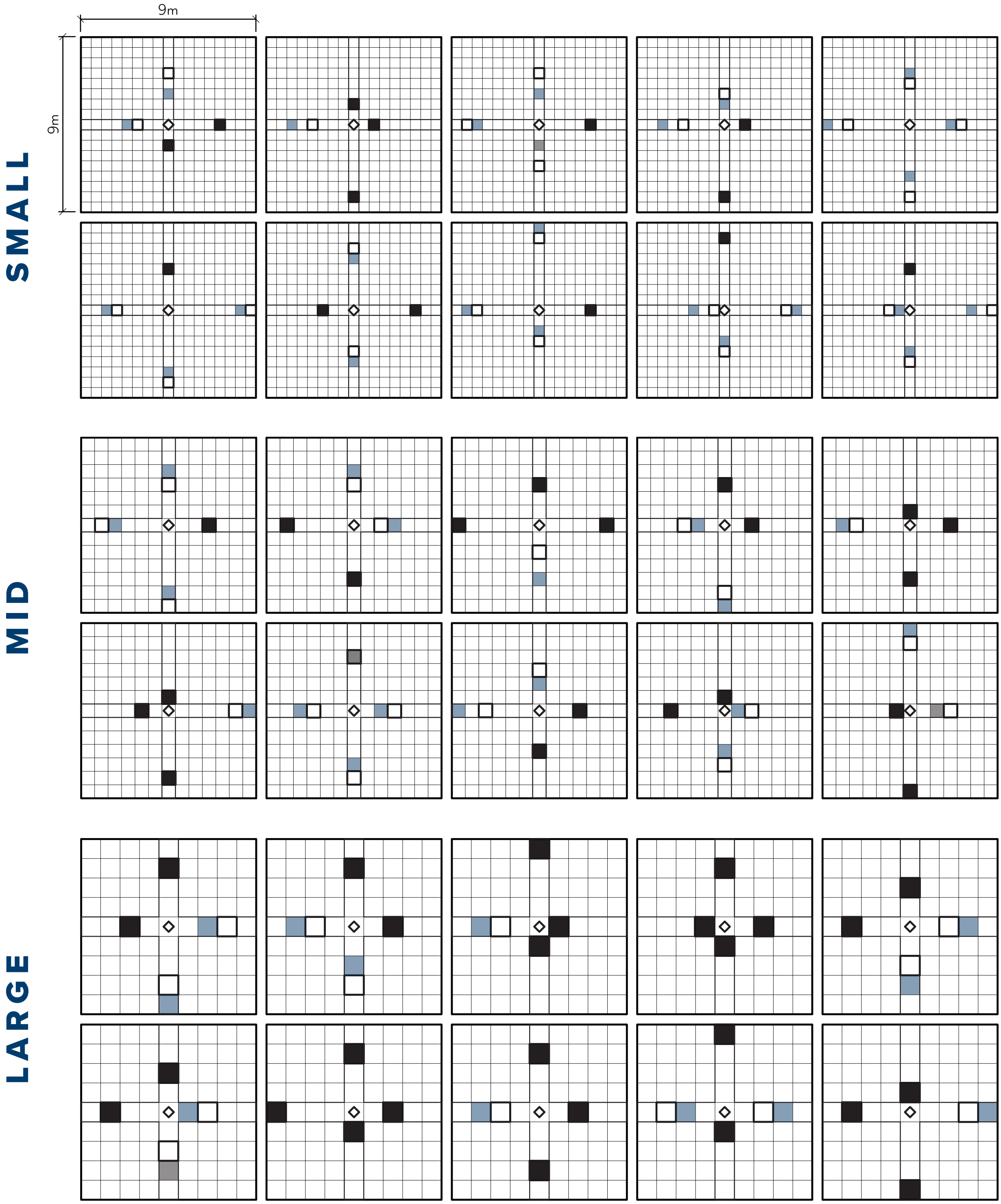
■ = Wood

■ = Metal

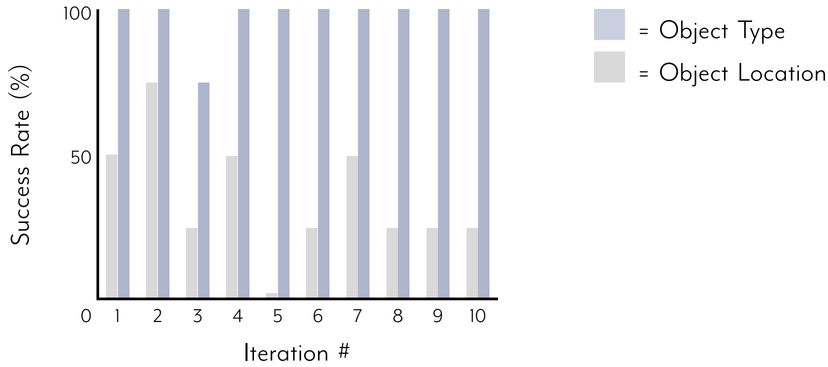
■ = Glass

■ = Plastic

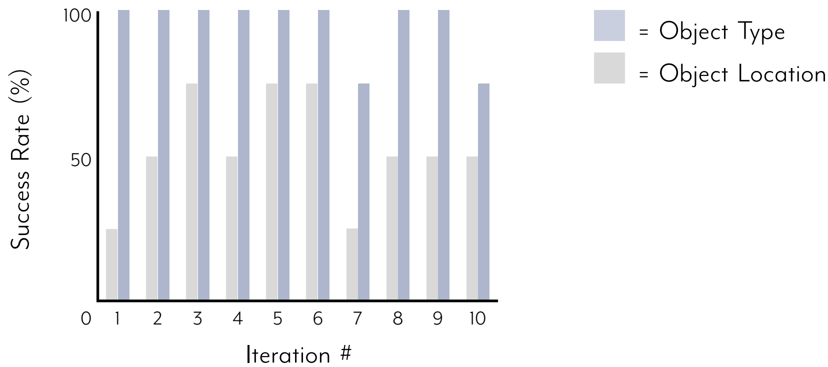
FULL RESULTS



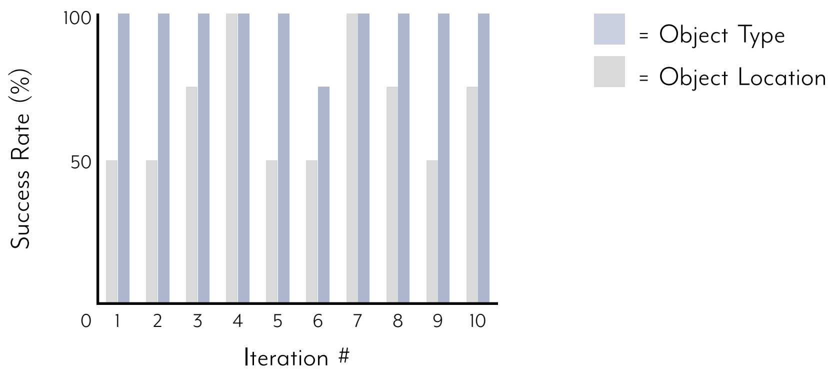
Success rate of object location and type identification - Small resolution



Success rate of object location and type identification - Mid resolution



Success rate of object location and type identification - Large resolution



RESULTS

The echolocation experiment assesses the mechanic's ability to provide information regarding object location and materiality through the use of sonic cues.

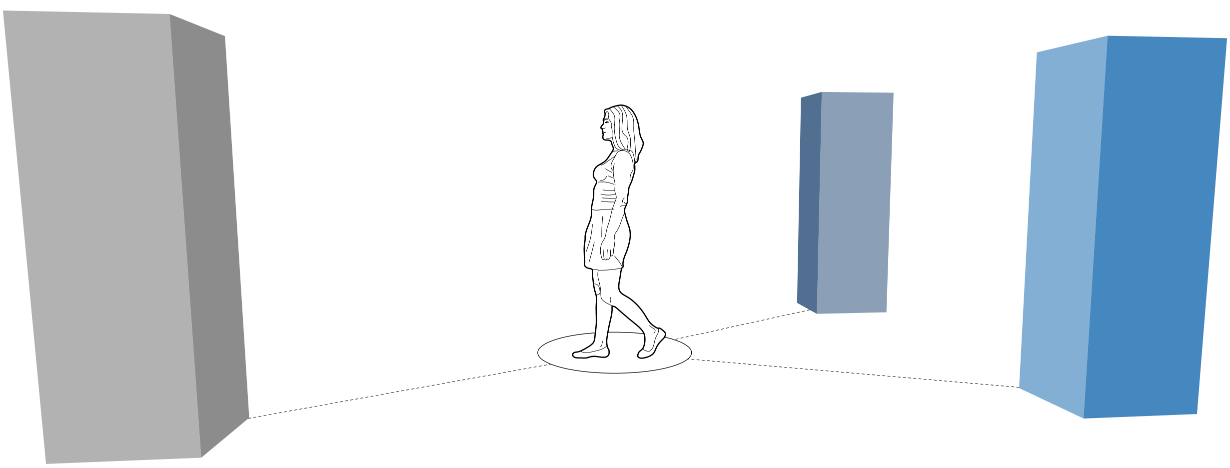
At the small scale, the scheme had a success rate for object location identification of 35%. In similar fashion to the distance measurement experiments, any incorrect location selection was within one metre of the correct space, which predictably meant that the success rate would show substantial increases once the spatial resolution was increased. This prediction was supported by the mid-scale testing, which showed a 17% in the success rate of location identification, bringing the success rate to 52%. This was followed by large-scale testing, which showed a further 18% increase, showing the highest location identification success rate of 70%. As for object materiality identification, each scale showed a near-perfect success rate, with both the small and large scale experiments success rates at 97% and the mid-scale at 95%.

The results show a reasonable success rate for object location identification and an excellent success rate for object materiality identification.

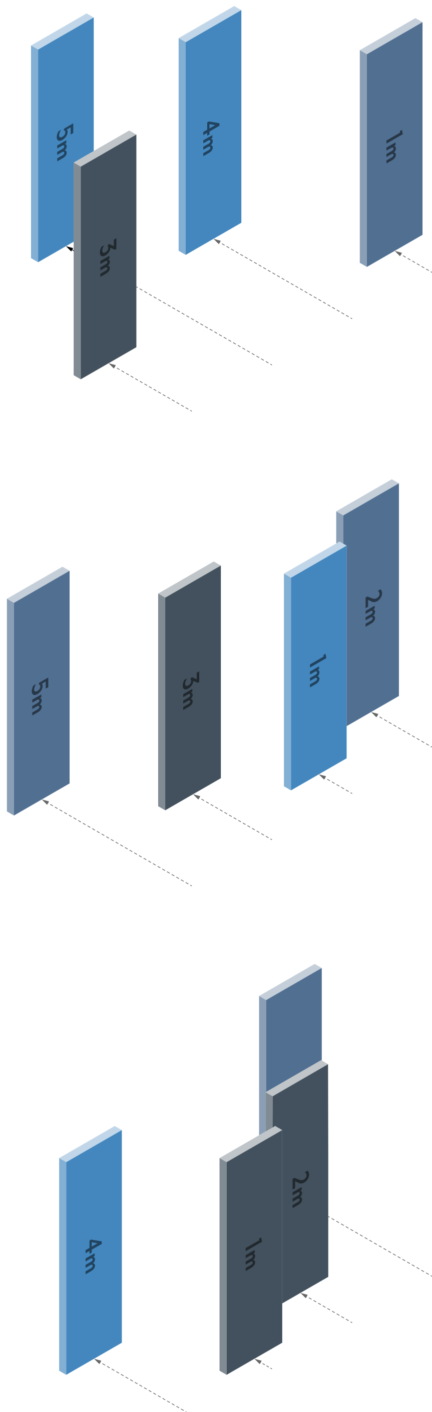
5.7 P-O-I MECHANIC DEVELOPMENT

The P.O.I mechanic aims to provide an indication as to object distance and type within a space. This is achieved through a previously developed singular-axis raycast method and haptic cues. The preliminary iteration indicates object distance through the strength of the haptic cue and object type through variance in the number of haptic cues (pulses). There is room for an investigation into the number of object types included, and the method used for indicating object distance.

This development experiment evaluates the best method for delivering distance information. The experiment borrowed the virtual infrastructure of the distance measurement experiment and assigned the objects various object types to replicate the appropriate haptic pulses.

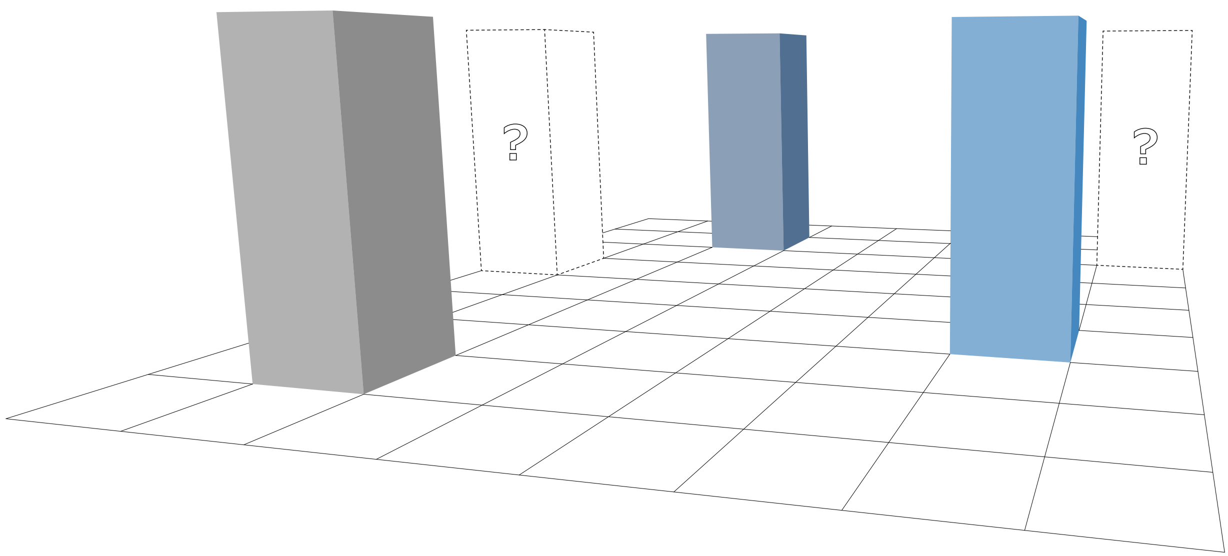


EXPERIMENT OVERVIEW

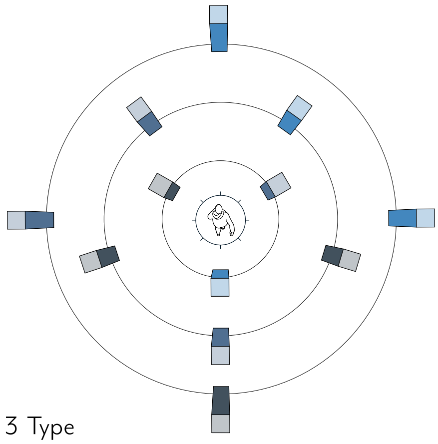


POINTS OF INTEREST

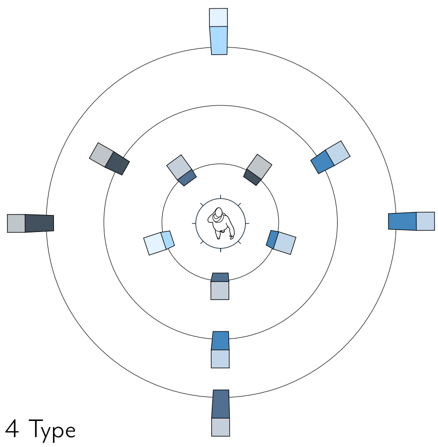
A secondary experiment was conducted. This experiment consisted of three rings of different diameters with a shared central point, where the user is located. A varying amount of objects are created on each ring and are assigned a unique haptic pulse pattern. The user is to identify the objects on each ring in a particular haptic order. This is done for the smallest ring first, followed by the two larger rings. This experiment will determine the optimal number of haptic pulse variants, thus, dictating the available number of points of interest.



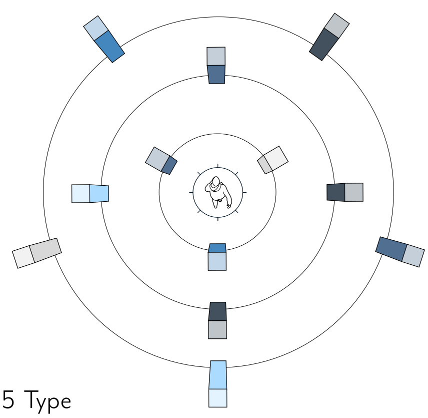
EXPERIMENT OVERVIEW



3 Type



4 Type



5 Type

FORMAL TESTING

The POI mechanic had now seen the function and the output resolved. The second developmental experiment revealed that the number of points of interest could be safely increased to four, matching the passive scheme. The formal testing of this mechanic will establish its success in providing environmental information. The test setup is similar to the distance measurement testing. In this instance, the randomly generated objects are assigned one of the POI haptic variants.

Key >

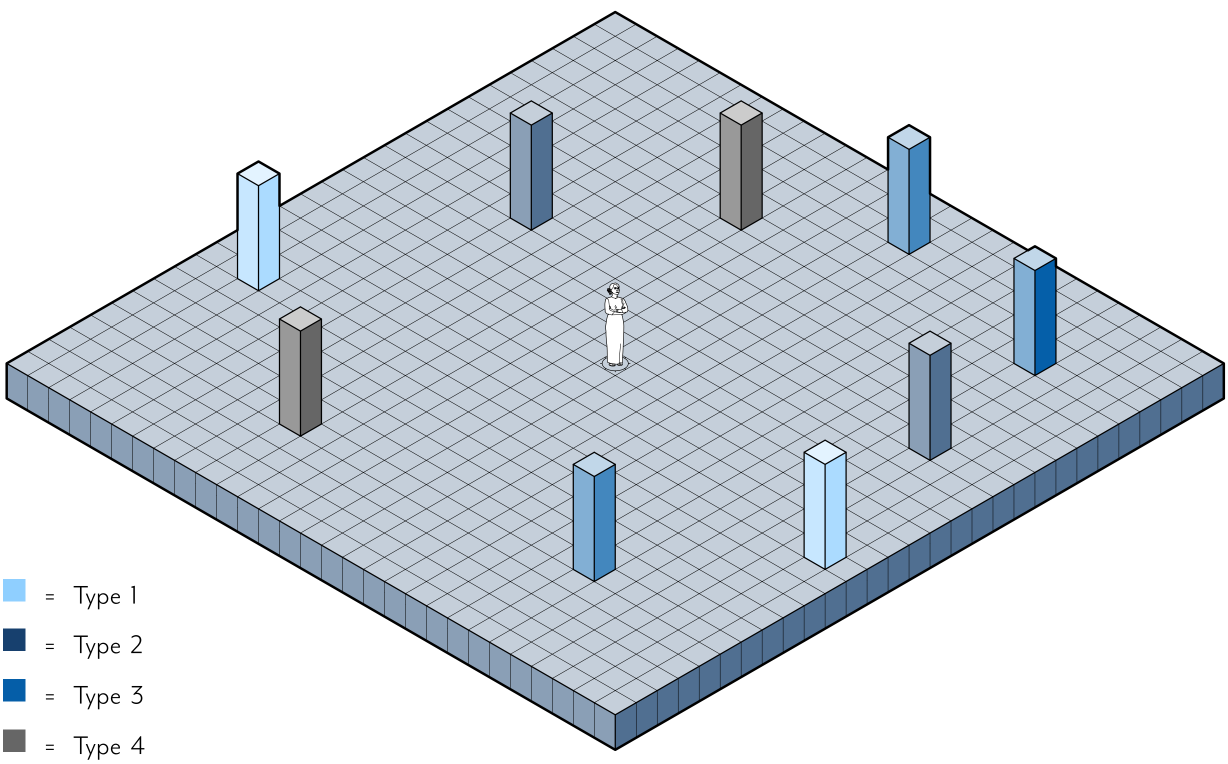
User Choice (Both Correct) =

User Choice (Location Correct & Type Incorrect) =

User Choice (Location Incorrect & Type Correct) =

User Choice (If Both Incorrect) =

Object Location (If Incorrect) =



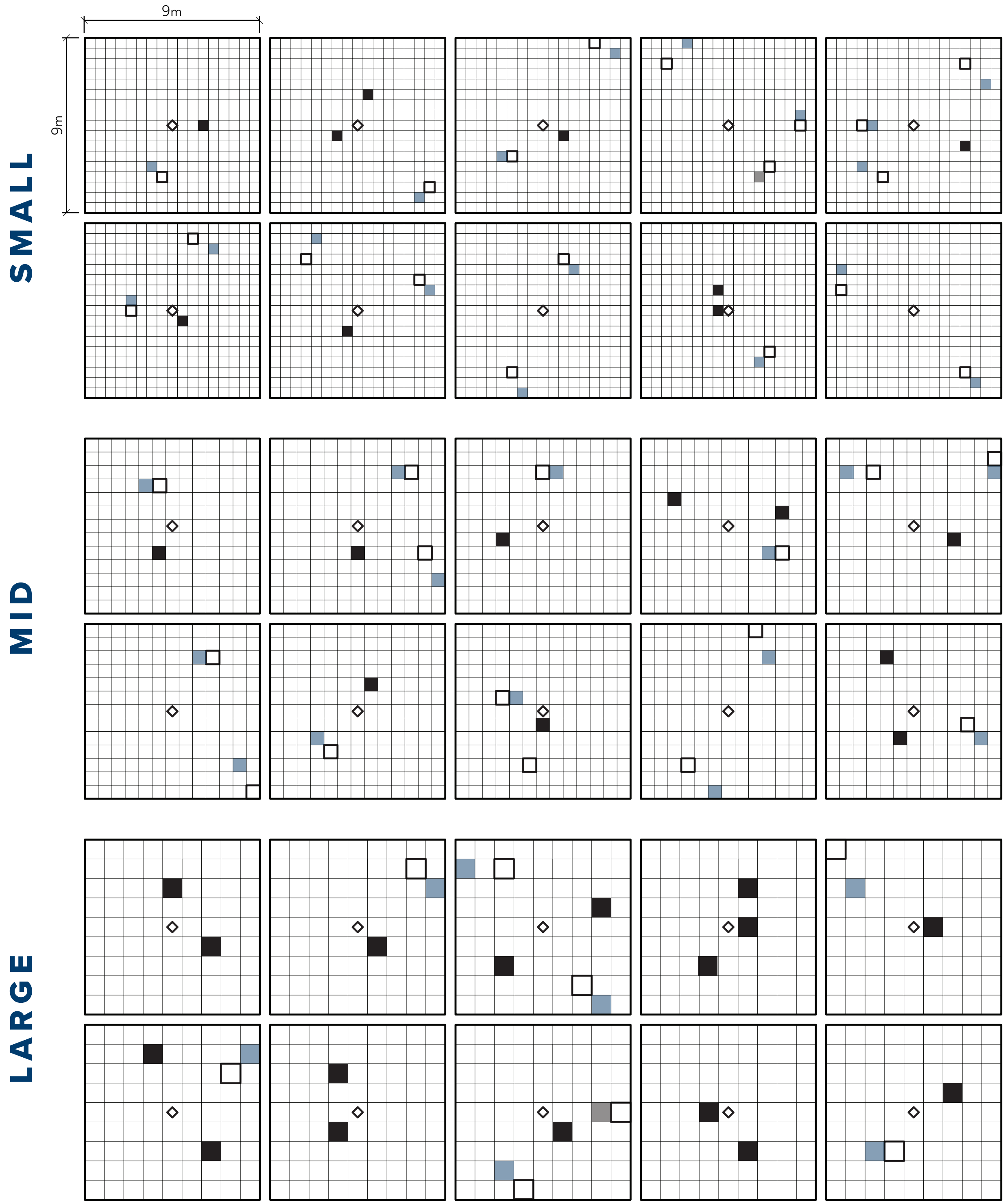
= Type 1

= Type 2

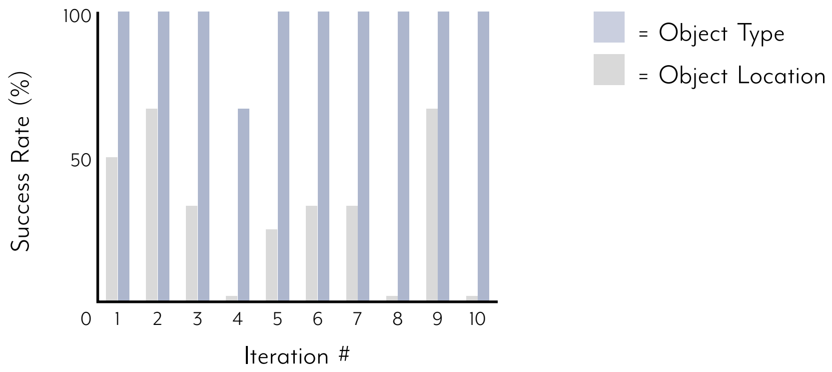
= Type 3

= Type 4

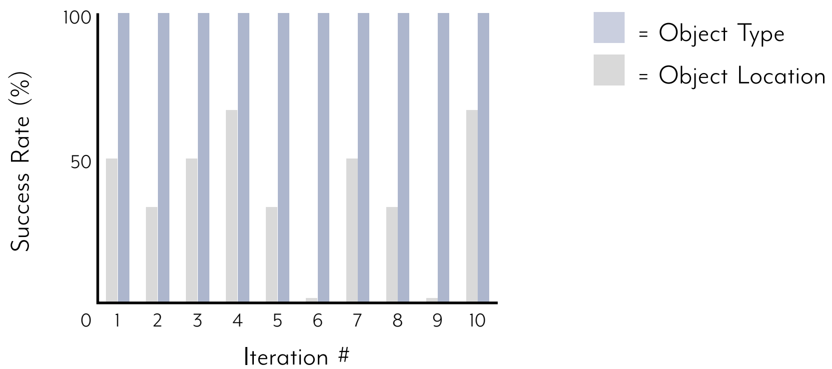
FULL RESULTS



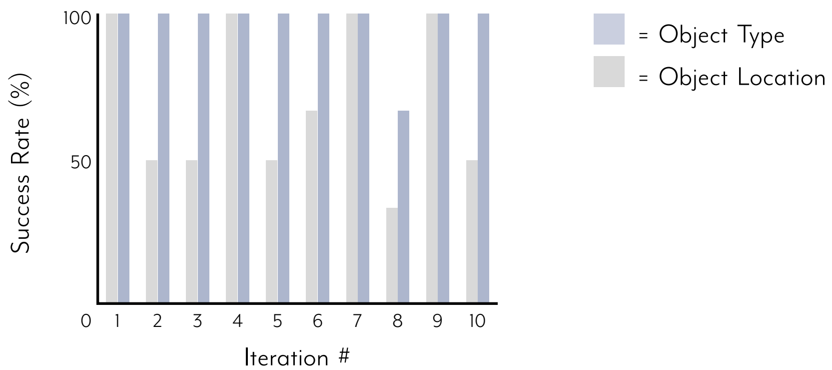
Success rate of object location and type identification - Small resolution



Success rate of object location and type identification - Mid resolution



Success rate of object location and type identification - Large resolution



RESULTS

The POI mechanic experiment assessed the mechanic's ability to provide accurate information regarding object distance (allowing inferences as to location) and object type.

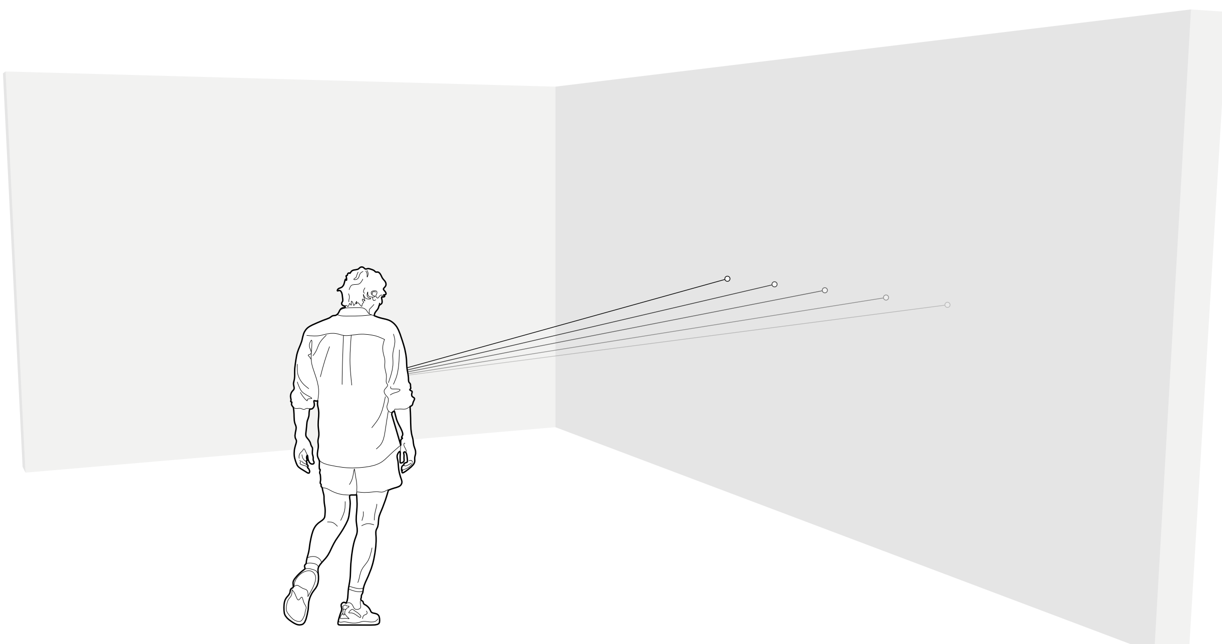
Throughout all testing scales, the mechanic showed an excellent success rate for object type identification. The success rates for the small, mid and large spatial resolutions were 93%, 100%, and 96% respectively. Identifying object location through the mechanic proved less successful. The success rate at the small-scale was only 32%. However, as displayed in both the echolocation and distance measurement tests, all incorrect choices were within a small radius of the exact location, meaning that any increase to the spatial resolution would predictably lead to a significant increase in the success rate. The next mid-scale test did not demonstrate this, with a success rate of just 41%, a 9% increase. The final large-scale test saw a 17% increase in success rate, giving the highest success rate of 68%, similar to the echolocation and distance measurement rates.

The results showed that the scheme was hugely successful at allowing for the identification of object type. The larger-scale showed a high rate of success in communicating object location. However, this rapidly decreased at the lower scales.

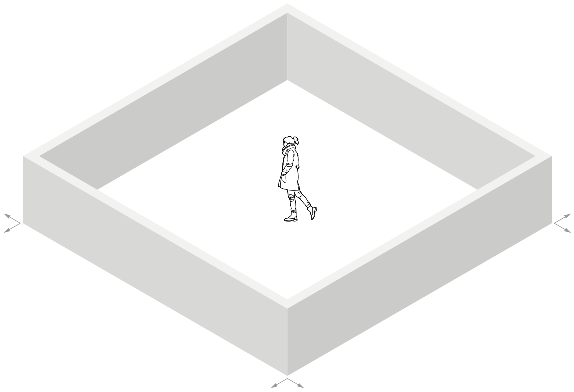
5.8 SCANNER MECHANIC TEST

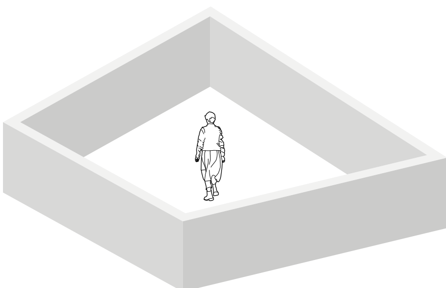
The Scanner mechanic was the fifth and final mechanic to undergo redevelopment. This mechanic sought to provide an idea of object location and, following success in preliminary testing, object shape. In order to achieve this, the mechanic relied on the consistent provision of haptic information. There was room for analysing: the relationship between the distance of the objects and the corresponding haptic cues, the potential for communication object shape and the frequency of haptic cues.

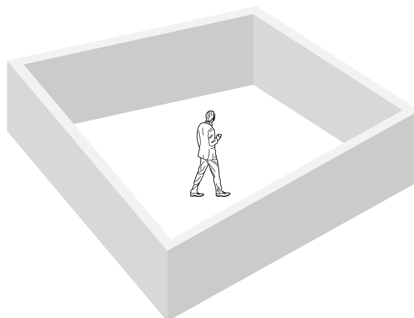
The scanner mechanic needed further refinement on the frequency and strength of the haptic information. The experiment took a rectangle object and skewed the corners to create quadrilateral shapes, which consistently varying in distance from the user. Users were to attempt to establish the dimension and shape of the object. This would then be compared to the virtual to check for accuracy.

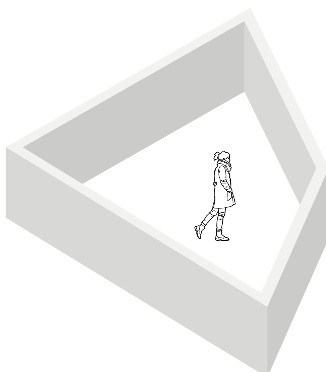


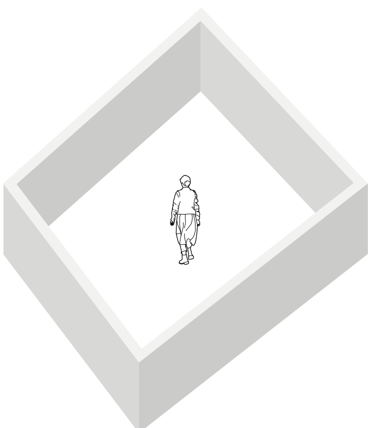
REFINEMENT

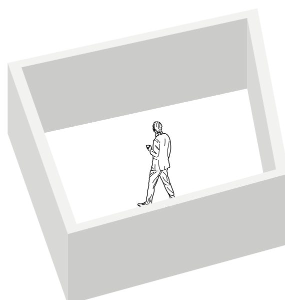












FORMAL TESTING

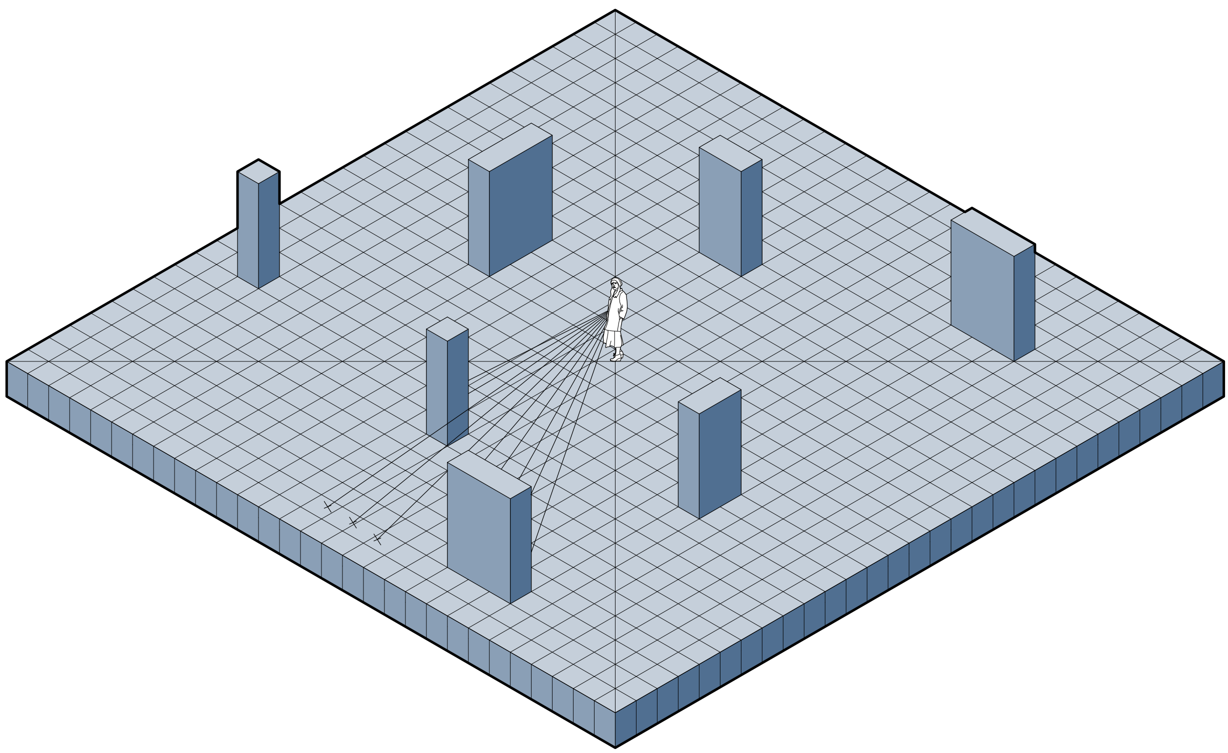
The formal test of the mechanic follows a similar setup to the POI and Distance mechanic testing. In this experiment, the same randomised objects are generated in a large scene, depending on the quadrant of the square space they may be extended beyond their standard 1:1 width, length ratio. In the preliminary investigations, the mechanic proved the most useful when it was providing continuous information. Replicating this in an environment with the standard singular objects and the extended length objects will validate whether this observation was correct.

Key >

User Choice (Correct) = ■

User Choice (If Incorrect) = ■

Object Location (If Incorrect) = □

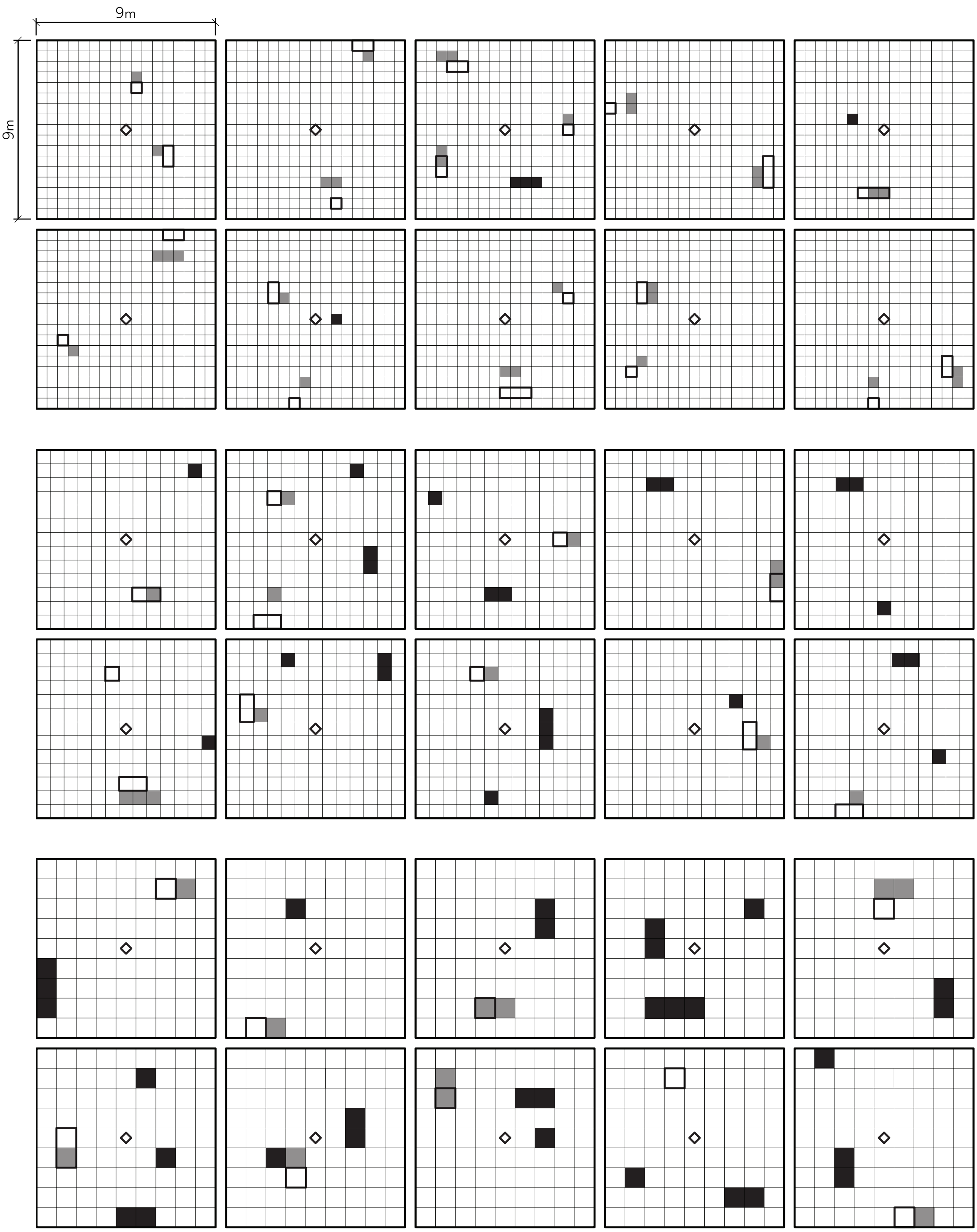


FULL RESULTS

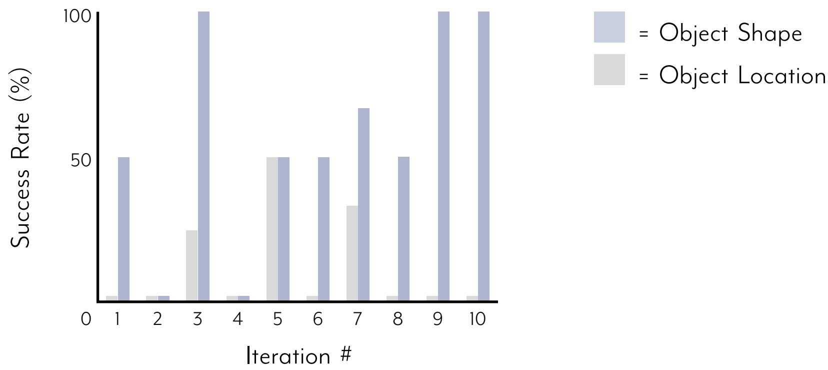
SMALL

MID

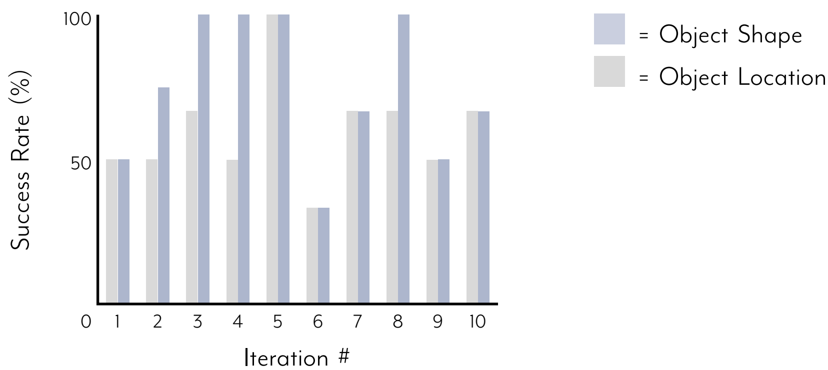
LARGE



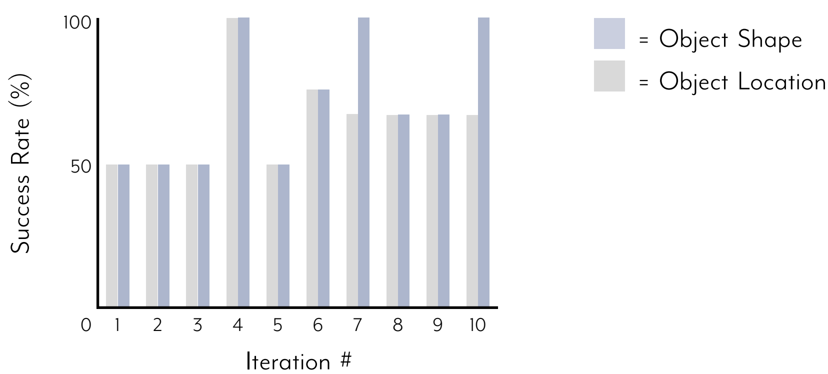
Success rate of object location identification - Small resolution



Success rate of object location identification - Mid resolution



Success rate of object location identification - Large resolution



RESULTS

The scanner mechanic experiment assessed the mechanic's ability to provide information as to the object location and size.

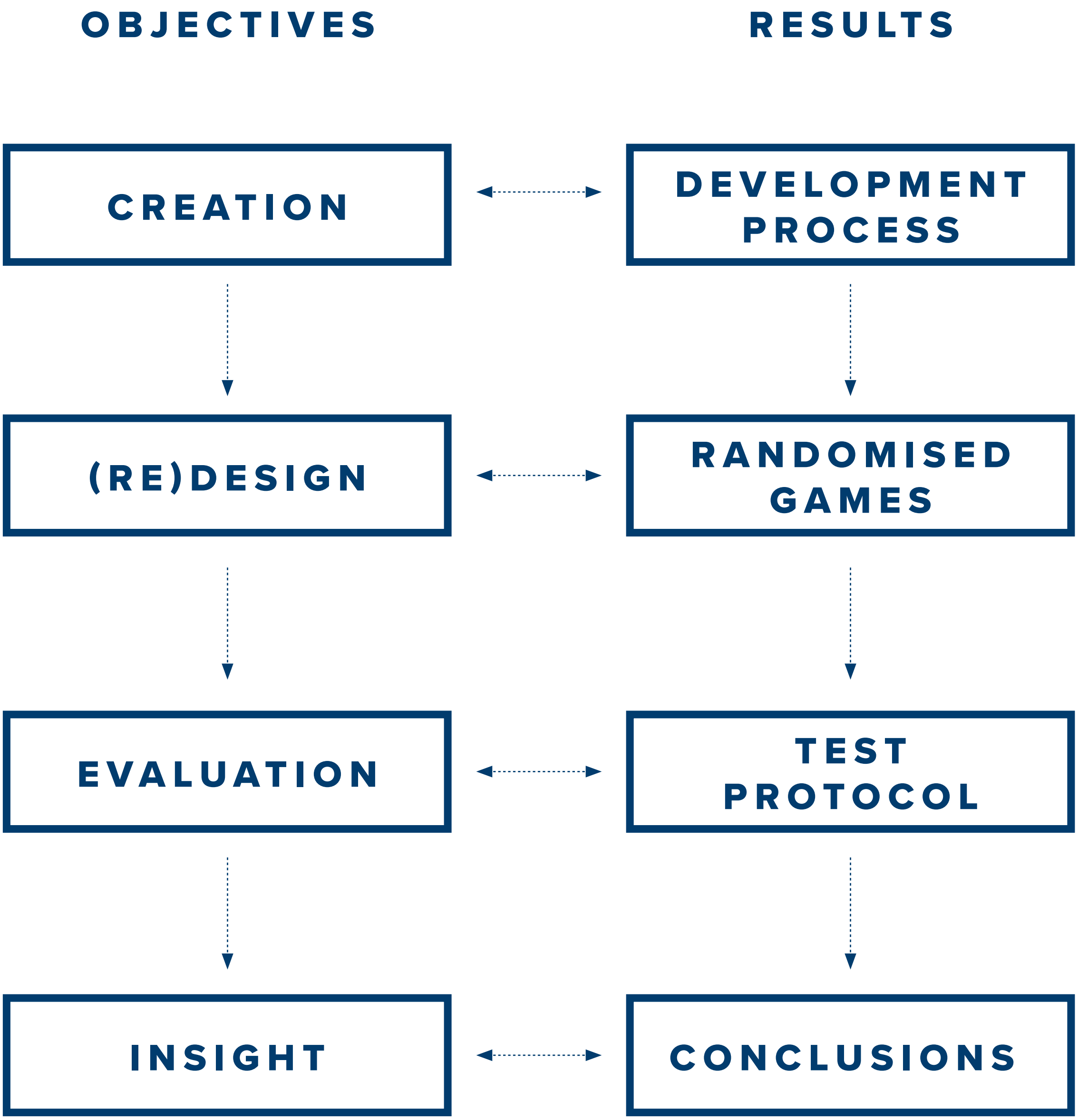
The mechanic followed a similar pattern to the previous ranged mechanics with a success rate for object position identification of only 12% at the small-scale. This rose to 63% and 69% for mid and large scales respectively. Identification of object shape was not something previously assessed. However, the main strength of the mechanic lay in its constant provision feedback regarding changing objects. Thus, in order to assess this, the object shapes were altered at random throughout the experiments. The mechanic showed high rates of success at identifying simple differences in object shape, with the lowest success rate of 56% at the small scale quickly rising to 78% and 85% for the medium and large scale tests respectively.

These results show that the mechanic shares a similarly high success rate for identifying object location as other ranged mechanics. Identification of object shape proved highly successful at the larger two scales and performed moderately at lower scales.

5.9 CRITICAL REFLECTION

This section successfully continues developing and expanding upon the previous design section, bringing the previously established technical lens to the progression of the project. This technical approach aided significantly in refining the scope of the investigation, as evidenced by the following design of test protocol, formalisation of the development process, and the testing of the mechanics. Each of these aspects is far more concerned with practical utility and systematic development when compared to the earlier design experiments. In contrast to the prior two sections of the thesis, this section is significantly more interested in the process underlying the design and evaluation of the outcome of the designs as opposed to interest in design in-of-itself.

The formal testing of the mechanics revealed success in communicating various elements of spatial information. When testing the ranged mechanics, the lower sized spatial resolution consistently failed to provide accurate environmental information. For this reason, the performance of ranged design outcomes will not be examined at this resolution in later iterations. Furthermore, the small amount of data overall means that slight variations in performance are prone to skewing success rates significantly. This gave cause to further testing with outside users in the next section to ameliorate this issue and bolster the validity of the results.


OBJECTIVES
RESULTS
CREATION
DEVELOPMENT PROCESS
(RE)DESIGN
RANDOMISED GAMES
EVALUATION
TEST PROTOCOL
INSIGHT
CONCLUSIONS

TESTING 6.0

6.1 INTRODUCTION

This section aimed to validate further the design schemes ability to provide spatial knowledge. In order to accomplish this, a pilot study with a small number of participants will repeat the previous formal testing for each mechanic. The results will provide essential conclusions as to the validity of the outcomes. A human ethics application was completed and accepted before this user testing was conducted (Application ID: 0000028058).

6.2 EXPERIMENT

Participants

Four participants were recruited for user-testing. None of the participants had previous experience with haptic devices. Only one participant reported previous experience with virtual reality technology. While it was not the author's intent to recruit visually impaired persons exclusively, all of the participants reported a mild-moderate visual impairment. All impairments were correctable with glasses or contact lenses.

Apparatus

The apparatus for the experiments was a single HTC VIVE controller. This controller has a built-in three-axis accelerometer and gyroscope, allowing accurate positional and rotational tracking. The tracking for the VIVE controllers further relies on HTC's infrared 'room-scale' tracking technology to update the position and rotation. The maximum range of motion available through the tracking space is 3.5x3.5m.

Experimental Task

Participants were required to take part in a total of five small-scale tests. For this purpose, each of the previous test environments is used. The exact purpose of each test differs slightly; however, a generalised explanation is that users are to use the chosen mechanic to identify the physical and embodied properties of randomly generated objects within the test environment. Users start in the centre of the scene and are to use the provided mechanic to establish a cognitive map of their environment. This cognitive map will include the objects in the environment and their properties. To remove their visual frame of reference, users will have their eyes closed when they complete the testing. Once a user feels that they have completed building this spatial understanding, they are to document this on a testing sheet. The users documented spatial understanding is then compared to the virtual scene and cross-referenced to check for success. The user is to complete this process a total of 10 times for each environment, giving 50 total tests.

Independant Variables

Four independent variables were manipulated throughout the study, all of which involve the objects. These variables are the number, layout, size, and properties of each object.

Number

The number of objects was dependant upon the size of the scene. For all scenes except the echolocation test, the number of objects was determined randomly from a range between 1-5. The echolocation test locked the number of objects at four.

Size

The size of the objects were changed in accordance with the spatial resolution settings drawn from the test protocol. The ranged tests each experimented with variance in the spatial resolution, changing between a 0.75m and 1m resolution.

Layout

The layout of objects in all instances was decided through the random generation of x and y coordinates. The echolocation only relied on one of these two values. The maximum and minimum numbers for the x and y position were set to correspond with the boundary size and spatial resolution setting of the test environment.

Properties

The properties of the objects in the scene are randomly assigned. The exact object properties subject to variation are dependant upon the scene. The objects within the distance measurement experiment do not have any differing properties.

Dependant Variables

Three dependent variables were measured to investigate the success of the design outcomes. The first is the rate of successful identification rate of object location. The second is the rate of successful object property identification, and the third is the time taken to complete the task.

Perceived Object Location

This variable is assessed by recording the user's impressions as to where the object is located on a sheet of paper. This paper has a series of grids that correspond to the spatial resolution and size of the testing environment. Once the user has recorded their attempts, the locations of these are compared to the object location in the virtual scene to establish the results.

Perceived Object Properties

This variable is assessed in parallel with the object location. The users are to note both the object location and properties simultaneously. For example, if an object is understood to have a metallic sound cue attached, the user may draw an 'M' in a particular position on the paper grid, denoting their opinion on both the material and location.

Task Duration

Once the user was confident they had completed the task, the running time of the virtual reality scene was recorded.

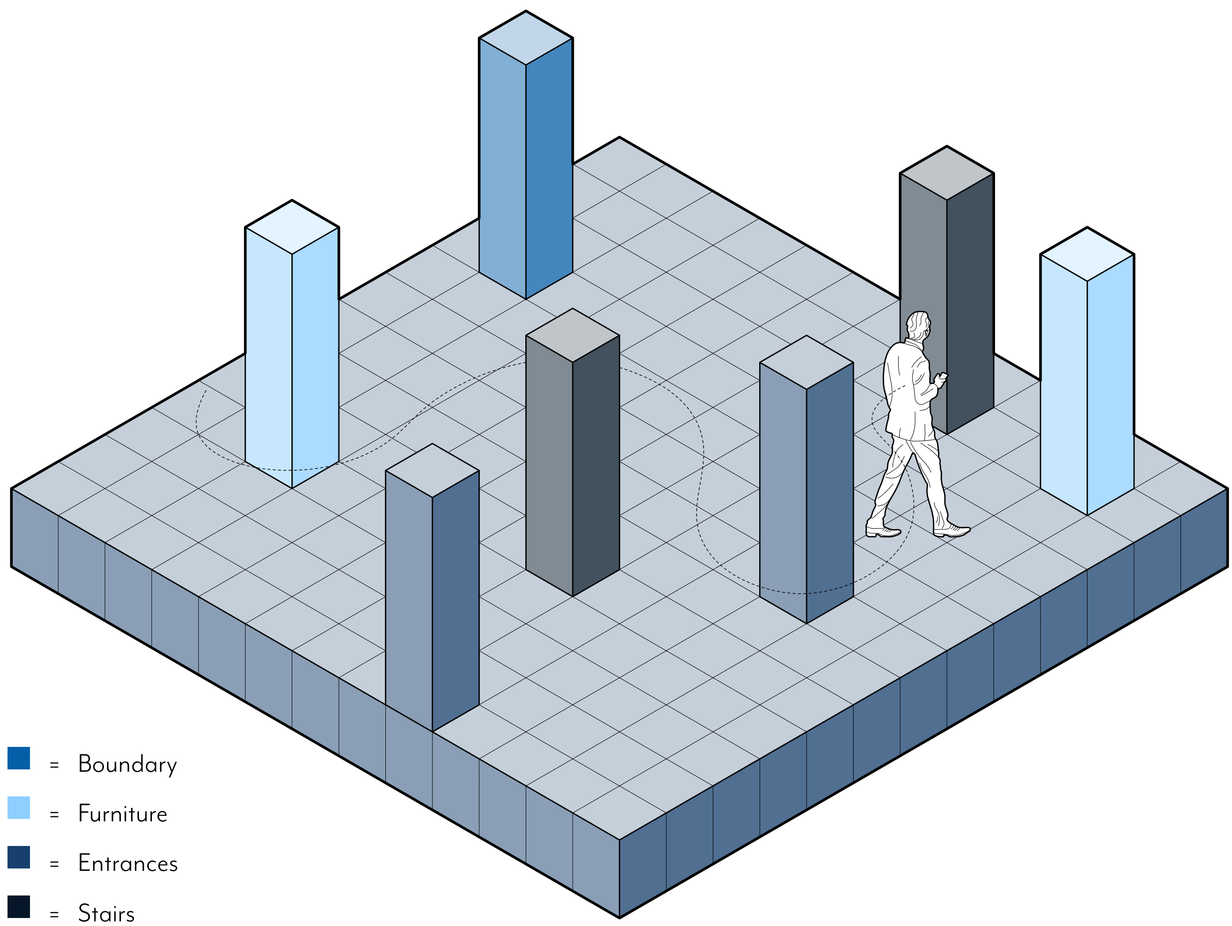
Task Procedure

Before partaking in the research, participants were informed about the nature of the research, what the objectives were, and why the research was relevant. Participants were required to read the provided information sheet and sign the consent forms. They were given the opportunity to ask any questions about the tasks and research, or to express any concerns. Before commencing the tasks, users were taken through a training session which provided familiarisation with the virtual reality technology and the haptic and sound cues. The randomised games created in the development process of the mechanics were employed for this purpose. After the familiarisation with the scene, users were asked to complete the five testing experiments while using the various mechanics. The user's impressions as to object location, material, type, or shape were documented on a gridded sheet and then compared to the virtual scene to check for accuracy. The duration of each experiment was approximately one hour.

6.3 PASSIVE SCHEME

Success rates for object recognition and average task duration over ten iterations

	Small Scale			Medium Scale		
	Object Type (%)	Object Location (%)	Duration (s)	Object Type (%)	Object Location (%)	Duration (s)
Personal	79	17	134	84	80	73
Participant 1	85	22	128	88	85	96
Participant 2	77	14	143	73	73	57
Participant 3	79	9	144	77	67	78
Participant 4	82	18	161	84	87	84
Average (Mean)	80	16	142	81	78	78



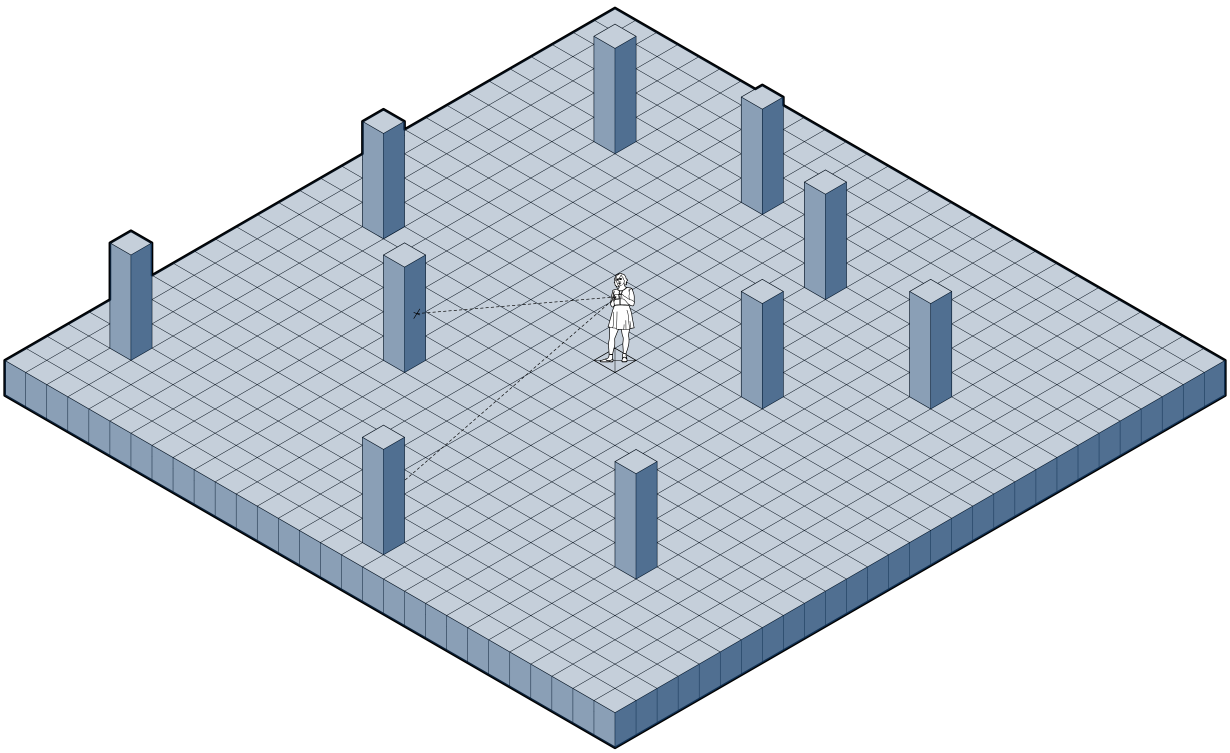
RESULTS

The passive scheme showed a precise replication of results from personal testing. The success rates for object location identification at the small scale remained low, averaging at just 16%. Once again, this rate increased sharply upon testing at the medium-scale, averaging at 78%, a 62% increase. The success rate for object type identification remained at roughly 80% throughout both scales, also matching the personal testing success rates. There was a substantial difference in the task duration, with participants requiring an average of 142 seconds to complete the small-scale testing and 78 seconds for the medium-scale testing. These results demonstrate the resounding success in bolstering human-scale spatial understanding at the medium scale, enabling users to identify object position, and typology through haptic cues successfully.

6.4 DISTANCE MEASUREMENT

Success rates for object location and average task duration over ten iterations

	Medium Scale		Large Scale	
	Object Location (%)	Duration (s)	Object Location (%)	Duration (s)
Personal	53	87	64	45
Participant 1	42	95	51	74
Participant 2	44	103	61	52
Participant 3	38	91	55	61
Participant 4	47	112	58	48
Average (Mean)	45	98	58	56



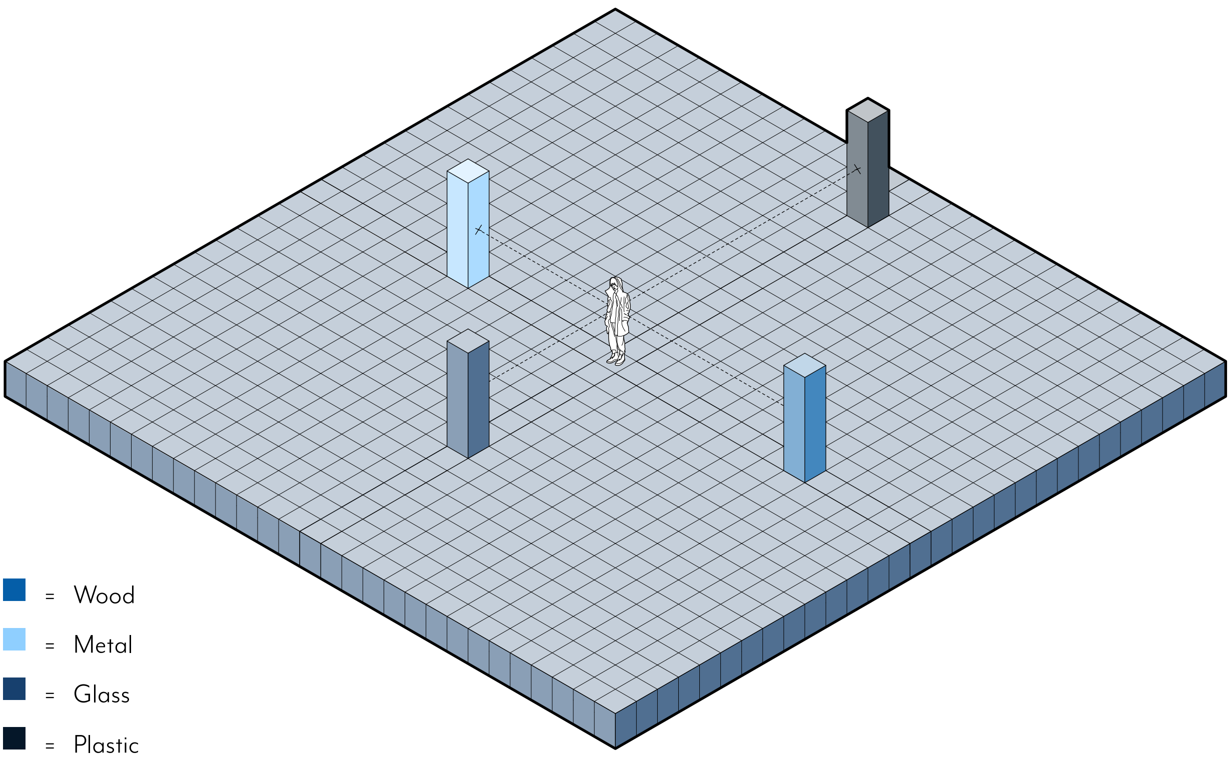
RESULTS

The distance measurement user testing showed moderate success in replicating the results from personal testing, with success rates dropping slightly, and task durations increasing. The success rates for object location identification at the medium scale showed an average success rate of 45%. This increased to an average of 58% for the large scale. The medium and large scale averages show a respective 8%, and a 6% decrease from personal testing. The task durations show a moderate decline between scales, with the medium-scale averaging 98 seconds for completion and 56 seconds at the large scale. Task duration at both scales shows a moderate increase when compared to personal testing, with an 11-second increase at both scales. Personal testing outperformed the average across all parameters, indicating that experience with the tool may provide moderate improvements in outcome. Overall, these results demonstrate an average level of success in providing locational information through variable haptic cues.

6.5 ECHOLOCATION

Success rates for object recognition and average task duration over ten iterations

	Medium Scale			Large Scale		
	Object Material (%)	Object Location (%)	Duration (s)	Object Material (%)	Object Location (%)	Duration (s)
Personal	95	52	57	97	76	49
Participant 1	78	46	53	88	62	52
Participant 2	81	31	71	71	73	65
Participant 3	88	61	67	82	65	58
Participant 4	91	55	78	94	80	74
Average (Mean)	87	49	65	86	71	60



= Wood
= Metal
= Glass
= Plastic

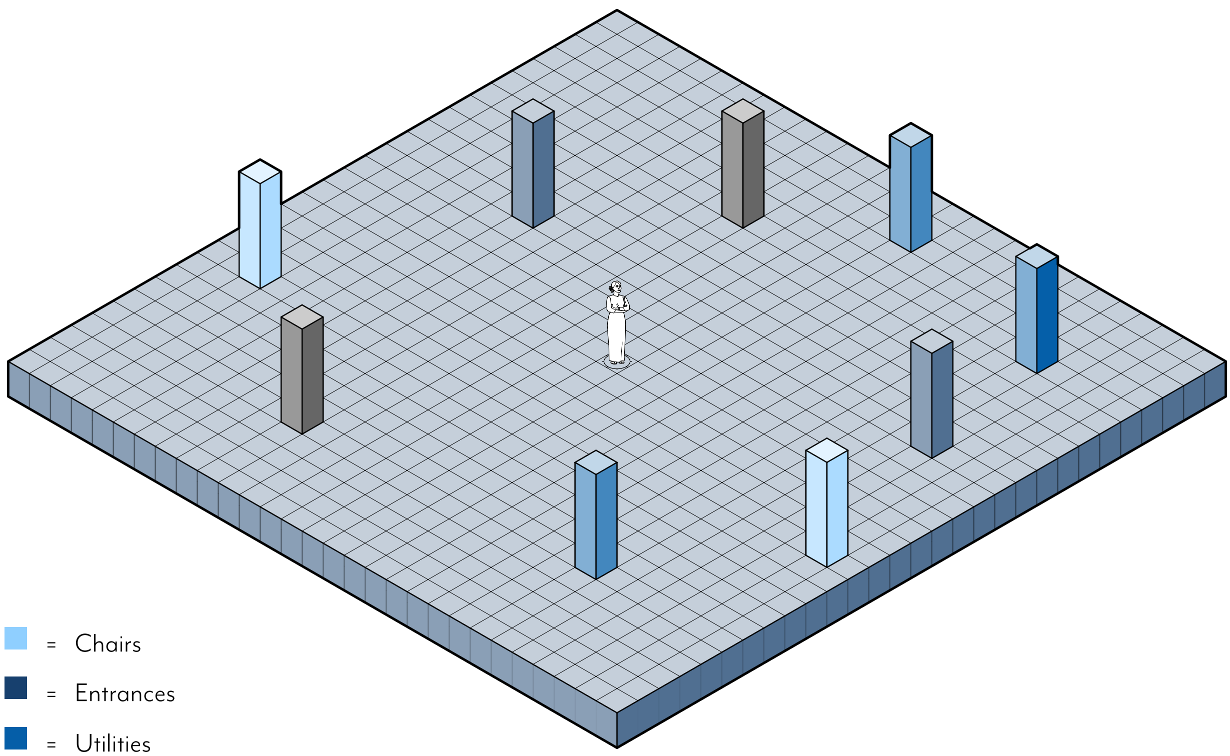
RESULTS

The echolocation user testing results show a high level of replication from personal testing. The success rates for object location identification show a 49% success rate for the medium scale and a sharp increase to 71% at the large scale. Results from both scales adhere strictly to personal testing. For object material identification, the mechanic showed high rates of success, with averages of 87% and 86% for the medium and large scales respectively. The average completion time for the medium-scale averaged 65 seconds, reducing to 60 seconds for the large-scale. Interestingly, the mechanic did not display much disparity in task completion times between scales, with only a 5-second average difference between them. The guaranteed of four objects in the scene may have assisted in this process as there was no uncertainty for object count or direction. The results show a fast and accurate identification of both object location and object material identification.

6.6 POINT OF INTEREST

Success rates for object recognition and average task duration over ten iterations

	Medium Scale			Large Scale		
	Object Type (%)	Object Location (%)	Duration (s)	Object Type (%)	Object Location (%)	Duration (s)
Personal	100	41	48	96	68	34
Participant 1	98	46	61	100	61	37
Participant 2	100	24	53	98	55	41
Participant 3	100	35	54	100	48	48
Participant 4	97	38	69	100	71	39
Average (Mean)	99	37	57	99	61	40



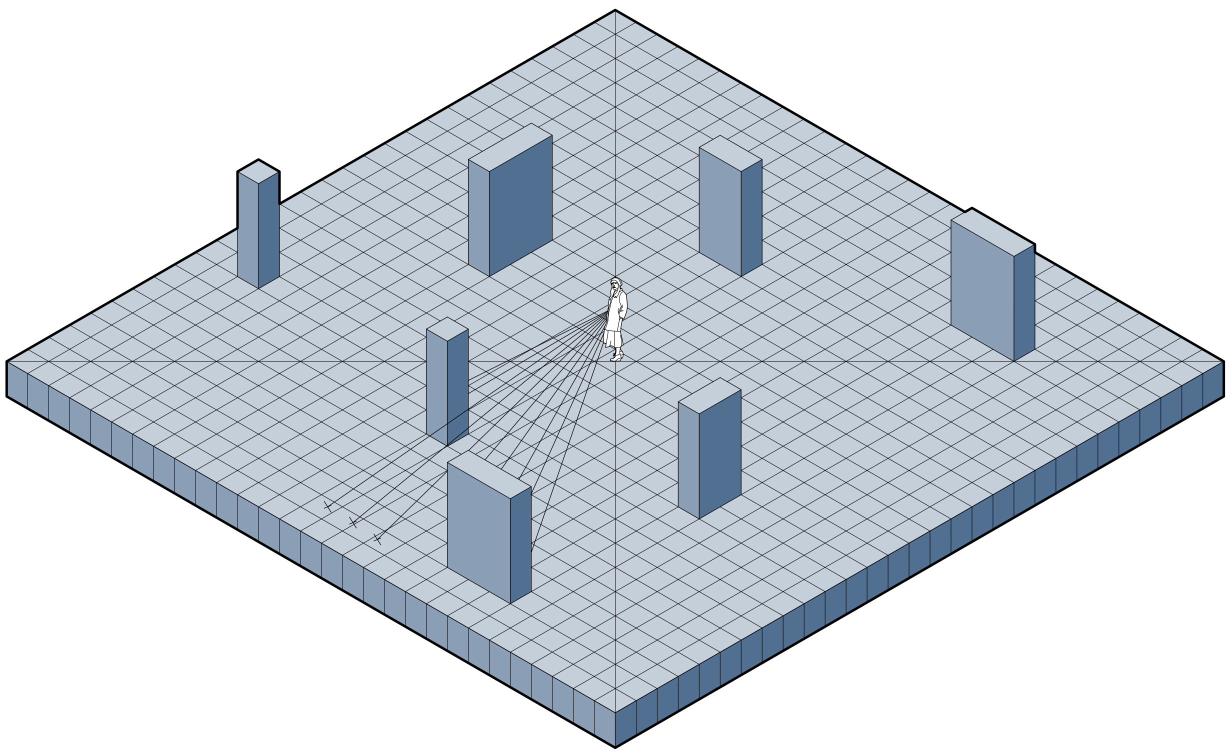
RESULTS

The point of interest user testing results demonstrated a high level of replication when compared to user testing. Success rates for object location followed the personal testing closely, with the medium scale averaging 37% and the large scale increasing to 61%. In contrast, the mechanic proved hugely successful in communicating object type, with both the medium and large scale testing resulting in a 99% success rate. Task duration results failed to replicate those shown in the personal testing, but remained low, with an average time of 57 seconds for the medium scale, and 40 seconds for the large scale. The results suggest that while the mechanic functions excellently against the time and object type identification parameters, this is likely at the expense of location identification.

6.7 SCANNER

Success rates for object recognition and average task duration over ten iterations

	Medium Scale			Large Scale		
	Object Shape (%)	Object Location (%)	Duration (s)	Object Shape (%)	Object Location (%)	Duration (s)
Personal	67	63	82	85	69	48
Participant 1	45	38	93	65	54	56
Participant 2	51	57	87	78	73	68
Participant 3	54	35	101	88	63	67
Participant 4	48	44	107	69	67	78
Average (Mean)	53	47	94	77	65	63



RESULTS

The scanner mechanic user testing illustrates a low-moderate replication rate from personal testing. Object location identification showed a 47% average success rate for the medium-scale, with this increasing to 65% for the large-scale. Identification of object shape proved more successful than location, with the success rates averaging 53% and 77% for the medium and large scales respectively. The duration of tasks remained high for both scales, with the average duration at 94 seconds in the medium-scale and 63 seconds in the large scale. Both durations show a substantial increase from the personal testing, with medium-scale durations increasing 12 seconds and large scale duration increasing 15 seconds. Despite the inconsistent replication of prior testing, the mechanic demonstrates moderate success in object location and object shape identification through haptic cues.

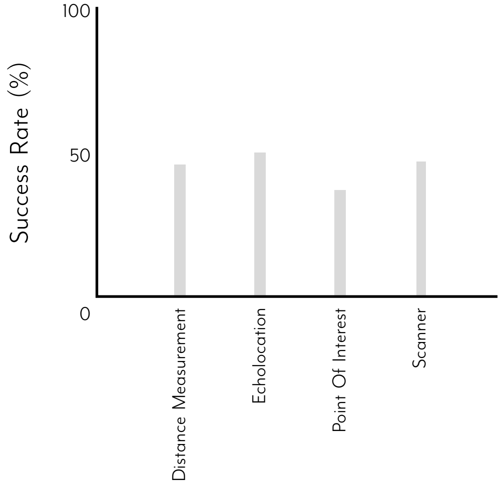
6.8 DISCUSSION

Inferring object location proved to be a difficult challenge for each of the ranged mechanics. The echolocation mechanic was the most effective, demonstrating the highest rates of success in both the medium and large scales with rates of 49% and 71% respectively. The lowest success rate for the medium and large-scales were the Point Of Interest mechanic at 37%, and the distance measurement mechanic at 58%, respectively. The Point of Interest mechanic provided the fastest task completion in both scales, averaging 57 seconds for the medium-scale, and 40 seconds for the large scale. At the medium-scale, this was followed by the echolocation mechanic with 65 seconds and then the scanner mechanic at 94 seconds. The large scale shows a significantly reduced range, with echolocation, the second-fastest averaging 60 seconds, followed by the scanner mechanic at 63 seconds. Overall, there was a consistently low rate of object identification throughout all mechanics; this would suggest inferring precise positional information is very difficult, regardless of sensory formats and variations in expression.

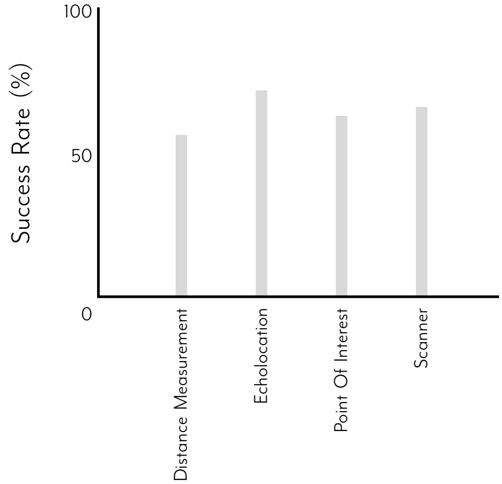
Despite the moderate results in the identification of object location, most mechanics demonstrated high levels of success in identifying unique object properties. The highest of which was the Point of Interest mechanic, which displayed a near-perfect recognition of object typology. The echolocation and passive scheme displayed high success rates at both scales, with all results averaging above 80%. The only mechanic which did not perform well was the scanner mechanic which identifies object shape. The mechanic only achieved a 53% success rate at the medium-scale and 77% success rate at the large-scale. The consistently high success rates for identifying unique objects characteristics suggest that this may be a fruitful area for future exploration.

DISTANCE MECHANICS

Success rate of object location identification - Medium resolution

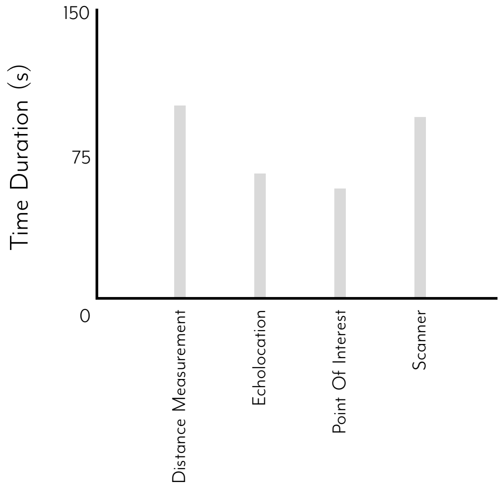


Success rate of object location identification - Large resolution

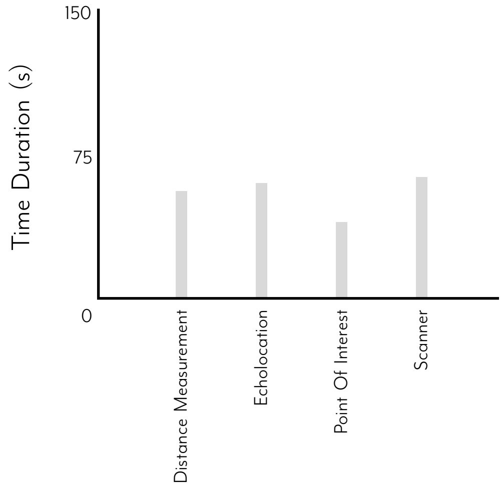


TASK DURATION

Task Duration - Medium resolution



Task Duration - Large resolution

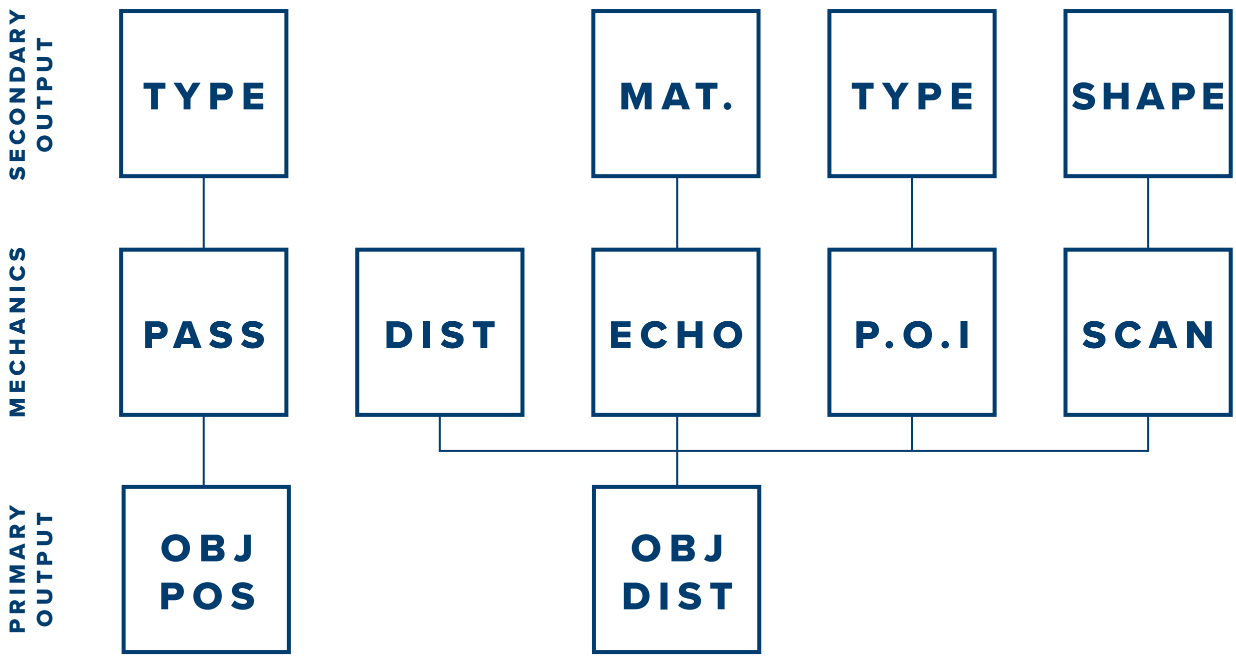


6.9 CONCLUSION & CRITICAL REFLECTION

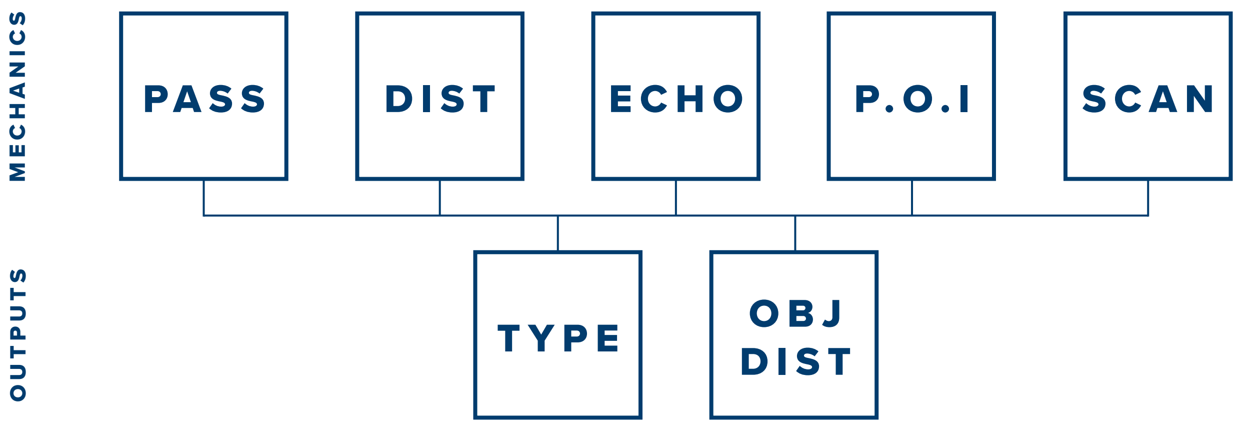
This section employed observational testing to evaluate the performance of the set of spatial interaction mechanics. User testing bolstered the preliminary observations made throughout the design and development stages and allowed for deeper conclusions to be drawn regarding digital spatial interaction. The results of the testing revealed a few key conclusions, as well as many regarding each mechanic. It was found that location inferences are very difficult to do accurately, but that a general idea of distance and angle was achievable. Recognition of object type, material, or shape proved much more successful, and communication of these aspects was far simpler.

Upon testing, it was evident that the broad functions of the mechanics, which were initially considered to be a strength, would be a hindrance for drawing these more valuable insights. Many elements of the mechanics do not focus on expressing the same information through variances in approach; instead, they coincidentally allow for the same information (namely, object location) to be inferred based upon other sensory outputs. The similarities in expressing object location allowed for the mechanics to be compared and gave rise to the most critical conclusion, this being that inferring any specifics about object location is very difficult. As comparison across mechanics is what provided valuable insights, it is unfortunate that the secondary objective of each mechanic is unique (material, shape, typology). This makes comparison difficult as there is no universal parameter for testing performance. If each mechanic focused on expressing one or two pieces of information in various ways, there may have been multiple impactful conclusions, rather than one.

EXISTING OUTCOME



PREFERABLE OUTCOME



REFLECTION 7.0

7.1 CRITICAL REFLECTION

These critical reflections analyse the body of work, searching for further insights, shortcomings and potential opportunities within the project. This section is organised into four sub-headings. The first reflects on the research scope, and the following three analyse each of the primary design-research components, the process, the design outcomes, and the methods of evaluation.

7.2 SCOPE

The design scope saw significant refinements throughout the progression of the thesis, with the establishment of a well-defined and appropriate investigation scope finally realised at the conclusion of the fourth chapter. The initial scope for the project was far too broad, this lack of refinement led to significant amounts of work going un-used in the final document, that which remains from the first three months has been mostly repurposed and heavily edited. The initial lack of scope also led to a variety of process issues. Initial design investigations were so broad that design experiments ranged from abstract sensory design features to highly-technical spatial mapping tools within a single chapter. The resultant design outcomes entered the technical sphere without the level of rigour demanded by the finalised goals of the project and substantial amounts of development, adjustment, and editing were required in order to rectify this. While developments and changes are somewhat intrinsic to a design-led investigation, many of the necessary changes may have been avoided with more careful planning and investigation.

The issues with scope also led to the late arrival at the final design result, which significantly impaired the ability for ethics applications to be submitted. This led to a lack of engagement with the visual impairment community as is further elaborated upon in the following sub-heading.

7.3 PROCESS

As alluded to, the refinement and changes to the scope and line of inquiry caused significant disruption to the thesis progression and outcomes of the work. Early changes in the scope and research directions of this thesis led to an exploration into the world of blindness and visual impairment which was more substantial than anticipated. Any development and creation in this area should seek to gather the expertise and lived experience of these communities and should work to integrate it with the design outcomes. Thus, a significant shortcoming of this research is the lack of formal engagement with these communities. It is plausible that with more input from this community, that the designs, outcomes, processes, and even entire sections of the thesis may have been different. This community bring large swathes of information and personal experience with them that are not covered in scientific papers; this acknowledgement becomes especially significant when it comes to unique design opportunities such as those explored in this thesis.

A different issue addressed in the previous section was that the spatial interaction mechanics entered the technical realm with many layers of arbitrary decision embedded in their design and sensory outputs. In response, much of the later thesis attempts to address this issue. Fortunately, the later development processes and refinements manage to account for the arbitrary decisions made regarding the subtler aspects of mechanic functions and sensory output, while also providing some valuable insights into the design work. Unfortunately, the same can not be said for the underlying conception of the designs themselves, the purpose and general functioning of the mechanics were not subjected to the same level of developmental scrutiny.

7.4 DESIGN

A criticism levied against the design outcomes following the testing chapter was that the function of the mechanics was too varied. Once the primary line of inquiry had been established, one of the stated objectives was to evaluate the existing design material and use the results to draw broader conclusions about digitally based non-visual spatial comprehension. This variation throughout the design of the mechanics made it challenging to meet this objective. They were conceived of in an exploratory manner, to build a wide range of different interactions. As a result, the mechanics express various pieces of environmental information through many different methods and sensory outputs. The critical reflection noted that the variance in mechanic function made it challenging to compare user testing outcomes, as none of the mechanics endeavoured to accomplish the same thing. Thus, the conclusions were mostly restricted to observations about the mechanics themselves, rather than broader insights into the field. In order to generate knowledge which had larger implications for the field, the mechanics would have required specific design decisions made that allow them to focus on evaluating particular elements of virtual spatial understanding. The one successful example of this was the object location identification, which all mechanics expressed in various ways. This allowed for more substantial insight into the operation of distance recognition in virtual environments.

7.5 EVALUATION

The evaluation of design work within the thesis largely relies on personal insight, ongoing critical analysis and user testing. Formal design evaluations employed the testing protocol and administered through the chosen virtual reality technology. As a result, all evaluations are imprinted upon by these two factors. There are three items of critical reflection, the testing conditions, testing protocol, and chosen technology.

The isolated testing environment (VASE space) and the lack of dynamic elements within it mean that the testing results betray the complexity of real-world spaces. The addition of real-world events will have unpredictable impacts on the outcomes of the research. Future investigations would be well served to complete testing in complex and dynamic locations to establish how these features impact the spatial knowledge provided by these digital tools. The small sample-sized used in the testing represents a potential issue for the validity of the data. A larger sample size of participants would provide further validity and strength to the testing results. The lack of evaluation with individuals who are substantially visually impaired or blind also represents a validity issue; this has been discussed under the process sub-heading.

A significant limitation with the testing protocol is that it only assesses spatial comprehension (also known as cognitive mapping), the most fundamental aspect of wayfinding. Any further investigation into navigation was far beyond the expertise and research capabilities of the author and would have been unachievable in the time allotted. Thus, there is no attempt made to establish the impact of the digital interactions on the other two wayfinding stages, decision making and decision-execution. The assessment of these later wayfinding stages may provide significant insights that are useful for design outcomes and how they function.

The chosen virtual reality technology, the HTC VIVE holds a limitation with its lack of play area. The final play-space is restricted to a 3.5x3.5m maximum. While the sound, haptic feedback and excellent tracking all provide valuable design foundations, the small area for movement significantly hinders the possibility for the assessment of spatial understanding. Fortunately, recent evolutions in digital technologies, such as the OCULUS Quest, provide self-tracking and thus, enable significantly larger play spaces to be employed.

7.6 KEY CONTRIBUTIONS

There are four outcomes of this research. The first is the five unique mechanisms for non-visual spatial engagement. The second was a defined development process that allows a systematic approach to the creation of these mechanisms. The third was an evaluation technique that could be used to establish the successes and failures of these mechanics. The final is the prior critical reflections. While there are many criticisms I have levied at this thesis, there are many points of success and key contributions made.

Spatial Engagement Methods

Each of the final mechanics represents a unique attempt to establish a successful form of digitally-based non-visual spatial engagement. The outcome of the final tools exist as a successful pilot-study, which validates an unconventional, but important mode of inquiry.

Development Process

The development process created and employed in the project focuses on the systematic creation, development, and evaluation of modes of spatial engagement. This approach stands in contrast to the attempts made in comparable fields, which are primarily focused on merely achieving a result. The development process was successfully employed in the development of superior design outcomes. Future research could further improve this process through the addition of more user-testing.

Evaluating Spatial Engagement Methods

Assessment of these tools is best done against the three stages of wayfinding. The established method allows assessment of these tools against the first stage of wayfinding. This provides researchers with a method for gaining insight into the non-visual spatial comprehension abilities provided by their design outcomes.

Line of Inquiry

The finalised line of inquiry itself is perhaps the most significant contribution of the research. The underlying justification of the project was the product of a meticulous investigation. The subsequent scope of the research was subject to substantial development due to the realisation of errors made in the conventional approaches and in the approach of the research. The resulting line of inquiry led an investigation into a field which generally sees very little attention from academia. However, through the results of the design investigation, it is proven as a valid area of research.

7.7 IMPLEMENTATION FRAMEWORK

One of the primary concerns throughout this research was whether the results were going to be applicable in real-world environments. This section describes various methods for real-world application for a design scheme of this nature. There are two viable options for this, UWB and SLAM technology.

Ultra-wideband technology (UWB) is a radio technology that can effectively transmit high-bandwidth communications at a short-range. UWB technology relies upon a combination of tracking sensors and tracking objects. The technology provides precise positional tracking, capable of measurements accurate to within 5-10cm. A combination of this technology with a virtual representation of space would allow for almost direct replication of the functions created within this thesis.

Simultaneous localisation and mapping (SLAM) is a computational process in which a virtual map of an environment is created, and the user-location is established within it. This form of tracking is commonly employed in augmented and virtual reality technologies, such as the Hololens, the Magic Leap and the OCULUS Quest. The virtual map created by these objects would allow for replication of most functions created within the thesis. There is potential that image and geometry recognition algorithms could be employed to establish object properties, which would allow for the near-direct application of the thesis content in a real-world context.

7.8 FUTURE RESEARCH

There are three paths forward for future research. The first path is to investigate the most fundamental concepts in this field of inquiry. While this thesis does provide some investigation into understanding how space may be engaged non-visually through a digital medium, there is a possibility for an investigation at a foundational level. Research at this level must firstly, attempt to define what information is most critical for this form of engagement (as examples: distance, object shape, room function), and secondly, must then investigate the best methods for the digital provision of this information.

The second path would involve re-investigating modes of digital interaction through the lens of more advanced digital technologies. The recent releases in the VR/AR market provide increases in play-space, computational power, and developer options. The research would require an exploratory approach, one of a similar manner to this thesis, searching for potential opportunities and then exploring them once they are established.

The final option for future research is an applied approach, which would take the outcomes of this research and assess them against the other aspects of wayfinding. While this thesis mainly addresses spatial comprehension, the first step of wayfinding, there is cause to assess the impacts that these outcomes have on decision making and decision execution (navigation). This research would provide significant insights as to how digital tools help the visually impaired engage with architecture in the real-world. As a general note, any work interested in the real-world implementation of design outcomes from this research would be well-served by visiting the discussion of Pawluk et al., (2015), who provide a comprehensive review of issues associated with the applied forms of this research.

7.9 CONCLUSION

This research explores methods of employing emerging digital technologies to facilitate the spatial engagement and understanding of the visually impaired. It recruited the native sensory opportunities and computational platform of these technologies in order to create methods of digital interaction with architecture and its component elements.

The built environment and the community responsible for its creation face a severe challenge in addressing the needs of the visually impaired. The existing accessible design solutions, while successful in rare instances, are insufficiently applied, challenging to apply correctly without experience, and are incapable of compensating for the vast amount of currently unsuitable spaces. Present-day technological solutions suffer from a different plethora of issues regarding the quality of the information provided, general effectiveness, and applicability throughout day-to-day scenarios. This thesis sought to employ these new digital technologies to negotiate between the two fields to outline superior solutions and opportunities for future use.

Early design investigations in the thesis sought to explore the plausibility of digital interaction. The capability for rapid development and freedom to explore outside of real-world restrictions led to a successful set of initial investigations. Critical reflection upon these outcomes revealed that more substantial questions could be investigated, ones that are largely ignored by the field. In response to this critique, the following stages explored two further research interests, how can digital technologies best engage with architecture, and what we can learn about digital-based spatial understanding from these engagements. The chapter interrogates the previous design material and establishes formal methods of development and evaluation of design results.

The outcomes of the project are the creation of multiple successful and unique forms of digital spatial interaction, an evaluative process, a formalised development process, and a refined line of inquiry for future research. These key contributions are a significant step into a lightly explored field. There is potential for further research to provide meaningful contributions to the lives of the visually impaired by assisting in the adaptation of our currently unsuitable built environment.

CODA 8.0

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8.2 APPENDIX

ResearchMaster

Human Ethics Application

Application ID :	0000028058
Application Title :	Methods for digital engagement with architecture.
Date of Submission :	N/A
Primary Investigator :	Mr Zach Cooper; Principal Investigator
Other Personnel :	Mr Tane Moleta; Supervisor

Research Form

Application Type

1.

IMPORTANT: Please select type of research below and click on 'Save' to access the rest of the form.

*

Research

Application Details

Category

B

3. Application ID

0000028058

5. Title of project
*(Click the ? icon for more info)**

Methods for digital engagement with architecture.

6. School or research centre*

Architecture

7. Personnel*

1	Given Name	Zach
	Surname	Cooper
	Full Name	Mr Zach Cooper
	AOU	Architecture
	Position	Principal Investigator
	Primary?	Yes

8. Are any of the researchers from outside Victoria?*

- ○ Yes
- ◉ No

9. Is the principal investigator a student?*

- ◉ Yes
- ○ No

Student Research

9a. What is your course code (e.g. ANTH 690)?*

ARCI593

9b. Supervisor*

1	Given Name	Tane
	Surname	Moleta
	Full Name	Mr Tane Moleta
	AOU	Architecture
	Position	Supervisor

9c. What is your email address? (this is needed in case the committee needs to contact you about this application)*

zwjcooper@gmail.com

Project Details

10. The following question is meant to help applicants consider their research application and any protocols that should be uploaded and to help committee members review the application. Please check the box if if your research:

- ☐ Is an anonymous questionnaire
- ☑ Uses tertiary students as participants
- ☐ Is a health or disability research project
- ☐ Includes Māori participants, or otherwise has an impact on Māori
- ☐ Includes participants from another significant cultural group, or has an impact on that group
- ☐ Uses highly sensitive information (see Policy for definition)
- ☐ Collects or uses human tissue, including blood, saliva and genetic material
- ☐ Uses noninvasive physiological procedures (e.g., EEG, heart rate monitor)
- ☐ Uses equipment (e.g., TMS) that may temporarily alter mental function
- ☐ Administers substances (e.g., food, alcohol, placebo pill) to be ingested by participants

11. Does this application relate to any previous applications submitted to an ethics committee?*

- ○ Yes
- ◉ No

12. Describe the aims and objectives of the project
Provide a brief summary in plain language of the purpose, research questions/hypothesis, and objectives of your project. *

This research explores how digital technologies (virtual reality, augmented reality and mixed reality) may be used to adapt existing environments to improve their accessibility for those with visual impairments. This thesis specifically engages with the use of augmented reality technology to provide alternative forms of spatial engagement and disseminate architectural information (distances, sizes, object types etc.) through nonsensory formats (haptic and audio cues).

Hypothesis: The use of digital technologies will provide a successful method to compensate for the existing deficiencies in the built environment as it pertains to those with lesser visual abilities.

Aims:
1. Establish a methodology to digitally/virtually augment existing environments
2. Develop a framework which provides a comprehensive non-visual spatial understanding
3. Outline a process by which the framework may be implemented at a large scale

Objectives:
1. Understand the practical and/or experiential requirements of those with vision loss.
2. Establish the limitations of existing solutions
3. Establish methods of disseminating information in a non-visual format through the use of digital tools.
4. Provide a range of various methods or tools for engaging with the environment.

13. Describe the benefits and scholarly value of the project
*Briefly place the project in perspective, explaining its significance and worthwhile outcomes. Include how this project will build on relevant literature, including references if appropriate.**

The primary aim of this research is to improve the relationship between vision impaired persons and the built environment. The increasing prevalence of vision loss and the lack of concern expressed in the built environment regarding this community poses a serious challenge to their health and well-being. Being able to understand the features of our surrounding environment is crucial for navigation. Visually impaired persons often find it more difficult to gather spatial information and must rely more on touch and sound to understand their surroundings. The study and creation of alternative non-visual tools to engage with architecture may have large implications for their success in navigating and functioning in the built environment, ideally alleviating social isolation and loss of autonomy that accompanies losses in visual acuity. This thesis draws upon the ongoing discussions of accessibility and inclusive design as well as the field of assistive technologies.

14. Explain any ethical issues your research raises for participants, yourself as the researcher, or wider communities and institutions, and how you will address these. This is an opportunity to present what you think the key risks are in your project and show how you have taken them into account.*

Consent: Before the user-testing (observation) and the following questionnaire are completed there will be an information sheet presented to users which outlines the nature of the test itself and what the following questionnaire will include. The intent of the project, purpose, motivation and the use of the data (publication formats and destruction) will also be explained prior. The participants will need to identify that they understand what the research entails and that they give their consent for them to partake in either part of the research.

Confidentiality: Confidentiality of the participants is of paramount importance. Participants personal information will not be asked for or recorded in the observation or questionnaire phases of the research. Email contact will be required to establish contact between myself and the potential participants. This email will be created for the purpose of this research and will be terminated alongside any correspondence with participants at the proposed date (45a. & 45b.).

Respect: The utmost respect for the participants will be required. Participants will be free to withdraw from the research at any time and will promptly have any data collected or personal information (email etc.) disposed of.

Key Dates

If approved, this application will cover this research project from the date of approval

15. Proposed start date for data collection*

10/11/2019

16. Proposed end date for data collection*

18/11/2019

17. Proposed end date for research project*

03/12/2019

Proposed source of funding and other ethical considerations

18. Indicate any sources of funding, including self-funding (tick all that apply)

Internally: by a University grant, such as the University Research Fund
Externally: funding from an external organisation for this project, or a scholarship awarded by an external organisation
Self-funded: paying for research costs such as travel, postage etc. from your own funds

- [ ] Internally funded
- [ ] Externally funded
- [x] Self-funded

19. Is any professional code of ethics to be followed?*

○ Yes
◉ No

20. Do you require ethical approval from any other organisation, such as another tertiary institution in New Zealand or overseas, or a District Health Board?*

○ Yes
◉ No

Data Collection and Recruitment

21. Please select all forms of data collection you will use in your project*

- [ ] Interviews
- [ ] Focus groups
- [ ] Questionnaires
- [x] Observation
- [ ] Other

22. Provide an explanation of the sampling rationale for your study.
E.g. representative sampling of a particular population, purposive sampling, convenience sampling. Include here your eligibility criteria for potential participants -- will there be particular criteria for participants to be included in your study, or criteria that will exclude them? *

The sampling rationale for this research will have no strict requirements. The only prerequisites are that the participants are willing to be included in the study and that they are comfortable independently travelling to the location in which the research will be conducted.

The research is merely intended to be a small pilot study from which further research may be recommended. Thus, the intent of the study is merely to establish the base successes and/or failures of the research design and to establish engagement with potential users. Due to these factors, very specific criteria for participants is not required.

23. How many participants will be involved in your research?
If there will be several different groups of participants, please specify how many groups and how many participants in each group. *

There will be four participants involved in the testing. These persons will partake in the research individually.

24. What are the characteristics of the people you will be recruiting?*

The only set characteristics for the participants is that they are over the age of 18 and are capable of travelling to the research location. While the thesis conclusions will pertain to visual impairment and the associated issues, the participants for this test will likely have near-standard visual acuity. It is rather commonplace for research of this type to use sighted participants to establish early success or failure and then conduct further research later with visually impaired participants (Pawluk, Adams, & Kitada, 2015). The use of sighted participants provides comparable results to those with visual impairments and requires less skill/experience from the researcher and carries a lower ethical risk (Pawluk, Adams, & Kitada, 2015).

Pawluk, D., Adams, R., & Kitada, R. (2015). Designing Haptic Assistive Technology for Individuals Who Are Blind or Visually Impaired. IEEE Transactions on Haptics, 8(3), 258–278.

25. Outline in detail the method(s) of recruitment you will use for participants in your study. *Include here how potential participants will be identified, who will contact them and how. Please include copies of all advertisements, online posts or recruitment emails in the 'Documents' section.* *

An A4 sized advertisement has been created which requests participants and outlines the details of the test (location, what is involved, contact info). This advertisement will be posted physically at the Te Aro and Kelburn campuses as well as on the appropriate Wellington related facebook pages (VicDeals for example). A separate email which only I will have access to will be created for the purpose of the organisation and correspondence with potential participants. This email, along with any emails sent and received shall be terminated once the research has been completed.

26. Explain the details of the method of data collection. For example, describe the location of your research procedures, if appropriate (e.g. where your interviews will take place). If necessary, upload a research protocol in the 'Documents' section.*

The location of the testing will be in the VASE lab room, WG2.03 within Te Aro Campus. Participants will be met in the atrium and taken to the room (it is difficult to find if one is not familiar with the school). The system uses HTC VIVE technology (only the controller, not the headset). Participants will be asked to read and sign the information sheets and consent forms and will have a chance to ask any questions that they may have. The research will ask users to explore the mixed-reality environment. This environment is created through the generation of virtual objects that have particular haptic and sound cues attached to them. These objects are spaced out within the Vase lab room. Users are free to move around in the space and use the controller to interact with the virtual items. The controller provides users with multiple different ways to interact with the objects, these can be either through direct contact with an object or from a form of virtual ranged engagement. These objects will then deliver feedback to the user through sound, haptics or a combination of the two. As this research is primarily concerned with participants understanding space through non-visual means, the users will not be using the headset and will not be able to see the items. They will only be able to perceive them through sound and touch. Observational notes will be taken and stored on a university computer. A research protocol has been uploaded which covers the details of the user-testing in depth.

27. Will your research project take place overseas?*

○ Yes
◉ No

28. Does the research involve any other situation which may put the researcher at risk of harm (e.g. gathering data in private homes)?*

○ Yes
◉ No

Participants and Informed Consent

29. Does your research target members of a vulnerable population?
*This includes, but is not limited to, children under the age of 16, people with significant mental illness, people with serious intellectual disability, prisoners, employees and students of a researcher, and people whose health, employment, citizenship or housing status is compromised. Vulnerability is a broad category and encompasses people who may lack the ability to consent freely or may be particularly susceptible to harm.**

○ Yes
◉ No

30. Have you undertaken any consultation with the groups from which you will be recruiting, regarding your method of recruitment, data collection, or your project more widely?*

○ Yes
◉ No

31. Will your participants receive any gifts/koha in return for participating?*

○ Yes
◉ No

32. Will your participants receive any compensation for participation (for instance, meals, transport, or reimbursement of expenses)?*

○ Yes
◉ No

33. How will informed consent be obtained? (tick all that apply to the research you are describing in this application)*

- [ ] Informed consent will be implied through voluntary participation (anonymous research only)
- [x] Informed consent will be obtained through a signed consent form
- [ ] Informed consent will be obtained by some other method

Treaty of Waitangi

How does your research conform to the University's Treaty of Waitangi Statute? (you can access the statute from Victoria's Treaty of Waitangi page)*

A key focus of this project is the idea of accessibility within the built environment for those with visual impairment. This focus strongly aligns with the Treaty of Waitangi principles of Whai wāhi (participation) and Rite tahi (Equality). Visual impairments disproportionately impact marginalised and disadvantaged communities who often lack the financial freedom to access the existing solutions (glasses, optometrists, contact lenses). A lack of accessibility to our built environment is shown to cause serious issues including anxiety and social isolation. Research which provides a viable approach regarding accessibility of our environment may aid in alleviating the disproportionate impacts. It is possible that the research may involve Māori participants however they are not specifically targeted for recruitment.

Minimisation of Harm

34. Is it possible that participants may experience any physical discomfort as a result of the research?*

○ Yes
◉ No

35. Is it possible that participants may experience any emotional or psychological discomfort as a result of the research? (E.g. asking participants to recall upsetting events, viewing disturbing imagery.)*

○ Yes
◉ No

36. Will your participants experience any deception as a result of the research?*

○ Yes
◉ No

37. Is any third party likely to experience any special hazard/risk including breach of privacy or release of commercially sensitive information? This may occur in the instance participants are asked to discuss identifiable third parties in the research.*

○ Yes
◉ No

38. Do you have any professional, personal, or financial relationship with prospective research participants? *

○ Yes
◉ No

39. What opportunity will participants have to review the information they provide? (tick all that apply)*

☐ Will be given a full transcript of their interview and given an opportunity to provide comments
☐ Will be given a full transcript of their interview and NOT given an opportunity to provide comments
☑ Will be given a summary of their interview
☐ Other opportunity
☐ Will not have an opportunity to review the information they provide

Confidentiality and Anonymity

40. Will participation in the research be anonymous?
*'Anonymous' means that the identity of the research participant is not known to anyone involved in the research, including researchers themselves. It is not possible for the researchers to identify whether the person took part in the research, or to subsequently identify people who took part (e.g., by recognising them in different settings by their appearance, or being able to identify them retrospectively by their appearance, or because of the distinctiveness of the information they were asked to provide).**

○ Yes
◉ No

41. Will participation in the research be confidential?
*Confidential means that those involved in the research are able to identify the participants but will not reveal their identity to anyone outside the research team. Researchers will also take reasonable precautions to ensure that participants' identities cannot be linked to their responses in the future.**

◉ Yes
○ No

41a. How will confidentiality be maintained in terms of access to the identifiable research data? (tick all that apply)*

☐ Access to the research will be restricted to the investigator
☑ Access to the research will be restricted to the investigator and their supervisor
☐ Focus groups will have confidentiality ground rules
☐ Transcribers will sign confidentiality forms
☐ Other

41b. How will confidentiality be maintained in terms of reporting of the data? (tick all that apply)*

☑ Pseudonyms will be used
☐ Data will be aggregated
☐ Participants will be referred to by role rather than by name
☐ Other

42. Will participation in the research be neither confidential nor anonymous, and participants will be identifiable in any outputs or publications relating to the research? *

○ Yes
◉ No

Access, storage, use, and disposal of data

43. Which of the following best describes the form in which data generated in your study will be stored during the study?
*See help text for guidance on these terms. Further info available on human ethics website**

○ Identifiable
○ Potentially identifiable
○ Partially de-identified
◉ De-identified
○ Anonymous
○ Other

8.2 Appendix - Coda

44. Which of the following best describes the form in which data generated in your study will be stored after the study is completed?
*See help text for guidance on these terms. Further info available on human ethics website**

- ○ Identifiable
- ○ Potentially identifiable
- ○ Partially de-identified
- ◉ De-identified
- ○ Anonymous
- ○ Other

45a. Proposed date for destruction of identifiable research data (i.e. the date when data will be de-identified and personal information on participants destroyed)

*

15/11/2019

45b. Proposed date for destruction of de-identified research data, including anonymous data

*

15/11/2019

46. Will any research data will be kept for longer than 5 years after the conclusion of the research?*

- ○ Yes
- ◉ No

47. Who will have access to identifiable, de-identified or anonymous data, both during and at the conclusion of the research?*

- ○ Access restricted to the researcher only (whoever is named as PI)
- ◉ Access restricted to researcher and their supervisor
- ○ Access restricted to researcher and immediate research team, e.g. co-investigators, assistants
- ○ Other

48. Are there any plans to re-use either identifiable, de-identified or anonymous data?*

- ○ Yes
- ◉ No

49. What procedures will be in place for the storage of, access to and disposal of data, both during and at the conclusion of the research? (Check all that apply)
Information regarding appropriate data storage is available on the human ethics website. Note that storing research data on USB drives is strongly discouraged for security reasons. *

- ☐ All hard copy material will be stored securely e.g. in a locked filing cabinet
- ☑ All electronic material will be held securely, e.g. only on University servers, password protected
- ☐ All hard copy material will be appropriately destroyed (e.g. shredded) on the dates given above
- ☑ All electronic data will be deleted on the dates given (ITS should be consulted on proper method)

Dissemination

50. How will you provide feedback to participants?*

A copy of the final report will be provided to participants via email if they wish.

51. How will results be reported and published? Indicate which of the following are appropriate. The proposed form of publications should be indicated to participants on the information sheet and/or consent form*

- ☐ Publication in academic or professional journals
- ☑ Dissemination at academic or professional conferences
- ☑ Availability of the research paper or thesis in the University Library and Institutional Repository
- ☐ Other

52. Is it likely that this research will generate commercialisable intellectual property?
*(Click the ? icon for more info)**

- ○ Yes
- ◉ No

Documents

53. Please upload any documents relating to this application. Sample documents are available on the Human Ethics web page.

Please ensure that your files are small enough to upload easily, and in formats which reviewers can easily download and review. To replace a document, click the tick in the column to the right of the document title. A green arrow will appear - click this arrow to upload a new document. To add a new document click on 'Add New Document', at top right of the documents window. Then enter the document name in the box that appears and click the green tick. A green arrow will appear to the right of the file name which allows you to upload the new file.

Please also collate all your documents into one PDF or Word file, and upload as a new document. This should be labelled as 'Combined Documents'.*

Description	Reference	Soft copy	Hard copy
Participant information sheet(s)	Information Sheet - R.pdf	✓	
Participant consent form(s)	Consent From.pdf	✓	
Combined Documents	Combined Documents.pdf	✓	
Mixed Reality Research Protocol	Mixed Reality experiment protocol.pdf	✓	
Recruitment Material	Recruitment Material.pdf	✓	

Amendment or extension request (available only for approved applications)

43. Are you applying for an extension, an amendment, or both?*

○ Extension

○ Amendment

○ Both an extension and an amendment

This question is not answered.

Please check that you have answered all mandatory questions and have saved the application before submitting your form. Any new or amended documents (e.g. Participant Information Sheet) to be added to your application should be emailed to ethicsadmin@vuw.ac.nz before submission. To submit your form, click on the Action tab and then click on Submit for review

44. Do you have a second amendment/extension request to make?

○ Yes

○ No

This question is not answered.

45. Do you have a third amendment/extension request to make?

○ Yes

○ No

This question is not answered.

46. Do you have a fourth amendment/extension request to make?

○ Yes

○ No

This question is not answered.

Date Reapproved

(For Admin Use Only)

This question is not answered.

Incident Reporting

Research teams must immediately advise the Human Ethics Committee if an adverse incident occurs in the course of their research project.

Adverse incidents are instances of potential or actual physical harm to participants or researchers; emotional harm or distress to participants or researchers; and any other unforeseen events that raise ethical issues.

A full incident report must be completed and emailed to ethicsadmin@vuw.ac.nz. You can download this form here (link to be added). After you have emailed the form, please complete the questions below, then click on the **Action** tab and click **Report Incident**

Do you have an incident to report?

☐ Yes

This question is not answered.

Please go to the **Action** tab and click on **Report Incident** to complete the process.

INFORMATION SHEET

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

Methods for digital engagement with architecture.

INFORMATION SHEET FOR PARTICIPANTS

You are invited to take part in this research. Please read this information before deciding whether or not to take part. If you decide to participate, thank you. If you decide not to participate, thank you for considering this request.

Who am I?

My name is Zachary Cooper and I am a Master student in Architecture at Victoria University of Wellington. This research project is work towards my Master's thesis project.

What is the aim of the project?

This research investigates how new virtual reality technologies can help us explore architecture through two of our non-visual senses, sound and touch. This project uses these new virtual reality technologies as a basis to design new ways of interacting with and understanding our environment. This is done through the use of a variety of audio cues and haptic feedback (vibrations). The project has been developed by the DARA Lab team (Digital Architecture Research Alliance), one of the Master of Architecture thesis streams at Victoria University. Your participation will provide valuable insight as to the strength and weaknesses of our virtual interaction tools. This project will provide information as to the potential for digital non-visual tools to help us understand our surrounding built environment. Understanding this potential will have large implications for our visually impaired and blind communities, who are forced to explore the environment through touch and sound every day and who may benefit from the use of these new virtual reality technologies. This research has been approved by the Victoria University of Wellington Human Ethics Committee 0000028058.

How can you help?

You have been invited to participate in order to gather public opinion as to the effectiveness of the developed virtual reality system. If you agree to take part you will be asked to use an augmented reality system operated with a controller, which will be provided for your use. This research will take place at the VASE Studio located with the Victoria University of Wellington's Te Aro campus. I will make notes of your use of the design system. The research will take 30 minutes. You can stop the user testing at any time by putting the controller down, without giving a reason. You can withdraw from the study by contacting me at any time before 18 November 2019. If you withdraw, the information you provided will be destroyed or returned to you.

1

WARNING - The use of virtual reality technology is noted to cause nausea in some participants. If you are prone to nausea or motion sickness, participation in this study should be avoided. If nausea arises at any point during the experiment, please stop the experiment, take a seat and notify the supervising researcher.

What will happen to the information you give?

This research is confidential. This means that the researcher named below will be aware of your identity but the research data will be combined and your identity will not be revealed in any reports, presentations, or public documentation.

Only my supervisors and I will access the notes of the user test. The material I collect will be kept securely and destroyed on the 19 November 2019.

What will the project produce?

The information from my research will be used in Master's thesis and presented at an academic conference.

If you accept this invitation, what are your rights as a research participant?

You do not have to accept this invitation if you don't want to. If you do decide to participate, you have the right to:

- stop the test at any time;
- withdraw from the study before 19 November 2019;
- ask any questions about the study at any time;
- be able to read the final report of this research by emailing the researcher to request a copy.

If you have any questions or problems, who can you contact?

If you have any questions, either now or in the future, please feel free to contact either:

Student:

Name: Zachary Cooper

University email address: zach.cooper@vuw.ac.nz

Supervisor:

Name: Tane Moleta

Role: Senior Lecturer in Interdisciplinary Digital Design

School: Faculty of Architecture

Phone: 04 4636205

Email: Tane.moleta@vuw.ac.nz

Human Ethics Committee information

If you have any concerns about the ethical conduct of the research you may contact the Victoria University HEC Convenor: Dr Judith Loveridge. Email hec@vuw.ac.nz or telephone +64-4-463 6028.

CONSENT SHEET

Methods for digital engagement with architecture.

CONSENT TO PARTICIPATE IN USER TESTING

This consent form will be held for 1 year.

Researcher: Zachary Cooper, School of Architecture, Victoria University of Wellington.

- I have read the Information Sheet and the project has been explained to me. My questions have been answered to my satisfaction. I understand that I can ask further questions at any time.
- I agree to take part in this user test.

I understand that:

- I may withdraw from this study at any point before 19 November 2019 and any information that I have provided will be returned to me or destroyed.
- The identifiable information I have provided will be destroyed on 19 November 2019.
- Any information I provide will be included in a final report but the observation notes kept confidential to the researcher and the supervisor.
- I understand that the results will be used for a Master's thesis and presented at a conference.
- My name will not be used in reports and utmost care will be taken not to disclose any information that would identify me.
- I would like to receive a copy of the final report and have added my email address below. Yes ☐ No ☐

Signature of participant: ________________________________

Name of participant: ________________________________

Date: ______________

Contact details: ________________________________

1

RESEARCH PROTOCOL

Mixed Reality experiment protocol

Methods for digital engagement with architecture.

Master Candidate: Zachary Cooper, Supervisors: Tane Moleta

1. Procedures

- The personnel of the project is Zachary Cooper and Tane Moleta (supervisor). I will be conducting the user testing. Tane Moleta will also be present during the testing.
- The research will use HTC VIVE controller. The VR headset will not be used for the test and thus the concerns regarding virtual reality headset induced nausea will not applicable.
- The research will be conducted within a test area (3m x 4.5m) in the VASE Studio (Wigan 2.03) located within the Te Aro campus. Participants will be met in the atrium and brought to the room as it may be difficult to find.
- The research will be conducted on a time within the data collection period (10/11/2019 – 18/11/2019). Participants will be free to select which date and time within this period that they wish to partake in the research.
- A participant will be able to interact with the augmented reality scheme for a maximum of 20 minutes. 10 minutes will be allocated for the reading and signing of the information sheet and consent form as well as the answering of any questions.
- Each participant will be tested separately from the others to ensure that confidentiality is retained
- No physiological measurements will be taken. I will take observational notes on a university computer, there will be no audio or video recording of participants.
- I will monitor the participant who is exploring in the test area and will guide the interaction. I will also provide monitoring to ensure that no bodily damage or property damage occurs.

2. Medical/Safety Plan

- I have the emergency medical number available (111). There are first aid medical supplies located on every floor of the Te Aro Campus and I am familiar with basic first aid processes.

3. Informed Consent

A written information sheet and consent document has been prepared which will be provided to the participant. These will both need to be read and the consent form will need to be signed. Before the signature is give, the participant will have to opportunity to ask questions or ask for clarification on any point of the form.

Participants will be notified before commencing the test that if they experience any discomfort or wish to leave that they may exit the research at any time and any identifiable information will be destroyed.

RECRUITMENT MATERIAL

DIGITAL ENGAGEMENT WITH ARCHITECTURE

WHAT?

Become a research participant for a Master of Architecture (Professional) thesis project which explores visual impairment and the accessibility of the built environment. As a particpant in this user-testing study you will be able to explore digital space through the senses, engaging with architecture through a range of haptic and audio cues.

WHERE?

The research will take place in the VASE lab, located within the Te Aro campus of the Victoria Univesity of Wellington. It will take no more than 30 minutes to complete.

WHEN?

The research will take place between the 10th of November and the 18th of November. The specific time and date will be chosen by the participant.

CONTACT:

If you are interested in participating or desire additional information please email: **researchvuw28058@gmail.com**

This research has been approved by Victoria University of Wellington Human Ethics Committee
Ethics application number: 0000028058