BEAUTY IS IN THE EYE OF THE BEHOLDER

Improving the Human-Computer Interface within VRAD by the active and two-way employment of our visual senses

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Abstract. Whether it is via traditional methods with pen and paper or contemporary techniques such as 3D digital modelling and VR drawing, the eye typically plays a mostly passive or consuming role within the design process. 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. Our research, however, developed the Eye-Tracking Voxel Environment Sculptor (EVES) that incorporates eye-tracking as there design actor. Through EVES we can extend eye-tracking as an active design medium. 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.

Keywords. Human-Computer Interface (HCI); Eye-Tracking; Virtual Reality; modelling; sketching.

1. Introduction

Eye-tracking within the realm of art, architecture, and the broader context of design has typically taken the passive or investigative approach to implementation within the design process. Studies that objectively analyse how we as humans perceive various types of information and how we build assessments of our surroundings (Lisińska-Kuśnierz and Krupa 2020) discuss the traditional implementation of eye-tracking. However, little has been investigated in the domain of using eye-tracking technology and three-dimensional space concerning eye-tracking technology as an active implementation. Through the development of the design tool, the *Eye-Tracking Voxel Environment Sculptor* (EVES) will explore these ideas.

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To begin using active eye-tracking within architectural space, Virtual Reality (VR) is deeply rooted within the core of our research. As noted by Carreiro and Pinto, through VR, the visual representation of architecture can have more robust understandings of virtual spaces (2013). Therefore, by combining these technologies, we can begin to improve and extend the Human-Computer Interface (HCI) within Virtual Reality Aided Design, or VRAD as presented by Donath and Regenbrecht (1995).

1.1. EYE-TRACKING VOXEL ENVIRONMENT SCULPTER (EVES)

Our investigation into the implementations of eye-tracking within VR environments began initially with the generation of 'gaze heatmaps', sitting firmly *within* the design process. By analysing where, when, and what a person is looking at within any particular environment, a designer can make design decisions accordingly. To continue to push eye-tracking to its limits, the development of EVES began to display eye-trackings potential to act as the design process.

EVES is a VR design tool that utilises eye-tracking as the input for a voxel-based modelling environment. The voxels allow for ease of sculpting and simplify the use of EVES as much as possible to allow users to learn how to use it quickly. Implementation of eye-tracking has been utilised within EVES as much as possible to understand its capabilities. In addition to the modelling input being controlled by the users‘ gaze, so is tool/brush selection and User Interface (UI) navigation. In general, bar some other features such as slight head and hand movements, EVES is controlled primarily via the users' gaze data (Figure 1).

Figure 1. Using EVES with HTC's Vive Pro Eye.

1.2. PRECEDENTS

The development of EVES can be broken down into two parts. The active use of eye-tracking and EVES's essence as a VR Design Tool. As such, these categories form the outline for which EVES takes a reference. The first part focuses more so on artists and their works which have experimented with Active Eye-Tracking before. In contrast, the VR Design Tools section explores existing instruments that share HCI traits and other operational similarities to EVES.

1.2.1. Active Eye-Tracking

In *"Active Vision: Controlling Sound with Eye Movement"*, Andrea Polli explores the use of active eye-tracking within music and notes on her ability to "control her eye in a very precise way to create specific sounds" (1999). She exemplifies humans' ability to utilise their eyes in a non-consummatory manner (despite the differences between auditory and visual art) by shifting the traditional method of melodic input from mouth and hand to that of the gaze. Behnaz Farahi explores the usage of this idea of active vision through her project Caress of the Gaze, whereby eye-tracking is implemented to manipulate a garment worn by a person whenever an observer looks at it (2016).

In the realm of drawing, artists Graham Fink and Sarah Ezekiel have both utilised eye-tracking as a direct method of input onto a digital canvas. While Fink explores the medium as an opportunity for 'purer' artistic expression directly from the subconscious to the canvas (Leander 2015), Ezekiel's exploration comes from that of necessity. Ezekiel is diagnosed with ALS (otherwise known as Motor Neuron Disease), which severely inhibits her ability to use her arms and body (Page 2020). While these technologies allow for increased interaction between human and computer, they also open gateways for those disadvantaged with disabilities.

1.2.2. Virtual Reality Aided Design (VRAD) Tools

The concepts behind VRAD and their supporting technologies greatly influence the field of architecture, design, and construction (Schnabel, 2009). Early VR programs like *HoloSketch* and *DDDoolz* have explored the usability of design tools through many different facets, such as HCI and modelling input. More recent examples like those of *SculptVR, Tilt Brush* and *Gravity Sketch* also explore a varying degree of different means of modelling and designing within virtual environments.

HoloSketch, while not utilising a Head-Mounted Display (HMD) like more modern examples of VR, explores the ability to interact and design with virtual 3D objects in front of a user. Through the use of a 'wand', these forms are visualised on a screen (Deering, 1995). *DDDoolz,* while similarly limited in comparison to modern VR technology, also investigated the applicability of VR within early design stages through the use of voxel-like massings (Achten, et al, 2000). Concerning more modern implementations of VR design tools, *SculptVR* takes a similar approach to modelling as DDDoolz with its integration of voxel and marching cubes. Other recent VR programs have different techniques such as *Tilt Brush's* planar stroke-based modelling and *Gravity Sketch's* NURBS-based modelling (Arnowitz et al. 2017).

1.3. DEVELOPMENT ENVIRONMENT

Through EVES 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. HTC's Vive Pro Eye, on the other hand, is an entirely in-built eye-tracker within the VR HMD. All things software has been developed within the *Unity3D* game engine.

2. Eye-Tracking 'Within' the Design Process (Passive)

This section of the research covers a brief explanation of developing a program that investigates the passive usage of eye-tracking within the design process. While not intrinsically related to EVES development, it is still a necessary step in the exploration of eye-tracking within VRAD.

2.1. EYE-TRACKING VIA VOXEL HEATMAP GENERATION

The intermediary program that was developed in this first stage of the research consists of two phases: i) the Recording Phase and ii) the Analysis Phase.

The Recording Phase involves a user or client to experiencing a space or environment within VR. During this time, the program gathers and stores their visual experience within an Octree data-structure. Almost everything is recorded, from where, when what and when, to how long a user looks at objects within the environment. The Analysis Phase then utilises this data recorded within the Recording Phase to generate a 3-dimensional voxel heatmap of the users' visual experience (Figure 2). In this phase, the user or designer can freely move around the environment to analyse the generated heatmap. Information about where and how long a user has looked at particular places is visualised as the heatmap. Information such as what is being looked at (along with other specifics) is displayed by hovering over individual voxels.

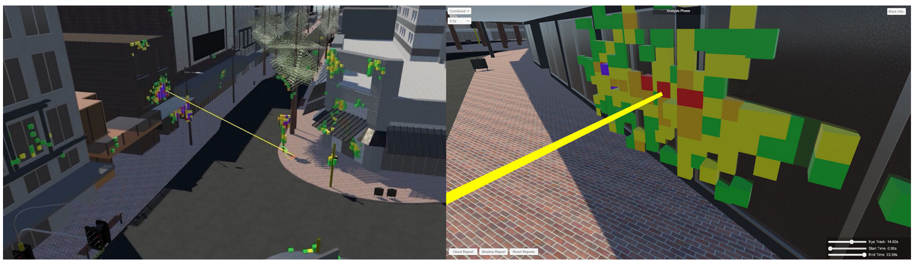

Figure 2. Within the "Analysis Phase" - displaying voxels and direct gaze rays.

3. Eye-Tracking 'As' the Design Process (Active)

This section of the research covers the development of EVES, which investigates the active usage of eye-tracking through VRAD. In this section, in-depth explanations of the operation and workings of EVES will be discussed and fleshed out.

3.1. VOXEL SCULPTING

At its core, EVES is essentially a voxel modelling tool that is controlled by the eye within VR. Voxels offer the opportunity for a user to sculpt as they might clay with their hands. 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 (Figure 3)

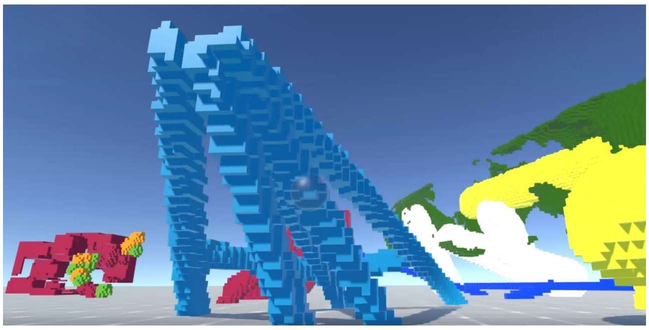

Figure 3. Voxels in EVES.

Other sculpting methods within the digital realm were also considered, such as marching cubes. Although marching cubes essentially work in the same way as voxels and boast smoother forms, it often requires a certain amount of precision from the user. This precision is needed when sculpting results in small meshes that would be problematic to manipulate and often make modelling difficult and tedious (Figure 4).

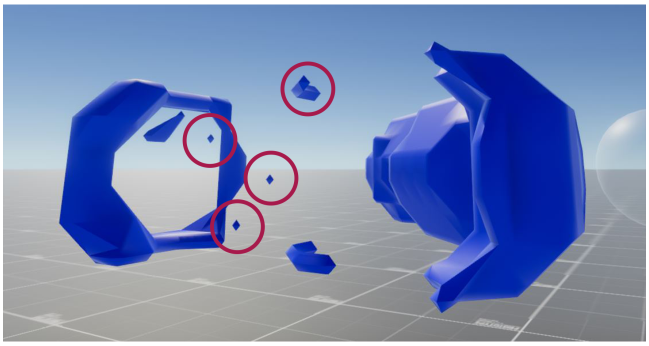

Figure 4. Marching Cubes in EVES with small tedious meshes.

3.2. METHODS OF INPUT

3.2.1. Active Eye-Tracking and HCI

EVES utilises eye-tracking in a very similar way to how both Fink and Ezekiel draw with their eyes, albeit rather than on a 2-dimensional canvas, we present it within a VR 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 to sculpt voxels and navigate in-program menus (Figure 5). Wherever the user looks within the environment, a guide-cursor follows to indicate where they will sculpt. The guide-cursor takes the form of whatever brush they currently have selected, and by pressing the trigger on the controller, voxels are sculpted and manipulated.

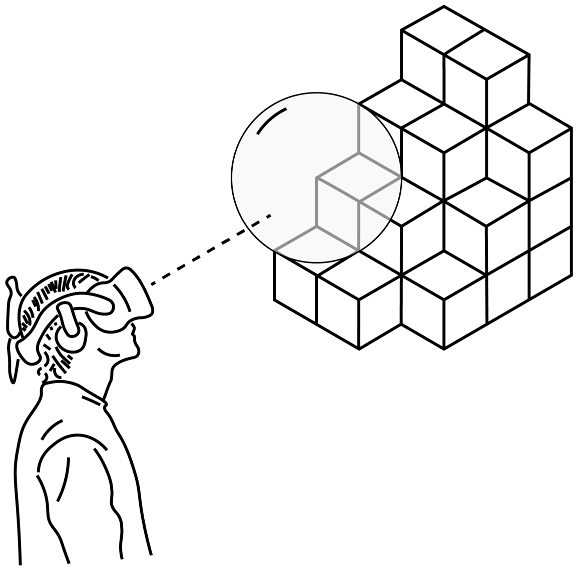

Figure 5. Eye-tracking data projected into the virtual environment to manipulated voxels.

As previously mentioned, in addition to gaze data being utilised for direct sculpting input, it is also the primary UI navigation and tool/brush selection method. In EVES, the controller is used as an anchor point for the 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 if it 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.

3.2.2. 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 (Figure 6)), tools alter how brushes act (such as single, line, and erasure (Figure 7)). Both brushes and tools allow for various uses that can be used in different ways 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.

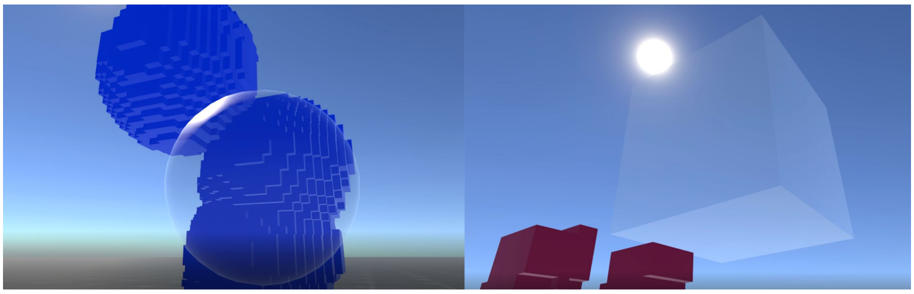

Figure 6. Sphere Brush (Left) and Box Brush (Right).

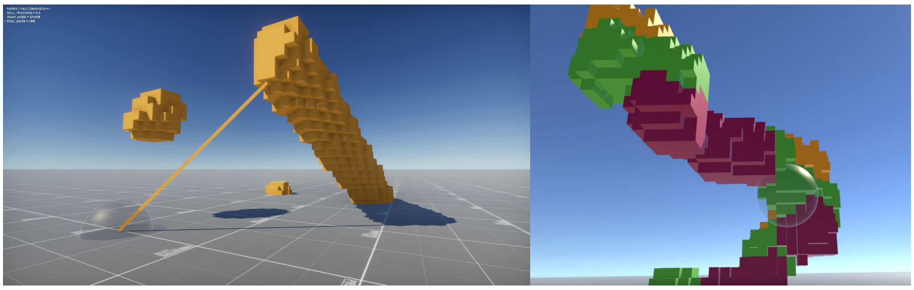

Figure 7. Line Tool (Left) and Curved Line Tool/Paint Tool (Right).

4. Outcomes

The development of EVES prompted further understanding of the potential for eye-tracking as a Human-Computer Interface within the realm of digital architecture and design. As explained, Eye-trackings usability can play different roles *within* or *as* the design process. Where Passive incorporation covers a more grounded approach, Active incorporation explores the more radical and artistic. By investigating the possibilities that eye-tracking can offer in these broader senses, we can understand how it may affect and benefit design.

4.1. THE PASSIVE (‘WITHIN’ DESIGN) APPROACH

When eye-tracking is incorporated in the design process as a passive method, a designer can track the visual experience of a user 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). This passive method enables a designer to confirm how their schemes operate and facilitate a connection between user and designer through VR and Mixed Reality (XR) tools. Not only that, but this approach highlights these visually active areas for the potential of revision or redesign if applicable.

Through the program’s development in this phase, we were able to analyse points of visual interest, visual experience, and behaviours. In particular, one space that we tested took place at a city intersection of two roads - with plenty of distractions and hazards. The precedence of our visual attraction would tend to be for moving objects and 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 with regards to its particular setting, the passive approach highlighted these visual experiences that we had.

4.2. THE ACTIVE (‘AS’ DESIGN) APPROACH

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 VRUI, and how vision can shape and mould the space a user inhabits.

Controlling or navigating anything with the eyes, whether it be the VRUI 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, ‘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 that of manual control can offer a slightly steeper learning curve. For example, when inputting the two points to draw a line, one would often be looking towards the next action before completing the previous. This action would then cause the line to be generated so that we did not intend. In contrast, the VR UI operation tended to be the easiest obstacle to overcome, as it relied mostly on the user’s existing muscle memory. Despite this, we found that once learning how to control our eyes, the operation of EVES became more instinctive 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 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 a way we may 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, we have made available the possibility for a user to utilise their eyes within the virtual realm to 'consume' and extend 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). It is this integration with VR technologies that, while these experiences tend to be visually focused, we can still explore what new ways people and designers can interact with the digital world (Rogers et al. 2019).

5. Conclusion

EVES at its core, is the exploration of the possibilities of eye-tracking within the virtual environment. 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 the 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 actors in the design generation.

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