VISUAL TEA

EVES: Vision as Touch

by

Cameron Wells

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

Victoria University of Wellington
School of Architecture

2021

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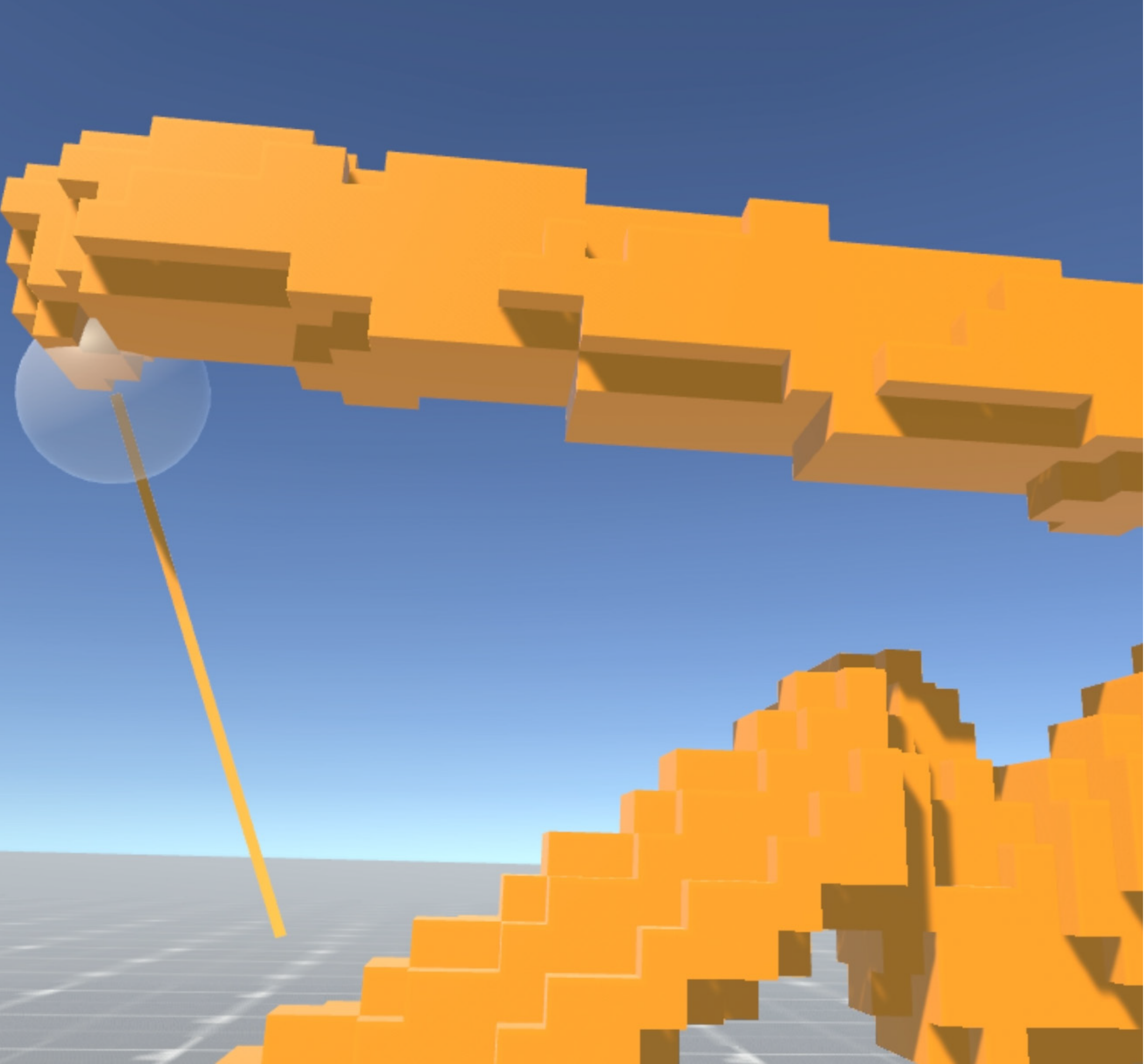

Figure 1:
Simple example of the voxel modelling environment as well as the Line Tool from EVES.

Acknowledgements

- I would like to thank my fantastic supervisors, ***Marc Aurel Schnabel, Tane Moleta, and Andre Brown,*** for their continual support over the year that this thesis and research took place. I am eternally grateful for their input, advice, and willingness to motivate me into new and exciting projects and opportunities throughout this research. Which, considering how many projects they did end up offering me to be apart of, it is a wonder that I managed to finish this thesis at all.
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Abstract

It could be said that the eye plays a relatively passive role in the creation of a design. Our fingers and hands are more capable of drawing, and our voice can be used to communicate our ideas or expressions. Our eyes, however, are a consuming function. They absorb light and allow us to understand, but they do not play an active role. This body of work aims to challenge this conception through a body of design research and self-testing.

By incorporating eye-tracking deeper within these methods, we can begin to discern this technology's possibilities as a method that encompasses the visual experience as an active input. This thesis is segmented into the two areas of eye-tracking utilisation within VR and the design process; passive and active. The passive investigations act as an intermediate phase to understand the extents of eye-tracking as a technology. In comparison, the active investigations act as the culmination and embodiment of this thesis as a whole.

The research will explore the Eye-tracking Voxel Environment Sculptor's (EVES) development that incorporates eye-tracking as an active design actor. Through the development of EVES, the extent to which eye-tracking can be implemented as an active design medium is investigated. The eye-tracking data garnered from the designer within EVES is directly utilised as an input within a modelling environment to manipulate and sculpt voxels. In addition to modelling input, eye-tracking is also explored in its usability in the Virtual Reality User Interface. Eye-tracking is implemented within EVES to this extent to test the limits and possibilities of eye-tracking and the Human-Computer Interface within the realm of Virtual Reality Aided Design.

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Presentation of Work

Parts of this project have been accepted and presented in multiple different conferences and exhibitions. They are listed below:

- Accepted into the 'PROJECTIONS', 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) in 2021.
    - Wells, C., Schnabel, M. A., Moleta, T., & Brown, A. (2021). BEAUTY IS IN THE EYE OF THE BEHOLDER. 10.
    - http://papers.cumincad.org/cgi-bin/works/paper/caadria2021_328
- Accepted into the 'Design Imperatives: The Future is Now', 19th International Conference CAAD Futures in 2021.
- The 'Passive' portion of the thesis was presented at the Forum8 Design Festival in Tokyo, Japan in 2020.
- Exhibited as apart of DARA's '*Geheimnis' exhibit at the Ars Electronica Festival via a Online VR exhibtion space hosted from Linz, Austria in 2020.

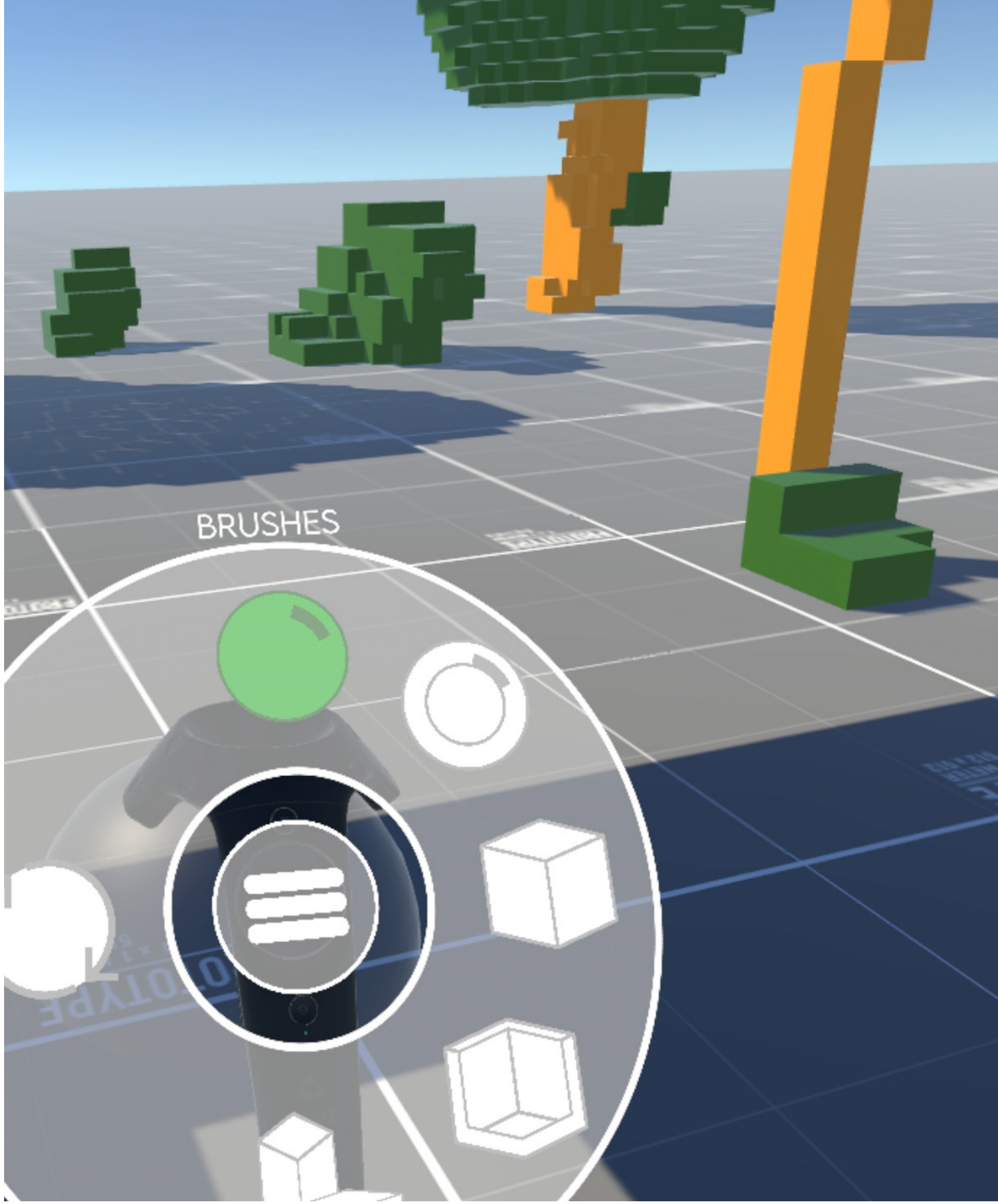


Figure 2:
Simple example of the User Interface in EVES.

1 INTRODUCTION

Chapter One:

Introduction

This section will establish the foundations for which the rest of this thesis and research is grounded in. Motivations, backgrounds, and the role of the research will all be discussed here.

Eye-tracking within the realm of art, architecture, and the broader context of design has typically been employed in a passive or investigative approach in the design process. Studies that objectively analyse how we perceive various types of information and how we build assessments of our surroundings (Lisińska-Kuśnierz & Krupa, 2020) discuss the traditional implementation of eye-tracking. However, little work has been undertaken to investigate architecture and three-dimensional space concerning eye-tracking technology as an active implementation. It is through the development of the design tool, EVES, that these ideas are explored.

To begin using active eye-tracking within architectural space, VR is deeply rooted within the core of this research. As noted by Carreiro and Pinto (2013), through VR, the visual representation of architecture can give a more robust understanding of space. Therefore, by combining these technologies, this research proposes that it is possible to improve and extend the Human-Computer Interface (HCI) within Virtual Reality Aided Design, or VRAD, as coined by Donath and Regenbrecht (1995).

> *"Architecture is basically the container of something. I hope they will not enjoy so much the teacup, but the tea."*
>
> \- Yoshio Taniguchi

1.2

Background

As with many aspects, this thesis's background is segmented into two parts that follow the passive and active utilisations of eye-tracking. The passive, or for that matter, any eye-tracking incorporation into architecture, VR, and Real-Time Virtual Environments (RTVE) is motivated by the awareness of how people visually understand spaces. The active utilisation is the same, albeit with an inverted design process. Rather than eye-tracking acting as a performance indicator for an existing environment, this sentiment is flipped on its head and looks towards the design environment as designed by visual inhabitation. This distinction is where the title of the thesis, Visual Tea, is generated. Taking inspiration from Yoshio Taniguchi's quote on architectural experience, the architectures and RTVE's are generated by a person's visual experiences within an environment.

This research is also deeply ingrained within the concepts of Human-Computer Interface (HCI). As the name suggests, HCI is the interface with which we interact and control what a computer or computer programs do. Early examples include Ivan Sutherland's Sketchpad in 1962 and the wildly more popular computer mouse invented by Douglas Engelbert in 1963 (MacKenzie, 2013). As an eventual evolution of these tools, VR and eye-tracking hold some exciting opportunities to expand the role of our senses within the HCI. Considering we experience architecture and environments with our senses, their literal incorporation into the design process spells out a more intimate relationship between experience and experiencer.

"As an eventual evolution of these tools, VR and eye-tracking hold some exciting opportunities to expand the role of our senses within HCI."

“How can the design of Architectural Spaces or Real-Time Virtual Environments be manipulated through the sense of vision?”

Question & Role of Research

“How can the design of Architectural Environments be manipulated through the sense of vision?”

This question explores the possibilities of how vision can supplement the design of architectural spaces and RTVE’s. The usage of vision regarding this question can have multiple meanings and is purposely left open-ended due to its unique proposition. Despite Jean-Paul Sartre’s critique of an ocularcentric[1] view of space, where Juhani Pallasmaa describes him to consider vision as a ‘medusian glance’ (1996), petrification of a visual experience can benefit the context of visual analysis. Understanding and quantifying visual activity within the design process can allow for an elevated awareness of how inhabitants visually exist within space. From this understanding, designers are then able to design accordingly.

While this method utilises eye-tracking via indirect/passive manipulation of environments and spaces, direct/active manipulation of spatial environments is yet to be tapped into as an area of research. This thesis aims to present the development of the EVES program/tool to respond to this particular interpretation of the proposed question. By utilising vision (and therefore eye-tracking) in this manner, we can both understand and explore how we experience and design spaces via how we visually inhabit them instead of how our bodies might.

[1]*Ocularcentrism:* A perceptual bias ranking vision over other senses (smell, touch, etc.) in Western Cultures.

1.4

Scope

The scope in which this research seeks to explore has a relatively broad initial phase that treads the waters of the ocean that is VR and eye-tracking. This vastness was deliberately done as the initial direction to take the idea of 'active vision' was ambiguous. In what way should eye-tracking be utilised with VR and the design process? How do you interpret the term 'active'? To what extent should a designer or user have over a vision-lead design?

As the research took place, answers to these questions weeded themselves out, but specific points of definition remained as beacons to guide the thesis's direction. At first, the idea of 'manipulating vision' took a bit of defining. Is manipulation the direct alteration of the gaze? Does a designed experience offer the space itself to dictate where and how a person visually occupies it? In the end, it was decided that it would be the inverse. Instead of the environment manipulating the vision, it would be the vision that manipulates the environment. This distinction then leads onto another central guidance point; there would not be any defined 'final design' at the end of the research. Instead, this final design would establish itself as a design tool in which designs can manifest.

1.5

Aim & Objectives

Aim
To allow a designer to digitally model and manipulate Architectural Environments by employing eye-tracking in a novel manner.

Objective 1:
Investigate current usages of eye-tracking within the architectural or creative fields that either uses it passively or actively.

Objective 2:
Explore the possibilities of methods that use eye-tracking somewhere in the design process that directly or indirectly assists in the manipulation of the Architectural Environment.

Objective 3:
Design, develop, and review a program or tool based on the exploration that manipulates the Architectural Environment.

2

PRECEDENT REVIEW

Chapter Two:

Precedent Review

This section will cover the essential precedents/projects that are paramount to this research and the development of EVES.

In accordance with Objective 1.

The investigation into relevant precedents to this thesis can be broken down into two parts. The first of these parts can be defined as 'Active Eye-Tracking Utilisations'. This section primarily focuses on artists and their works that incorporate eye-tracking in the active sense. The second part investigates specific projects and programs that incorporate VR design and display HCI traits in general. This section can be defined as 'VRAD Tools' and will mainly focus on these developed instruments and programs that have looked into the development and furthering of HCI and VRAD.

Eye-Tracking Utilisations **17.**

Active Vision 17.
Controlling Sound
with Eye Movement

Ezekiel & Fink 21.
2D Artisitic
Implementations

VRAD Tools **23.**

HoloSketch & DDDoolz 23.
Early VR Design

SculptVR, vSpline etc. 25.
Modern VR Design

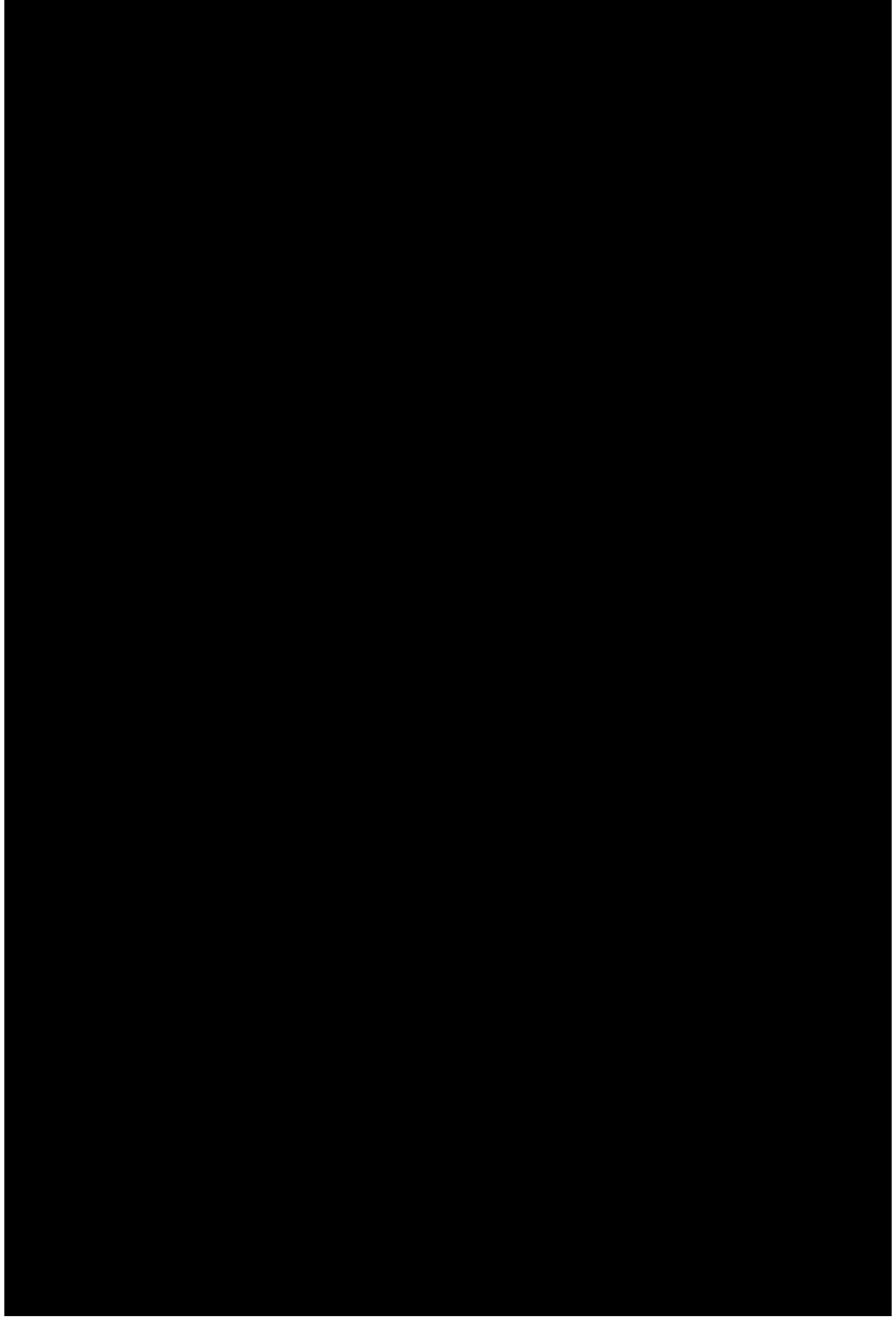


Figure 3:
Performing a muscial peice with the eye-tracker.

2.1

Active Vision

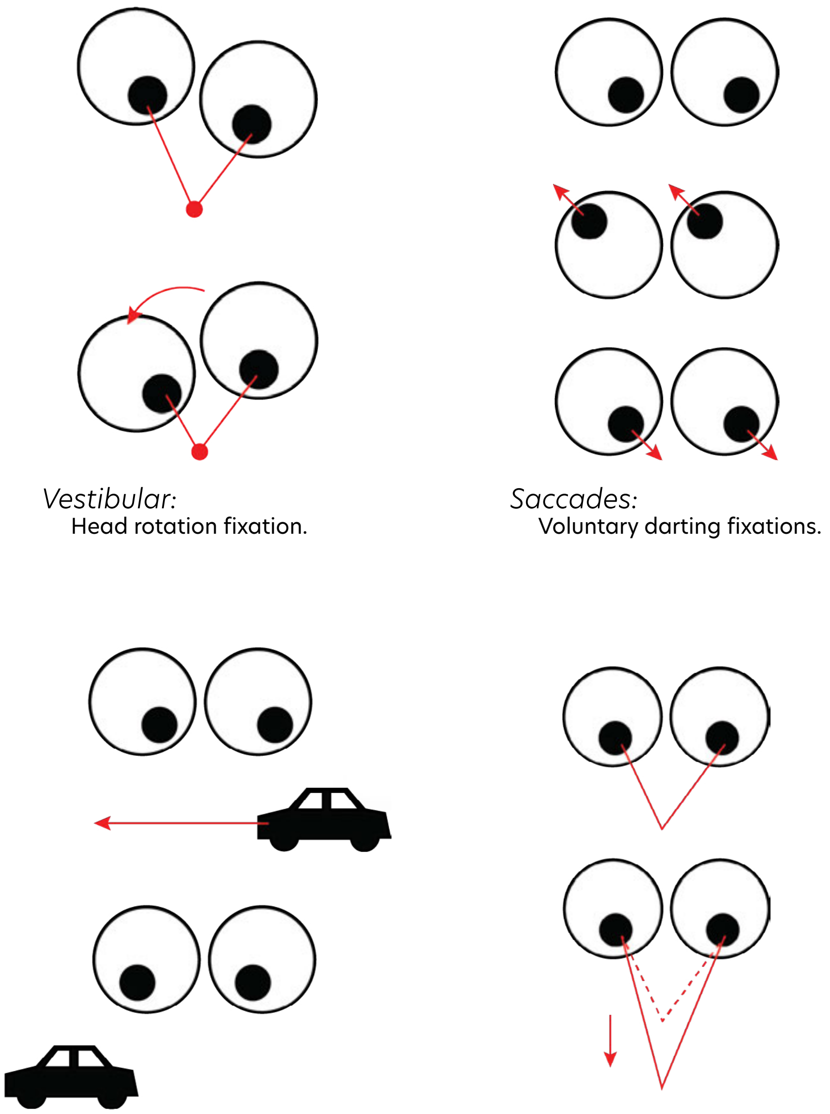
Although she discusses sound and music explorations with the idea of 'active' usage of eye-tracking, Andrea Polli's research into vision as a non-consummatory sense still informs the niche operations of how we can control our eyes in different ways. In her article, Polli documents the development of an instrumental program that allows one to control different notes or sounds via the eye's saccadic movements. The usage of the saccadic movement was deemed essential in the process of active vision as when referencing A.L. Yarbus's 1967 experiments on eye movements when looking at paintings, "... the eyes would repeatedly look at those elements that would seem to be most relevant to the paintings content" (Polli, 1999). In short, if the eye were focusing on the most critical aspects of a painting or instrumental interface, those would be the aspects of the piece of art that were the most visually important. Through this interpretation, in the case of Polli's work, the musical output would be that of the visual habits and not that of bodily habits that arise when playing traditional instruments.

Polli also notes the necessary simplicity of the interface that the performer was interacting with to generate music. By having a more complicated visual interface, the user tended to be more distracted by it instead of focusing on the musical output (Polli, 1999).

As mentioned before, while Polli's project has an overwhelming focus on musical and auditory creativity, the investigation into how we use our eyes in different ways is a crucial aspect of the thesis. Of note, how we interpret visual information such as through saccades is a vital aspect to consider.

This point is especially true when translating this information from a two-dimensional plane that Polli worked with into a three-dimensional one which this research explores. The other point to consider is the simplicity of the interface and modelling environments. As this research utilises only one sense compared to Polli's two senses, the minimalisation of complexity in the design process will assist in the developed tool's operability.

Figure 4:
Four types of Eye-Movements.



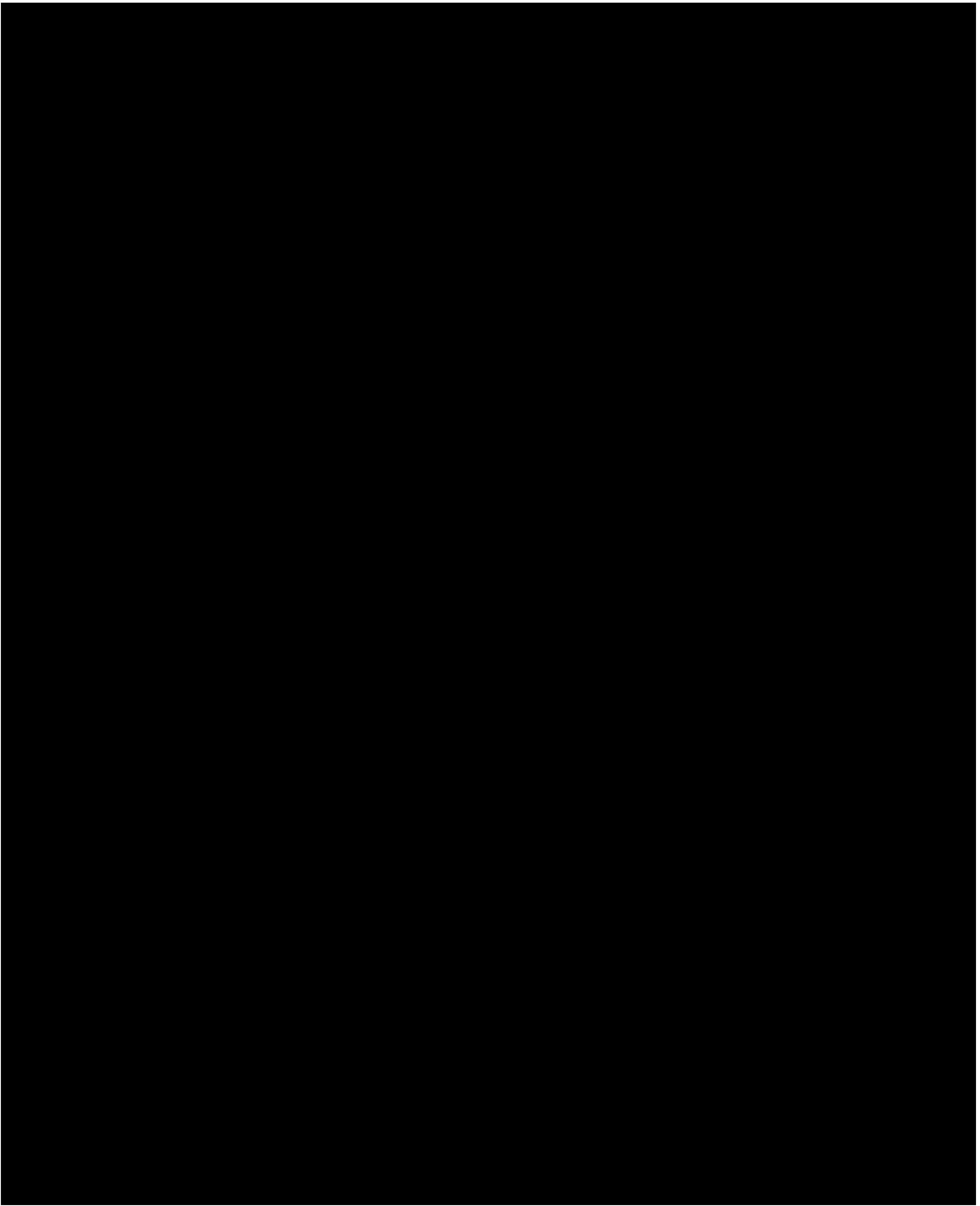
Vestibular: Head rotation fixation.

Saccades: Voluntary darting fixations.

Smooth Pursuit: Steady following of a moving object.

Vergence: Change of depth on fixation.

Figure 5:
'My Life of Brian' by Sarah Ezekiel.



2.2

Ezekiel & Fink

More directly related to this research topic, Sarah Ezekiel and Graham Fink's artworks are generated through their gaze and projected onto a two-dimensional canvas. Ezekiel, in particular, utilises this method of artistic expression because of the limited control of her body due to the effects of ALS (or Motor Neuron Disease) (Page, 2020). Interestingly, Ezekiel herself notes that her artworks' style has not changed that much from before her diagnosis. Instead, the advent and utilisation of eye-tracking has allowed her to continue to create and, in her own words, make her life worth living (Page, 2020).

On the other hand, Fink seized eye-tracking as an opportunity to express the connection "... from the subconscious, straight from the eyes and onto the canvas" (Fink, 2015). In his artworks, this eye-tracking application is distinctly apparent as it incorporates every little movement that the eye makes. Fink also mentions that the act of drawing with the eye takes practice, going onto say that controlling the movements of the eye would take considerable concentration to be able to do what he wanted (Fink, 2019).

Both Ezekiel and Fink use eye-tracking in an artistic way relatively similar to each other, though both present differing takeaways. Ezekiel displays eye-tracking potential to assist in the design process for people incapable of using traditional methods. Fink's interpretation of the medium is the visual involvement in which a designer experiences or understands the design process. While both artists consider the application of eye-tracking in their artworks in two dimensions (as opposed to three), these interpretations of the medium are significant.

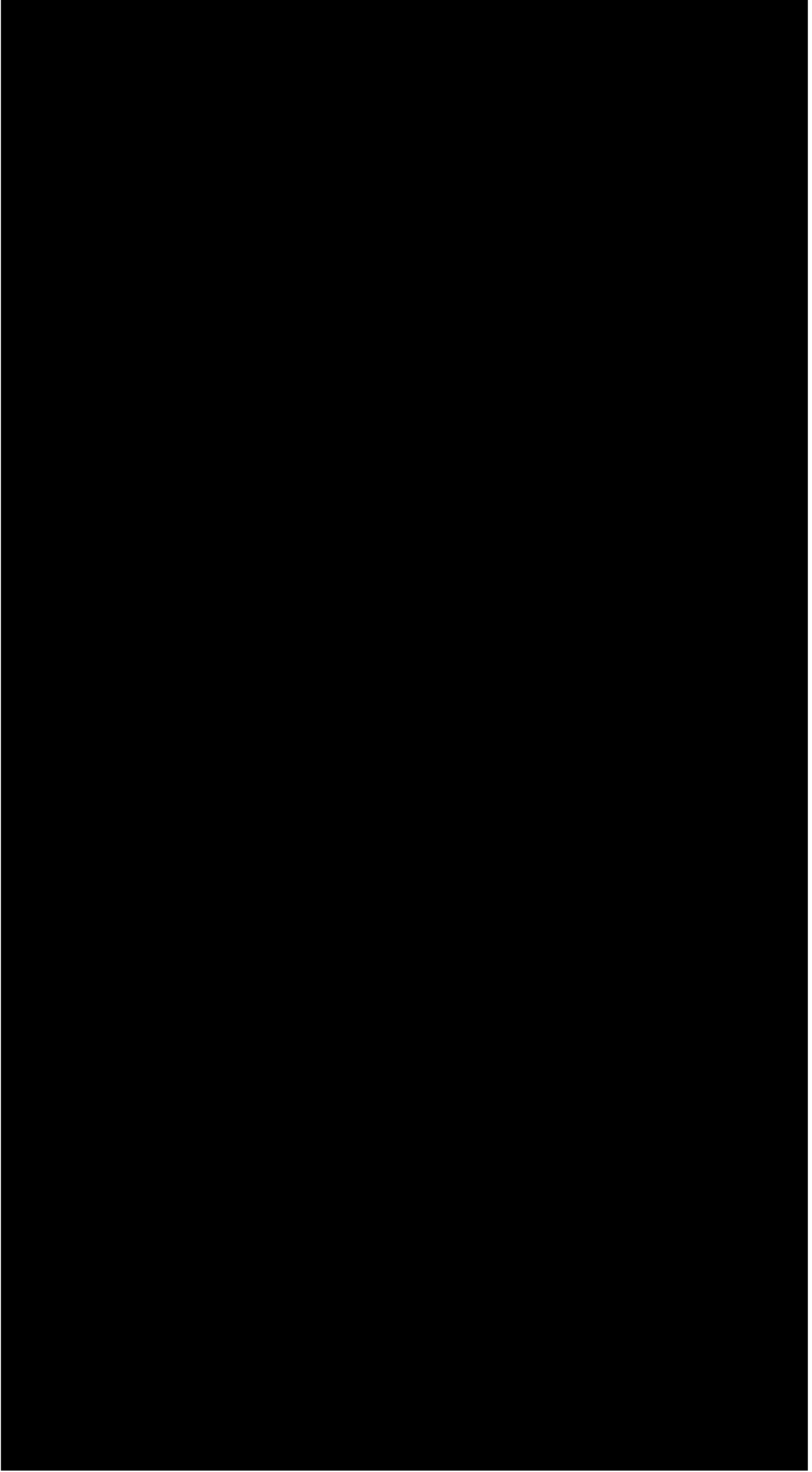


Figure 6:
HoloSketch Virtual Holographic Workstation.

HoloSketch & DDDoolz

Early VR programs like HoloSketch and DDDoolz have explored VRAD tools' usability through many different facets, such as HCI and modelling input. While they both approach the idea of designing in virtual reality differently, the explorations that they go through to improve the HCI is significant.

HoloSketch, while not following the more modern definition of VR (instead, it closely resembles Augmented Reality), uses a 'Virtual Holographic Workstation'. This station consists of a pair of "... head-tracked field sequential stereo shutter glasses ... and manipulates the virtual world through a hand-held six-axis mouse/wand" (Deering, 1995). Within this environment, a user can manipulate geometry primitives in various ways to construct and build more extensive and complex wholes.

DDDoolz showcases a voxel-based virtual modelling environment focusing on the early-stage architectural design (Achten et al., 2000). As described by Achten and de Vries, DDDoolz was envisioned as a method of 3D Painting as opposed to a more constructive modelling tool. Due to this distinction, the program was defined as having an ease of creation, minimal command-actions, and easy visual evaluation of the created model (2002).

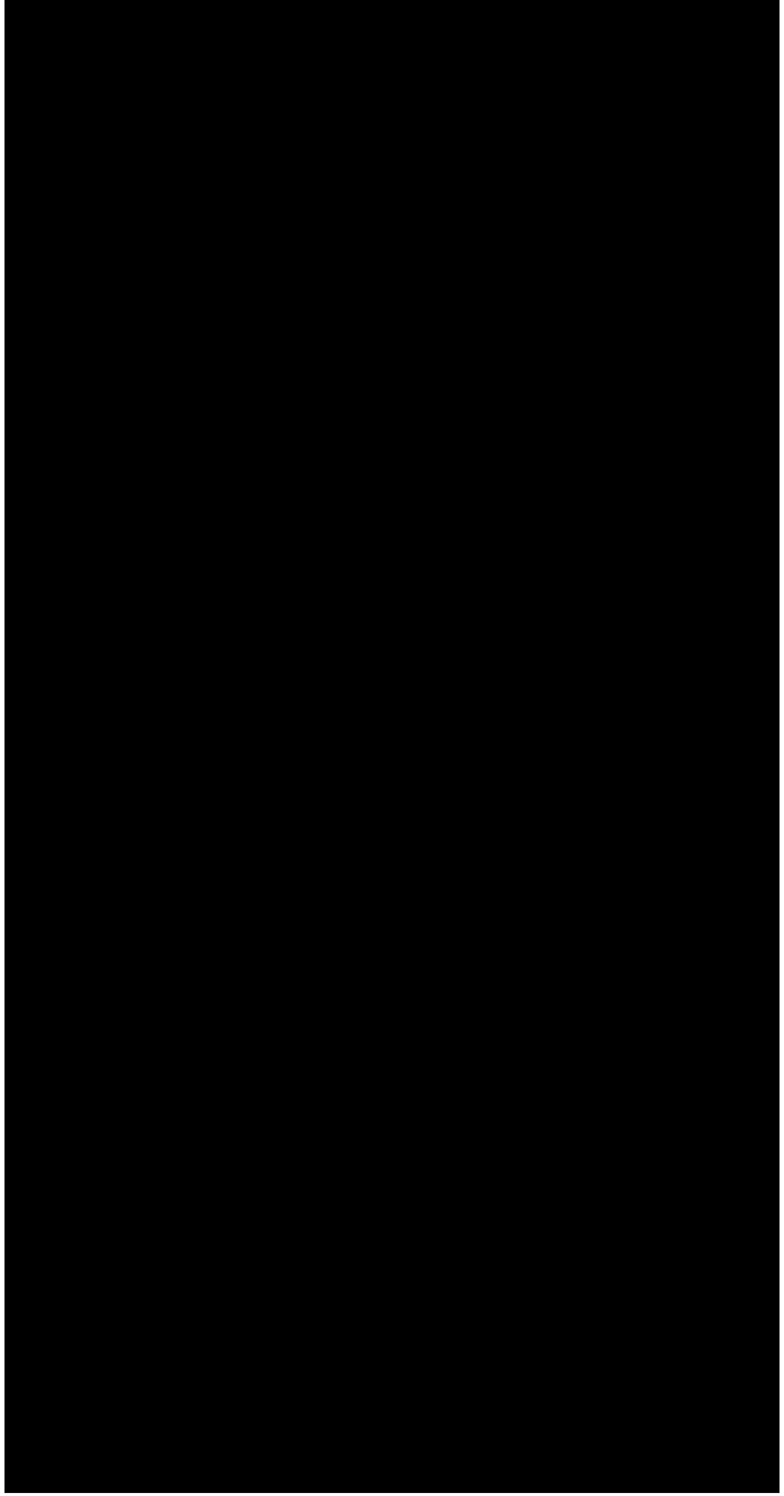


Figure 7: *TiltBrush Example Scene.*

2.4

SculptVR, vSpline & TiltBrush

More modern examples of VRAD tools such as SculptVR, vSpline, and Google's TiltBrush all carry on their predecessors' torch in their development by improving and enhancing the HCI. Each example has a relatively similar input, as they all utilise modern VR Head-Mounted Display's (HMD) such as HTC's Vive and the Oculus Rift. How they differ, though, is through their methods of modelling and the kinds of generated outputs.

SculptVR, in a way similar to DDDoolz, utilises adaptive voxel geometry as a medium to build and manipulate form. In doing so, they allow for relative levels of detail to be built at multiple scales. Being able to play with the scales and detail in this manner can allow users of multiple skill levels to use the program with ease. They allow more recent users a lower entry-level while also giving more experienced users a chance to stretch their creative wings.

Both vSpline and TiltBrush have similar roots in drawing within the third dimension in comparison to SculptVR. TiltBrush utilises a modelling technique whereby a user brushes with the controller to generate plane-like forms and primitives. vSpline, on the other hand, focuses on the ability to perceive the scale of models within VR, and from that, be able to 3D print them into reality (Arnowitz et al., 2017). Therefore, the modelling within vSpline consists of spline modelling (as per the name) which are modelled in a similar method to Tiltbrush - albeit within a more three-dimensional modelling typology.

[2]*Spline Modelling:* Modelling that utilises splines, which are curved lines within three-dimensional space.

3

EXPLORATION

Chapter Three:

Exploration

This section covers a myriad of aspects of EVES development, mainly centring around the design decisions and operability of both the Passive and Active stages.

In accordance with Objective 2.

Eye-Tracking

Passive	**Active**
'within' *the Design Process*	'as' *the Design Process*
Indirect Manipulation	*Direct Manipulation*
Analytical	*Artistic*
User Lead	*Designer Lead*
Assesses Existing Designs	*Creates New Designs*

The area of this section that covers the Passive utilisation of eye-tracking is an explanation and exploration into how eye-tracking be utilised within the design process. In other words, it is a more analytical and responsive approach. While the Passive stage informed later decisions within the Active stage and EVES development, very little is carried across regarding operability. This disconnect is because Active utilisation operates in an inherently different way as it utilises eye-tracking as the design process.

3.1

Development Domain

Through EVES's development, two leading eye-tracking hardware were used, the Tobii Eye-Tracker 4C and HTC's Vive Pro Eye.

The Tobii Eye-Tracker 4C is a monitor-mounted bar eye-tracker that gathers the users gaze data as they look at the screen. This particular eye-tracking method allowed for quick alterations and testing throughout the development and design cycle of EVES. This method's major downside is that it fell flat as an accurate measure of what it would be like to design with the eye due to the user's disconnect while looking at a screen while compared to VR.

HTC's Vive Pro Eye, on the other hand, has an eye-tracker entirely built into the VR HMD. This method closes the disconnection between the user and the computer as they are entirely enveloped in virtual reality.

All software elements have been developed within the Unity3D game engine.

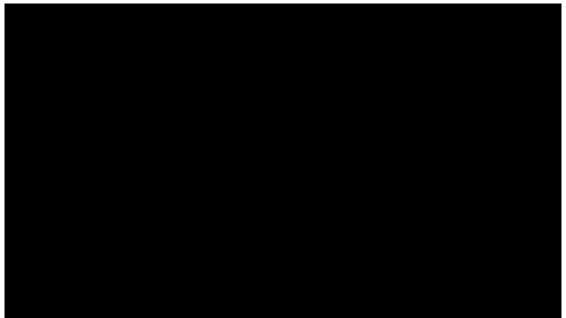


Figure 8:
HTC's Vive Pro Eye.

3.2

Passive

As explained previously, the Passive utilisation of eye-tracking focuses primarily on incorporating it 'within' the design process. In this sense, it is merely a step within the process used to confirm or critique spatial designs' visual experiences. The purpose of this method of implementation then lies with how a designer can interpret and purpose the outputted information to elevate the qualities of their designs that a user is experiencing.

In this step of the research, it was decided that there would be two phases: a Recording Phase and an Analysis Phase. As the name suggests, the Recording Phase records a particular user's experience within any given environment. Information such as what the user looked at, how long they looked, where they looked, and where they stood when looking can be recorded and saved. This information can then be baked into a heatmap which can be looked at and analysed within the - you guessed it - Analysis Phase.

As this distinction between the two phases was made pretty early on, the main point of interest in developing the Passive stage lay in how these phases would play out. What was eventually decided on was the incorporation of an Octree data structure. As this particular data structure is three-dimensional, its incorporation into a spatial analysis tool was ideal. An Octree, in essence, is a recursively subdividing structure whereby it is most simply visualised as a cube either finitely or infinitely subdividing into eight sections (known as leaves) to locate a particular point in space. In this research, these points in space are the places of the visual interest of the user. When the user's gaze ray intersects an object in the virtual environment, the Octree subdivides itself down at that position and records the time, object, and other relevant information.

By using this particular method of data storage, the generation of a heatmap is relatively easy. As the Octree is inherently a cube, a voxel can be generated at the final leaf position where a user has looked. Visual interest is visualised via a change in the voxel colour. Any other numerical or specific data is presented through a pop-up window when hovering over the voxels with the mouse.

Figure 9:
Octree Data Structure.

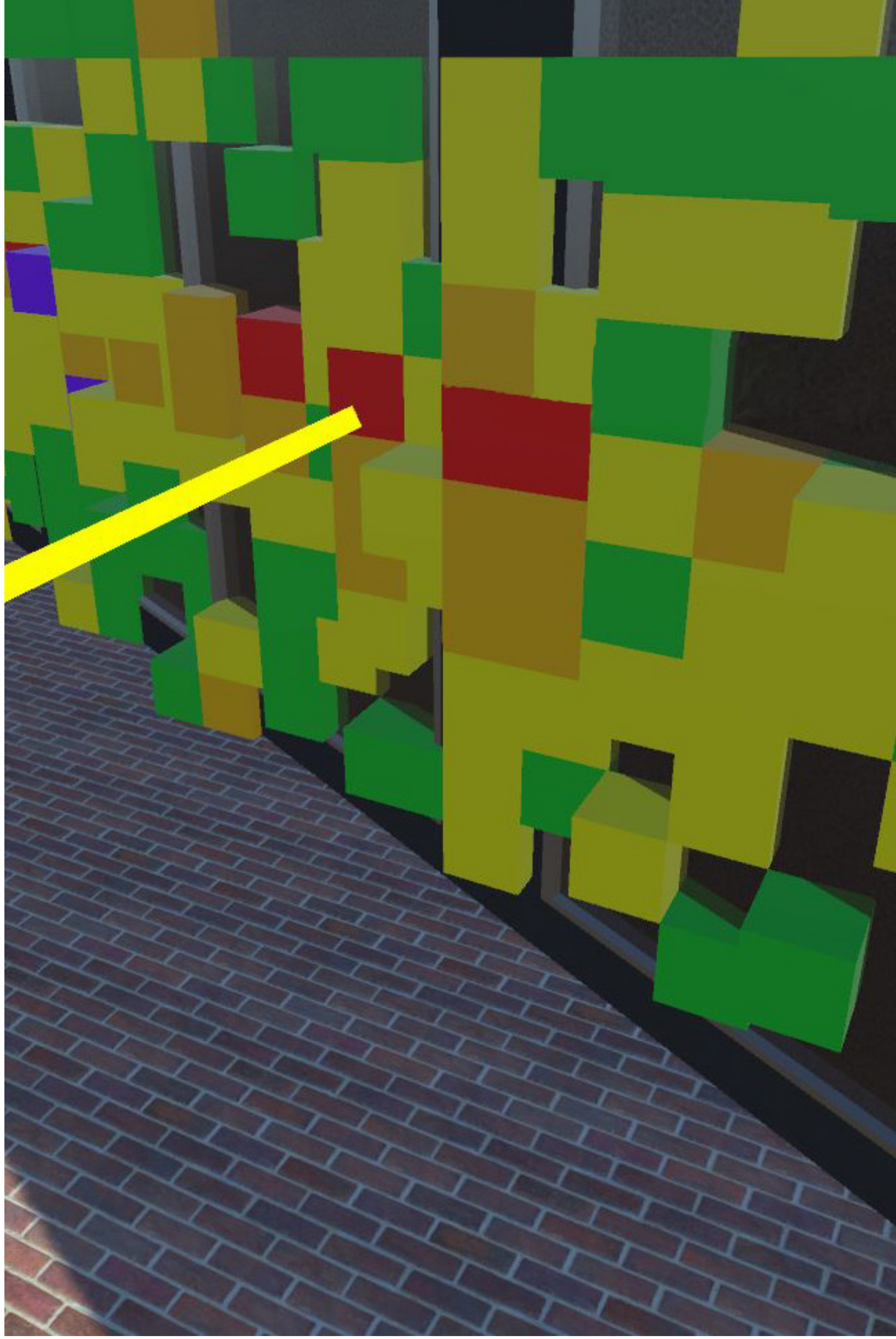


Figure 10:
An example of a generated voxel heatmap.

Active

Voxel Sculpting
At its core, the Active stage of EVES is essentially a voxel modelling tool controlled by the eye within VR. Voxels offer the opportunity for a user to sculpt in VR as they might clay with their hands. As informed by Polli's findings of visual simplicity within her program, this method allows for rough means of input without the user's overwhelming need to make precise modifications to their models. Further, despite their simplicity, voxels are capable of creating complex wholes due to their modular nature. Voxels can be generated and erased as well as modified via colour.

Other sculpting methods within the digital realm were also considered, such as marching cubes which rely on a similar underlying voxel-based system. The primary point of difference is that the generated meshes that form the modelled masses are algorithmically simplified based on surrounding voxel information. This generation method means that the forms' overall mesh loses its blockiness and is therefore much smoother. While this may seem moreso ideal over voxels considering their similar function, due to the simplification of the generated meshes, operation tends to require a certain precision level. This precision is needed when sculpting results in small meshes that are problematic to manipulate and often makes modelling difficult or tedious (see figure 11 for an example).

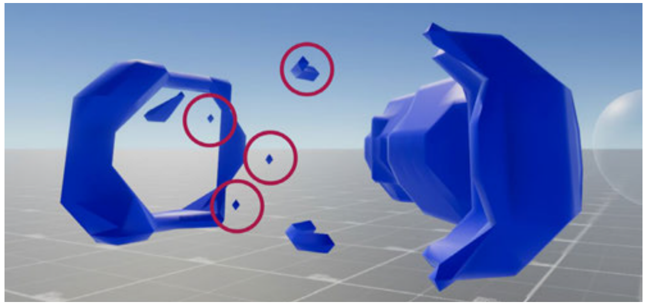


Figure 11:
Marching Cube small meshes.

Active Eye-Tracking and HCI
EVES utilises eye-tracking similarly to how both Ezekiel Fink draw with their eyes, albeit rather than on a 2-dimensional canvas, we present it within a three-dimensional VRAD environment. Within EVES, a ray is projected into the VR environment. This ray is informed by the gaze data from the eye-tracking hardware and is then utilised as the input method for the user to sculpt voxels and navigate the in-program menus. Wherever the user looks within the environment, a cursor follows to indicate where they will sculpt. This cursor takes the form of whatever brush they currently have selected, and by pressing the trigger on the controller, voxels are manipulated.

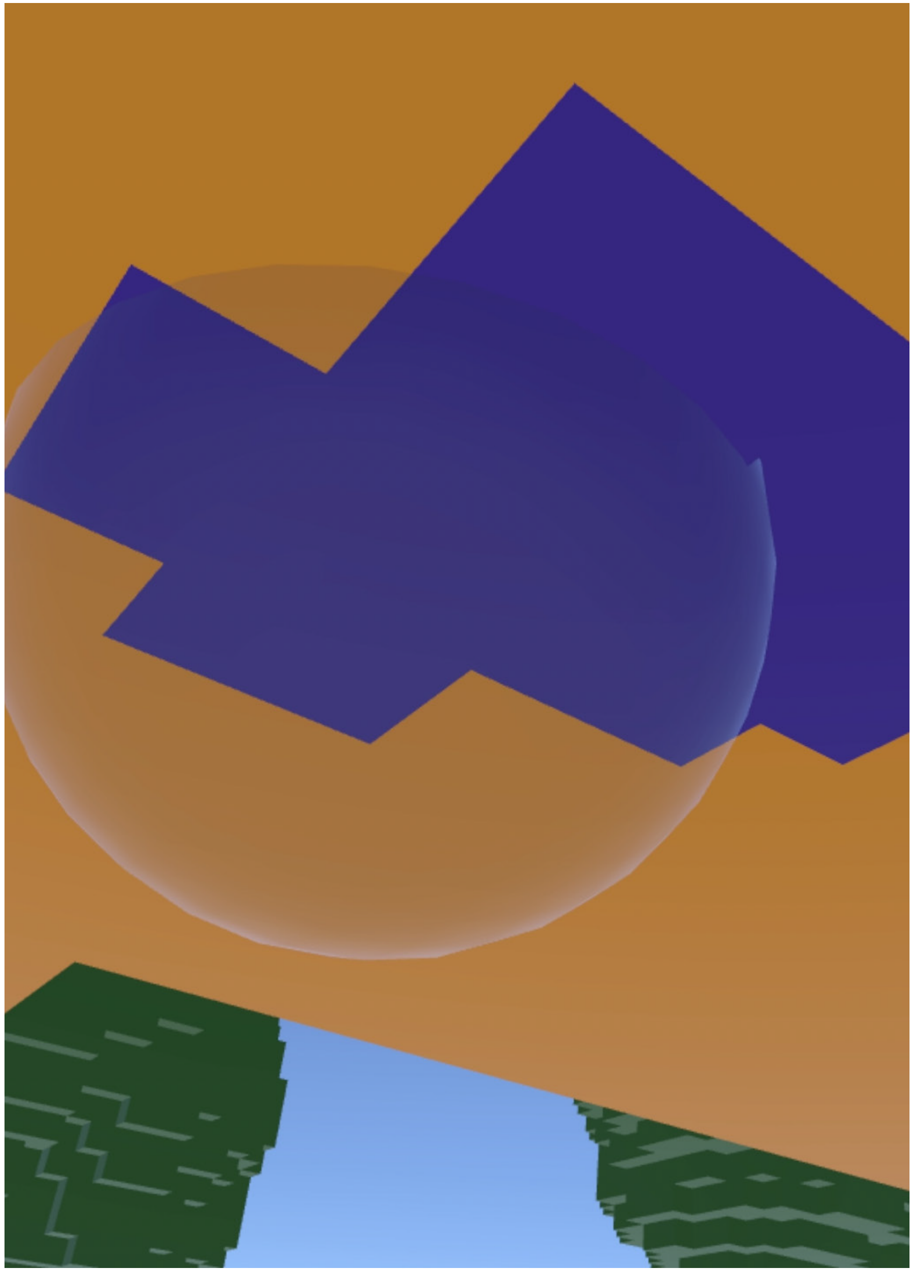
As previously mentioned, in addition to gaze data being utilised for direct sculpting input, it is also the primary VR User Interface (UI) navigation and tool/brush selection method. In EVES, the controller is used as an anchor point for the VR UI. When looking at the controller, a user can focus on any icon in the menus to select it. Indicators display whether the icon is being focused on or has been chosen. Interaction with the controller and the user's hand is limited as much as possible to allow for simple operation. With the hand-controlled interaction bound to the thumb, the user controls simple values such as brush size and distance. With this operation method, the user does not have to continually look back to the UI, reducing interruptions to the primary modelling input.

Brushes and Tools

Brushes and tools in EVES are simply the differing ways a user's gaze generates and manipulates voxels. While brushes act as the base shapes that voxels are generated in (such as spheres and boxes), tools alter how brushes act (such as single, line, and erasure). Both brushes and tools allow for various uses to generate forms and environments through simple inputs. Like the Hollow variants and MorphBox, other brushes grant the ability to generate more complex spatial forms with relative ease. MorphBox specifically allows for multiple uses in and of itself. Walls, rooves, floors, windows, columns, and more can be generated via a two-point input system whereby the user defines a box's extents by selecting two opposing corners.

Figure 12:
UI in EVES.
Left: Brushes, Middle: Tools, Right: Colour and Values

Figure 13:
Painting Tool in EVES.



4 PASSIVE EYE-TRACKING

Chapter Four:

Passive Eye-Tracking

This section covers the Outcomes and discussions about the Passive stage of EVES's development and it's potiential implications.

In accordance with Objective 3.

4.1

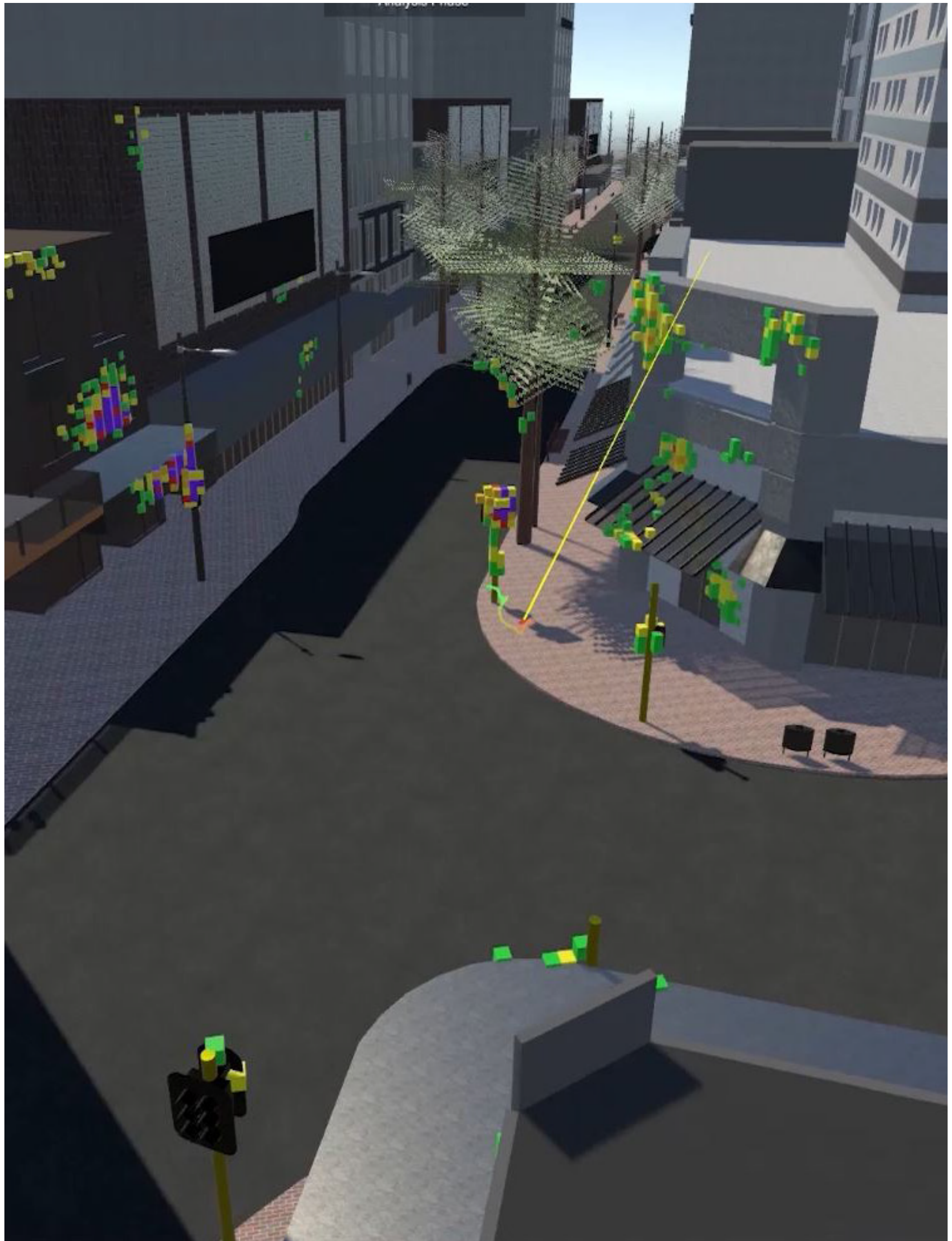
Outcomes

When eye-tracking is incorporated in the design process as a passive method, a designer can track the occupants' visual behaviours within any given space. By knowing what experiencers of space are visually drawn to, a designer can reliably validate and evaluate their behaviours within the architectural realm (Wang et al., 2019). It is through the Recording and Analysis Phases that these behaviours are reliably garnered in reliable data. Although this stage of EVES does not exactly print out a compendium of all the exact reasons why a person behaves a certain way in a particular situation, it does say that they behave in that way. In the Analysis Phase, a designer can then begin to curate the experience to particular behaviours shown through testing environments. This process acts as a method of confirmation or critique of a designer's designed space.

Notably, the utilisation of eye-tracking by passive means facilitates a connection between the designer and the potential occupants of the spaces they are designing through VR Mixed Reality (XR) tools. It allows a designer to intimately relate to a user to understand their space's exact performative qualities, rather than designing based entirely on theoretics and hoping for the best.

Through this program's development, the analysis into these points of visual interests, visual experiences, and behaviours that a particular environment was tested. This space took place at a city intersection of two roads – with plenty of distractions and hazards. Our visual attraction's precedence would tend to be for moving objects and

Figure 14:
Voxel Heatmap Generation.



colours and shapes that stood out from the rest of the scene. Cars, traffic lights, trees, and advertisements, for example, all tended to take up more visual interest than that of any architectural feature in particular. Although the scene favoured these aspects regarding its particular setting, the passive approach highlighted these visual experiences.

5

ACTIVE EYE-TRACKING

Chapter Five:

Active Eye-Tracking

This section covers the Outcomes and discussions about the Active stage of EVES's development and it's potiential implications.

In accordance with Objective 3.

5.1

Outcomes

When eye-tracking is incorporated in the design process as an active method, we can understand how we can use our VR/XR eyes and extend their capabilities within the virtual environment. The development of EVES investigated active eye-tracking in two ways: how the eye can influence a virtual experience via the control and navigation of the VR UI and how vision can shape and mould the space a user inhabits.

Controlling or navigating anything with the eyes, whether it be the VR UI or the act of sculpting voxels, tends to take a bit of practice. Our bodies often run on performative or procedural movements; in other words, on 'muscle memory' (Shusterman, 2011). Arguably, the act of looking and using our eyes would fall under this idea of effortless, spontaneous skill performance. However, shifting the eye's usage to manual control can offer a slightly steeper learning curve. For example, inputting the two points to draw a line, one would often be looking towards the following action before completing the previous one. This action would then cause the line to be generated in a way unintended by the user. In contrast, the VR UI operation tended to be the easiest obstacle to overcome, as it relied primarily on the user's existing muscle memory. Despite this, after learning how to control one's eyes, the operation of EVES became more fluid and streamlined.

Despite the eventual ability to control EVES, there remained a relative warping of perceived space and environments when modelling. These distortions would often manifest through the shape and scale of modelled architectures. In "Vision and

Touch", Rock and Harris discuss vision's influence over the sense of touch. This dominance over touch is present even if the eye is fed distorted images. Rock and Harris note on an observation by James J. Gibson whereby a subject runs their hand along a straight rod while looking through a prism. Despite the rod's linear form, the subject was said to have felt it as curved (1967). In this instance, the subject's vision overruled the touch of their hand, in contrast to reality. Tim Law et al. discuss a scalar distortion when designing within VR spaces whereby subjects would often be more precise yet less accurate. Often favouring the space to be much smaller (albeit more consistently) than it was when compared to other traditional sketching methods (2020).

In respect to EVES, vision and touch are inherently blended. Vision is the touch. Therefore, when considering the visual inconsistencies of designing within VR, such as those discussed by Law et al., it is not surprising that the user's perceived reality is modelled into a true-reality. EVES takes in the user's perceived shapes and scales and models them accordingly, not necessarily in the way that a user may initially consider to be accurate. Consequently, this creates the architectures and spaces that our eyes inhabit, not our bodies. The three dimensions of reality are translated into our minds as a two-dimensional plane and reinterpreted back into the third-dimension via EVES.

Through EVES's development, the program has allowed for the possibility for a user to utilise their eyes within the virtual realm to 'consume' and extend

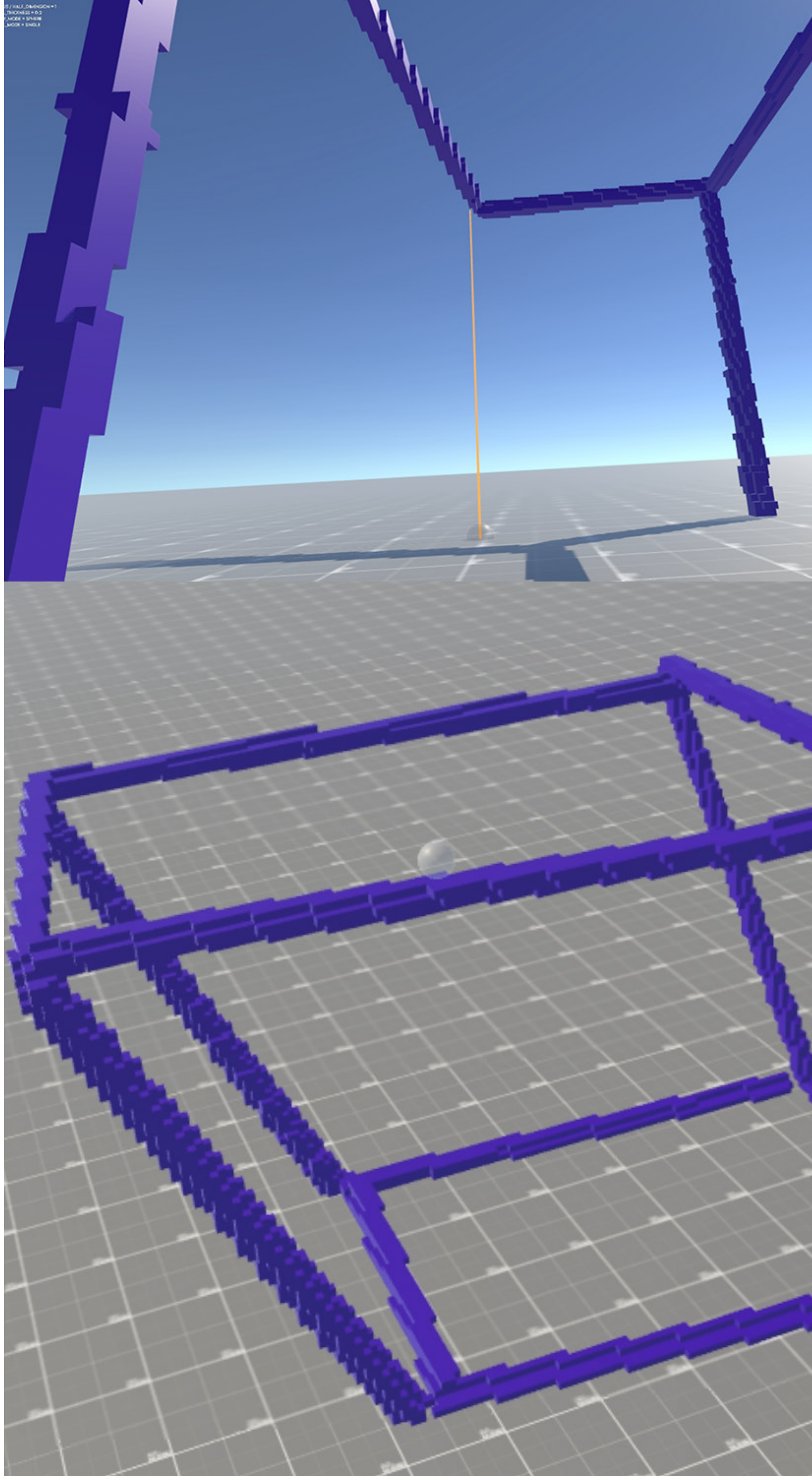


Figure 15:
Perspective warping of a cube outline.

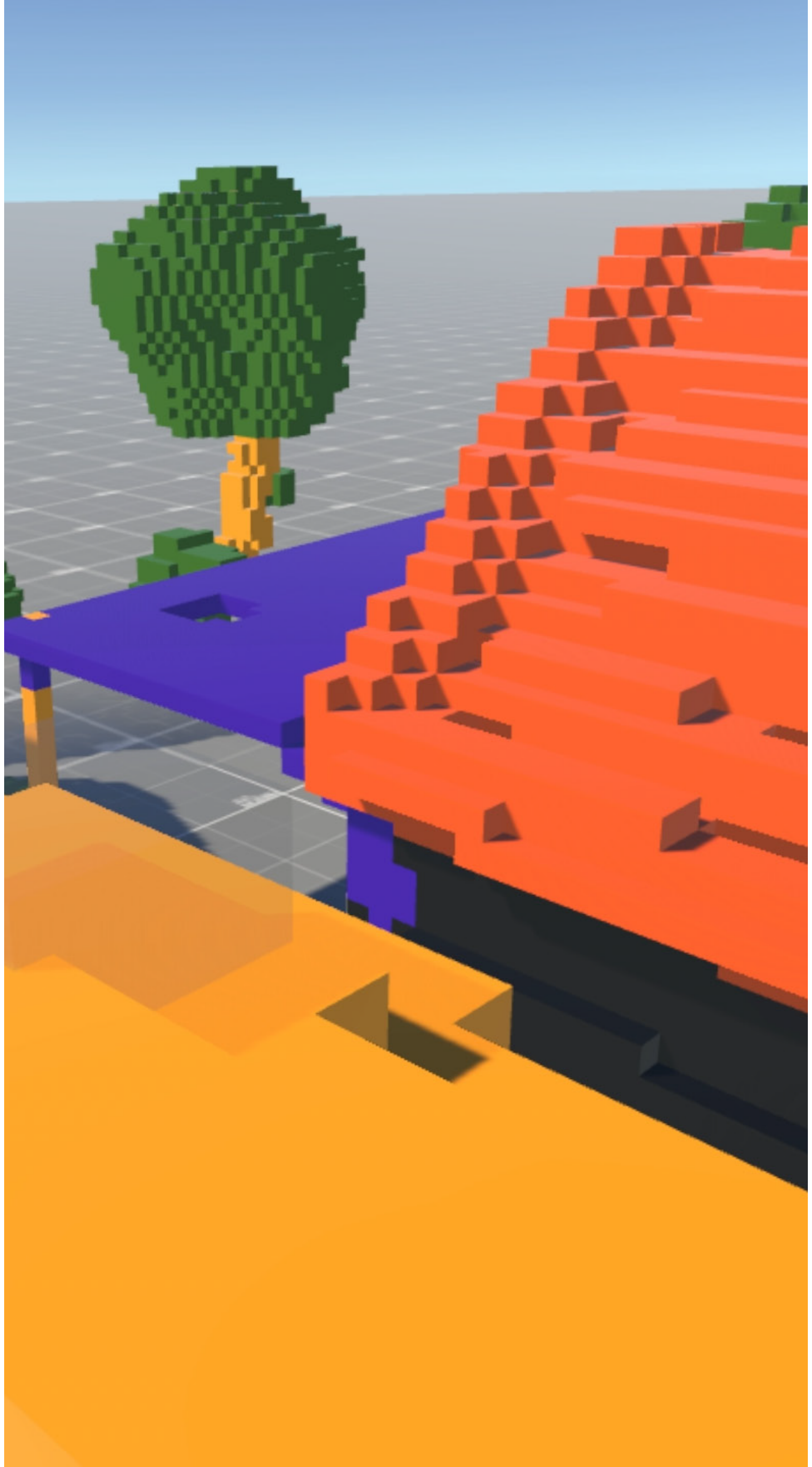


Figure 16: *Simple House and tree forms in EVES.*

its capabilities to 'generate' – a novel way to use one's senses. The HCI becomes more than just a person interacting with a computer and connecting and integrating with it (Schnabel and Chen, 2011). Through this integration with VR technologies, while these experiences tend to be visually focused, we can still explore new ways people and designers can interact with the digital world (Rogers et al., 2019).

6 CONCLUSIONS

Chapter Six:

Conclusions

This section covers the final conclusions and discussions for this thesis.

Visual Tea, and therefore EVES, is at its core the exploration of the creative possibilities of eye-tracking within virtual environments. Through passive and active means of implementation, the length and breadth of eye-tracking within a design or architectural context is investigated: first, the paper discusses eye-tracking as a tool that informs design and is treated as being 'within' the design process; second, eye-tracking treats gaze as an extension, and therefore 'as' the design process. By extending the employment of eye-tracking, we can further the interactions between human and computer. Both the navigation of VR UI and considering vision as touch are integral to the scope of active eye-tracking. Allowing a users eye to sculpt and manipulate form directly amplifies the capabilities of what our eyes can do, beyond that of which is possible within the everyday context. Our eyes are 'touching the untouchable' (Schnabel et al., 2008) and become active actors in the design generation.

5.1

Personal Reflection

My interest in coding and computational design was a combination of my love for video games and architecture. So what better way to integrate the two with a thesis topic such as this! Initially, the research started as an interest in understanding how people inhabit spaces and how we might computationally or parametrically design architectural spaces around those behaviours. The evolution from people's overall general behaviours in space such as movement, vision, sounds, and other personal senses and environmental conditions to that of a solely vision-based investigation rests in a somewhat petty but rather opportunistic reason.

As touched on in the body of this research, certain philosophers and spatial thinkers such as Jean-Paul Sartre have been described as being rather anti-vision or anti-ocularcentric (Pallasmaa, 1996). While I do not necessarily entirely disagree with his standpoint that we are sometimes too enthralled with vision, I think it is somewhat contradictory to disregard such a significant sense when considering spatial qualities altogether. This stance also brings us around to the other part of the reason for this research's rather ocularcentric nature - eye-tracking. Little had been done in the vein of the Active utilisation of the technology. Even then, though, nothing had been done in the realm of three-dimensional creativity and virtual environments and was an exciting prospect to push the HCI boundaries.

In this regard, I believe this research has been successful. I managed to allow the eye to directly model and manipulate a virtual environment and achieve what can be defined as active vision. While this written part of the thesis is relatively short, it is by no means the absolute or even majority of its content. That award goes to the EVES program that was developed as the core of this research. As much as I could write and theorise and explain what EVES does, how it performs, or what it is like, EVES speaks for itself (as cliché as that might sound). The best way to understand EVES is by jumping into the VR headset and experiencing it for yourself.

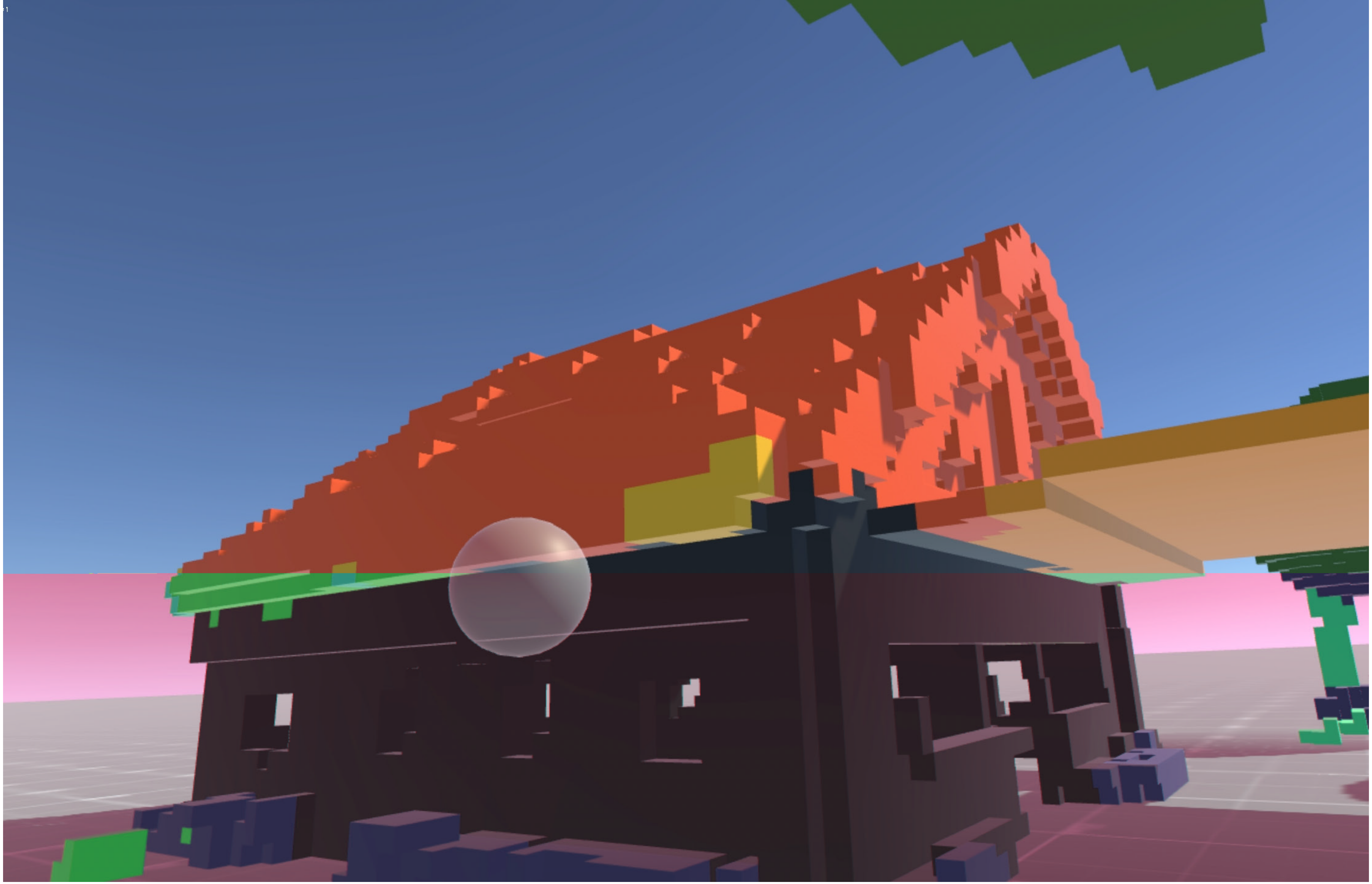


Figure 17:
House in EVES.

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This section covers the references to works, figure list, and additional content such as images and videos relating to this thesis.

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Figures

The figures listed here that do not include a citation will have been produced by the author. All other figures that have been gathered externally are cited.

Figure 1: Simple example of the voxel modelling environment as well as the Line Tool from EVES.

Figure 2: Simple example of the User Interface in EVES.

Figure 3: Polli, A. (1999). Performing with the eye tracking device [Photograph]. MIT Press Journals. https://www.mitpressjournals.org/doi/pdf/10.1162/002409499553479

Figure 4: Four types of Eye-Movements.

Figure 5: Ezekiel, S. (n.d.). My Life of Brian [Digital Painting]. The Nameless Gallery. https://www.thenamelessgallery.com/sarah-ezekiel

Figure 6: Deering, M. (1996). Desktop virtual reality display system, with head tracked stereo glasses and 3D mouse/wand. [Photograph]. ACM Digital Library. https://dl.acm.org/doi/10.1145/229459.229466

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Figure 8: Vive. (n.d.). Vive Pro Eye [Image]. Vive. https://www.vive.com/media/filer_public/newsroom/pro-eye.png

Figure 9: Apple. (n.d.). Spatial and logical arrangement of an example octree [Image]. Apple Developer. https://developer.apple.com/documentation/gameplaykit/gkoctree

Figure 10: An example of a generated voxel heatmap.

Figure 11: Marching Cube small meshes.

Figure 12: UI in EVES.
Left: Brushes, Middle: Tools, Right: Colour and Values

Figure 13: Painting Tool in EVES.

Figure 14: Voxel Heatmap Generation.

Figure 15: Perspective warping of a cube outline.

Figure 16: Simple House and tree forms in EVES.

Figure 17: House in EVES.

Videos

Video 1:

Example of using EVES pt.1

Video 2:

Example of using EVES pt.2

Video 3:

Example of using EVES pt.3