DRAWING LIGHT IN THE CAVE

Embodied Spatial Drawing in Virtual Reality with Agency and Presence

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Abstract

This thesis project began as an exploration of the ways in which Virtual Reality (VR) could revolutionize drawing. What I learned through this research journey was that drawing could also revolutionize how we see, and therefore, what we can do, in VR.

I will begin by establishing a contextual background about the vision that some artists and theorists have had about the potential of VR over the past three decades. These individuals hoped to see VR become a tool that could help us learn to see and do things differently than the conventions of our everyday reality. Throughout this background context, I will form links to how three themes in VR: agency, presence, and embodiment, are all linked to drawing. With a focus on creative works made in VR, I will summarize the challenges to embodiment that I observed through my design research. I will present the pivotal insight in my research: that the root of these challenges lies in the use of linear perspective, a drawing method that evolved into a coordinate system that now underpins computer graphics systems. I will propose that an alternative method of drawing in perspective is made possible through VR; one that is based on the perceptual qualities of how we naturally see. In addition, I will show how VR also offers the possibility of drawing in an embodied way through techniques of spatial gesture drawing.

Lastly, I will present two methods for applying these concepts for creatives working with 3D geometry in VR. While these methods will help creators today, I hope that this research can contribute to the innovation of VR software and tools.

Keywords: drawing, gesture, creator, agency, presence, immersion, embodiment, visual perception, gesture, sketching, cross-contour, perspective, virtual world, 3D geometry, form, space.

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A special thank you to Char Davies, for showing me that I could breathe life into the void, and to Jacqueline Ford Morie, for letting me know I would not be alone in there. A thank you Sir Colin Blakemore, for giving me the confidence to believe in what I saw inside, and to Robert Pepperell, for encouraging me to look deeper. Finally, I hope to one day shake the hand of Gregory P. Garvey, for showing me how to get in.

Dedication

This work is dedicated to the memory and artistic spirits of
Adrian Duck, Susie Brown, and Leif Cuzner
Wind-blown seeds of wildflowers
In the fields of my irises
Saturating space
In all that
I see.

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Drawing Light in the Cave: Creating Hand-Drawn Worlds in Virtual Reality

I am completing a master's in design in the Digital Futures program. My thesis work was an exploration of many ideas surrounding digital artmaking in VR. As I entered this program as a mid-career artist, my research was both motivated and directed by two decades of experience. I have a degree in Film Animation from Concordia University and a diploma in Computer Animation from Sheridan College. In my professional life thus far, I have worked as a digital artist and animator, a digital design instructor, as well as an Interaction Designer for mobile applications. I currently work as a fulltime VR artist and animator for a video game production, and I apply this research and the ensuing methods in my work every day.

My personal and professional practice is founded on a lifelong passion for drawing. I learned to draw as a child and this skill has been the key that links all my endeavours as an artist, both in traditional media as well as digital design. I spent a decade working for Wacom, the leading brand in digital drawing tablet technologies. My courses introduced both graphic professionals and novices alike to digital workflows using the tablet. I also taught drawing as a foundational skill, and my tablet courses were designed around drawing techniques. My teaching ideology is that core drawing skills can increase the sense of personal agency in digital design workflows. This view was cultivated from the years of frustration in working with software as an artist, which I had experienced both observationally in my peers as well as first-hand.

When I first heard about VR applications like Tilt Brush, that enabled creatives to draw three-dimensionally inside a headset, I immediately recognized this technology could be the next step in the evolution of digital drawing. Without having even yet tried VR, let alone creating in it, I intuitively felt that I could be of value in these early days of establishing what it means to draw in this new way. I was excited about this new tool and what doors it could open, while at the same time being weary of what implications it could impose on creatives working in graphic industries.

I set out on this research path with two goals: first, to establish techniques for drawing spatially in 3D virtual space, and second, to translate these techniques into learnable skills. Furthermore, I wanted to take an approach that would make these skills as accessible as possible. My experience teaching to students with a wide range of experience had shown me that anyone can learn creative expression through digital workflows if they so desire. This observation stood in contrast to what I witnessed in educational and professional environments, where the learning curve of digital workflows is often unnecessarily daunting. Learning to create in digital formats entails a dependency on the technical nuances of the software, like tool features, workflows, and interface menus. These variables tend to involve a high learning curve while differing drastically from one application to the next. Their dependency on third-party software to achieve content goals is practically unavoidable. Spatial sketching in VR presents an approach to digital creation that prioritizes cognitive and motor-muscular adaptation over the linear skills so implicit in the conventional workflows of graphics software.

The practice of creating content directly in VR is a recent phenomenon that is permeating across a sector of graphic industries, like animation, industrial design, architecture, and filmmaking. I took this transition into creative VR as an opportunity to appeal to students and professionals in digital graphics to use this technology as a way of regaining creative control.

I conducted this research with my past students in mind. The drawing-based teaching methods I designed helped students from a wide range of backgrounds flourish as digital artists, despite their lack of prerequisite aptitude or the technical learning curve. Additionally, I hope to appeal to computer scientists and engineers, as the ideas in this document will culminate in the proposal of novel approaches to the design of CAD tools for creative content made in VR. These ideas were made possible in part by the contributing research of my predecessors in relatable fields of digital art. A primary example is Professor Gregory P. Garvey, who twenty years ago envisioned ways to humanize the tools of 3D graphics in ways that, from a technological standpoint, are only now feasible. In a similar way as Garvey had inspired me, the underlying aspiration of this research document is that it may one day contribute to the design of creative tools.

The title of this work, “Drawing Light in the Cave” has a two-fold meaning. The first meaning is literal, in that ‘light’ refers to the usage of creative VR tools, where the outputs of the artist are received as inputs in the form of light pixels. The second term in the title, the “Cave” is a nod to one of the earliest iterations of VR in 1992 which remains in use today: the Cave Automatic Virtual Environment (CAVE). The second meaning points to the epistemological problems I encountered while thinking about, working in, and reading summaries of the cultural discussions surrounding VR. “Light” and “Cave” are positioned as metaphor about how artists and engineers can build a bridge by working together in the design of VR software and tools. This meaning was inspired by a passage in the writing of acclaimed VR artist Char Davies, who argues that the fractures that have impeded such a bridge can be understood through Plato’s Allegory of the Cave[1]. For more on this discussion, refer to Appendix 2: Some notes on the title.

My chief aspiration in this work is to show how drawing can increase the potential for VR as a creative tool, and conversely, how VR could improve the way we draw.

[1] (Davies, Osmose: Notes on Being in Immersive Virtual Space, 2002)

My project became a plight of assembling the network of connections between drawing and VR. I found parallels in seemingly unrelated topics, like the cultural ideas surrounding VR, and the benefits of learning to draw from observation. I also reached much further back in time, to the origins of drawing concepts dating back to the Renaissance, and how these concepts directly affect the experience of creating in VR.

Throughout this document I will be summarizing the synthesis of ideas surrounding how we perceive the relationship of form and space. The design solutions I will present are premised by the upheaval of the mathematical method of Linear Perspective. Also known as Formal Perspective, this method is used for emulating a representation of depth relationships. It was created by artists in the Renaissance and is now embedded in computer graphics as well as a fundamental component of drawing and visual design. My creative research in VR led me to insights about how this method is not entirely natural to human vision. In my readings, I discovered that many artists, professors, researchers, and modern scientists who had all come to the same conclusion. Linear perspective could be limiting our potential for perceiving and interpreting the world, as much in our physical reality as the virtual.

Before I could even begin to fathom design solutions to this problem for what it meant to draw in VR, I had to first dismantle everything I thought I knew about the visual relationships of form and space. To find an alternative to linear perspective, I had to assume that the invention of the method in the Renaissance was a point where we went wrong - and reach even further back. This text begins with an overview of what it means to consider VR as an artistic medium. This is a contextual background, recalling ideas that had initially been discussed in the academic sphere in the earliest days of VR. Given the technological limitations of the 1990s, these ideas focused more on the imagined potential that VR could offer in advancing our creativity and sense of connectedness. I will be introducing three themes that link creative uses of VR with drawing: first, agency and presence, and how both are components of the third theme: embodiment. In expanding on each theme, first in its correlation to VR and then to drawing, I will describe how my own experiences in digital drawing and teaching relate to these themes.

This groundwork will hopefully set the tone for why VR presents such exciting possibilities as a creative tool, which in the following section, I will contrast with the negative apprehensions I have come across throughout my research. I will present all the ways in which this technology contradicts the best parts of each of the three themes, from the philosophical (what is the point of making art if I am unable to share it the way it is intended), to the practical (making virtual worlds is an extremely daunting task), to the physical (working in this format could, and has, led to vision impairment). I will synthesize how the concept of linear perspective is the common denominator that links computer graphics, Western Art History, and Western Science. I will argue, with the support of artists, academics, and scientists, how this concept may be at the root of many issues we encounter in our approach to CAD software today.

Finally, I will begin the building of a framework that upends this concept. Here, the three themes of agency, presence and embodiment will form the cornerstones of a new foundation. This framework is built from ideas new and old that suggest how we can redirect our approach to the creative use of VR. These ideas range from the philosophical (ie., making art in VR opens gateways to alternative perspectives), the practical (how we can avoid reinventing the wheel of optimization strategies), and the physical (how creatives working in VR can avoid strain on vision). The framework will culminate in the proposal of the two methods I have designed for the spatial drawing forms within immersive 3D space, respectively. These methods translate the agency and presence found in 2D drawing, by integrating the motor-sensory inputs of the tools and transforming the VR workspace into an embodied experience for the creator.

Methodology

My methodology in this project was an autoethnographic approach based on a model of research creation. The model I applied was inspired by a paper by Owen Chapman and Kim Sawchuck, entitled “Creation-as-Research: Critical Making in Complex Environments”. In this paper, Chapman and Sawchuck attempt to develop and refine the vocabularies of research creation in the hopes of expanding the potential of the methodology and emphasize the relevance of research creation in the “digital humanities[2]”. Chapman and Sawchuck present a process of research creation as a cycle of four categories: Research-for-creation, Research-from-creation, Creative presentations of research, and lastly, Creation-as-research. I found this approach extremely practical because my research depended so much on my own first-hand experience in the act of trying to create with this new tool. Additionally, because creating in VR is a very novel concept, the research would very much need to be created. It made sense then, that the autoethnographic methods I used would be of a reflective nature. I maintained a written blog and a documentation logbook. I kept a sketchbook on-hand, and I made use of the voice-recording feature on my phone.

To break this model down somewhat, I need to first reiterate a point made by Champan and Sawchuck, in that the cycle of these categories by no means follows a consistent order. Rather, there are aspects of each category that overlap into the others. In my own use of the categories, I found the lack of order and overlapping nature to be an essential aspect of my research. Creation-as-research often came first, where the act of creating in VR would lead to observations

[2] (Chapman & Sawchuck, 2012)

and critical questions. These would in turn be addressed in my documentation log and reflective blog posts respectfully. My log recordings usually accounted for technical challenges I encountered during VR sessions, that would leave me musing over questions that were often philosophical and intangible.

My written posts sometimes helped me work through these questions, but often, bigger questions would come to light through the writing. Especially in the early months of my work, for instance, in these posts I often grappled over my tumultuous relationship with technology as a working artist. I wrote about how much I loved these tools for the creative potential they offered, but how inspiration in practice was all-too-often thwarted by obstacles that can feel counter-intuitive to the creative process. The topic of what art and technology means to me came to govern the second act of my research, which fell mostly into the category of Research-from-creation. This period followed several consecutive months of creating, or trying to create, in VR. I had by then reached an impasse that prevented me from devising techniques that made any sense, let alone be teachable. As it tends to go, I eventually concluded that the only way past this impasse was through it, and so I dug deeper into the underlying questions.

I worked through the challenges I encountered, which were often underpinned by my own lifelong struggles with STEM-based learning. The writing culminated in a significant piece I wrote once I had reached an initial impasse in my creative work in VR about the difficulty in sharing my work without a significant amount of time and energy devoted to acquiring abstract, linear skills in technical processes. Conversely, I battled with the sense of void I encountered when working in a vacuum, that is, of creating work that I could not readily share with audiences as an immersive experience. For example, the blog post, “Dimming down my thesis” describes my week-long departure from my VR work to focus on an electrical problem in my household wiring. Through this writing, I realized that my goal in VR was to see the creative process as a circuit with a beginning and end point. The starting point would need to be derived by an intention to express something creative, and the end point was to share this form of expression in the format it had been created: within a virtual setting.

Where my sense of agency as a VR artist was developed through my introspective and reflective blog writing, I was able to target the challenges I encountered with feeling a sense of presence while creating in VR through documentation log. I maintained a practice of diligently recording my creative sessions in VR applications directly after removing the headset. It was through this practice that I was able to pinpoint the gaps in connection between my habitual modes of creating and the process of creating inside the virtual workspace. In reviewing the summaries of my daily sessions, for instance, it became apparent that my own physicality was compromised when pitted against the goal of creating work that could be shared in an immersive platform. In short, the technical challenges of designing for optimized content that could be successfully output in a software pipeline seemed to take all the fun out of it.

My VR work log recordings revealed patterns about physical pain points, like eyestrain, headaches, and contorted positions, all of which seemed a necessary means to an end, if the end-goal is sharing the work. These recordings also brought a more subtle, but equally substantial epistemological challenges to the surface, like the lethargy I would experience after long sessions in a headset. Such feelings were expressed through recordings of my own sensations, which were often experienced on an impulsive and deeply intuitive level, like a sudden longing to be in nature or a strong signal from my brain to relinquish the headset for the remainder of a day where I had intended to accomplish a great deal of creative work.

The writing practices were complimented by further modes of problem-solving through introspection, namely audio recordings that I would make either in the morning, before commencing a creative session in VR, or late in the evening, often after pouring through texts about VR and artmaking. At times, the source of a problem or moments of inspiration would come to me in the middle of the night, and I would reach for my phone to record these musings. The reflective process of reviewing the entries from my blog and process log, and listening to my audio recordings, became my pathway to building my own identity as a VR artist.

The practice of creating VR being a new phenomenon, it was nearly impossible to discern between the ‘right’ or ‘wrong’ avenues of thought. My research extracts design concepts from the ancient architecture and astronomy of the Greeks, and attempts to synthesize methods from Euclidian algebra, Modern Neurobiology, and the practice of Life Drawing. While I was painfully aware of struggling to establish constraints in the design problem, it was often the case that the best moments of clarity were the result of introspective wandering. For example, in the outset of my research, I could never have anticipated that I would argue the greatest challenge to VR creation is an art technique for conveying the illusion of depth: linear perspective. Nor could I have found alternatives to linear perspective without embarking on a thorough study of my own vision through written observations inside and out of VR, which led me to research the science of visual perception. These examples are by no means arbitrary; coming to understand that the concept of perspective is a cultural construct that influences our visual perception is how I was finally able to unlock the tool of VR as a tool for artistic expression and representation.

The seemingly endless questions I posed about the nature of reality, time and space were needed to be able to understand VR as more than a graphical interface strapped to my eyes. To acquire an in depth understanding of the potential of the medium, I needed to deconstruct my preconceived notions of how I perceived and interpreted reality. Doing so was only possible through the struggles I waded through in my writing. The framework of ideas that resulted is the foundation for how we can use the skill of drawing in VR as a tool that enables us to explore, dismantle, and ultimately, create new perceptions of reality, from the unique vantage of the individual within the simulation.

Chapter 1

The Creative Potential of Virtual Reality

Throughout the course of this research, I witnessed the hold VR has been taking across a vast array of sectors. The world may finally be ready for VR, and the technology finally ready to address the needs of the world. However, the technology of VR nor the ideas about how it can serve us are far from new. The earliest iterations of the Head-Mounted Display (HMD) began to emerge in the cultural sphere in the 1980s, although a historical timeline predates this period. To learn more about the historical background of VR, see Appendix 3: The historical context of VR.

VR emerged in pop culture of the late 80s and early 90s in tandem with the influx of video games and cinematic visual effects that were made possible because of 3D graphics. The group of artists, professors, and scientists who took interest and / or worked with the HMD at the time are, today, often referred to as the pioneers of VR. A number of these individuals were actively designing VR prototypes that highlighted the benefits of immersive environments, but because the technology of computer graphics was still in its infancy, a great deal of these investigations took the form of speculative imaginings of a future for VR. The renowned computer scientist Jaron Lanier, who is also known as the Godfather of VR, best summarized this tendency to envision how VR could help us achieve new heights of creativity and connectedness in his 2018 book on the topic, Dawn of the New Everything. “The best thing about VR is thinking about VR,” Lanier writes, a statement that aptly reflects many of the views and aspirations in this document.

One artist and professor that was writing about VR as well as prototyping with the technology is Dr. Jacquelyn Ford Morie. In 1994, Morie described VR as having “the potential to expand our ways of seeing, feeling, and experiencing – far beyond those of our everyday lives."[3] Morie saw VR as a tool that could enable the creation of immersive experiences that could not be achieved any other way. In those early days of VR, Morie argued that it could be "a revolutionary means of expression that provides capabilities beyond any other in human history."[4] As I will describe in the coming chapters, my own reflective speculations about how VR could be used to explore drawing in ways never-before possible led me on a path that led to Morie. The 'true'[5] potential of VR, Morie argued in 1994, lies in how the quality of involvement can be improved for the user. I was inspired by how Morie linked the tools of VR to collaborative world-building, and her design of a VR application that demonstrated an early use-case of high school students using creative tools in a networked, immersive environment. Morie called on creatives to imagine the ways we will engage with virtual worlds, then make those worlds a reality.

After a long period of relative dormancy, recent advancements over the past decade in VR have enabled new uses for the tools in ways that Morie and several others had, three decades ago, only dreamed of. HMDs are now connected through social networks, at once realizing the technological reality that Morie, Lanier, and many others had decades ago, only dreamed of. However, the corporate control at the helm of these networks comes with far-reaching negative ramifications for how we are already adapting to VR. My own creative research in a Facebook-owned VR product (Oculus Quest) meant that considerations about the implications of big tech, like privacy and ownership, were unavoidable. Oculus VR is arguably the leading company in

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[3] (Morie, Inspiring the future: Merging Mass Communication, Art, Entertainment and Virtual Environments, 1994, p. 136)

[4] (Morie, Inspiring the future: Merging Mass Communication, Art, Entertainment and Virtual Environments, 1994, p. 135)

[5] (Morie, Inspiring the future: Merging Mass Communication, Art, Entertainment and Virtual Environments, 1994)

independent creative projects made in and for VR. My specific concern relates to what user experience paths would be forged into VR hardware and software before there was any chance for open-source experimentation. For example, at the time of writing, Oculus owned the VR application Quill (now independently run by the chief engineer who designed the software, Inigo Quilez), which I used predominantly in this research. One of the most prominent VR artists curating the learning content for creating in Quill is Goro Fujita, the art director at Facebook VR. And in my current occupation as a VR artist, the studio I work for is fully dependent on future funding from Oculus. For more on the topic of corporate ownership of VR, refer to Appendix 4: Big Tech and the negative ramifications for VR.

This research addresses the positive outcomes enabled by technological advancements of commercial enterprise. For example, not only is it now possible for everyday users to interact in VR, but it is also increasingly becoming commonplace for VR to be used in remote settings, and in the privacy of one's own home. Additionally, the graphics of HMDs now boast an enhanced mode of navigation known as six degrees of freedom, which simulates how we move around in the physical world. A third feature, which plays particular significance in my research, is haptic feedback, which gives us an intuitive way of interacting through motor-sensory outputs.

I will connect these affordances to the world-building potential of VR addressed by Morie, that is, the creation of immersive environments, whether as an isolated act or in collaboration. In doing so, I hope to show how drawing can be seen as learnable skill that can make world-building a more inclusive and accessible activity.

Defining VR as an artistic medium

Three decades after Morie first called on creators to develop VR as an artistic medium, the qualities and characteristics that define this medium remain ambiguous. Artist Jonathan Rathman, who began designing VR experiences for museum installations in 2016, positioned the technology as the leading format in contemporary art. "I think it's the new medium," says Rathman, "we've just got to figure it out." Eugene Chung, the former head of film and media at Oculus VR, compared the present challenge of defining VR as a medium to that of "trying to create the paintbrush while trying to create a painting."[6] These statements suggest that in the surging popularity of VR, the fact that VR is not a new technology, but rather a reemerging phenom with a well-founded groundwork of cultural discussion, is being overlooked. A rehashing of some of the key ideas about the creative potential of VR from 30 years ago is needed so that we can pick up where the creators of the past had left off. By unearthing this foundation, we as creators can be reminded of the qualities about digital creation that help us to become better artists, rather than simply more employable in our respective fields.

In 2018, Morie herself implored today's creators to look 'Back to the Future'[7] to the groundwork of the themes she and others had attempted to define long before the influx of consumer-accessible gear and software that have made VR what it is today. The emphasis on how to build cultural meaning in VR is being called into question by educators across an array of creative fields. For example, Dr. Asher Warren, a professor of theatre and performance, recently proposed that the physical language of the theatre arts has much to offer in how we will learn to communicate with one another in immersive virtual settings. Like Morie, Warren

[6] (Gottschalk, 2016)
[7] (Morie, Considerations on creativity and technology in the twenty-first century, 2018)

suggests that the first step is to distinguish the ways in which current uses for VR reflect the themes from the 1990s. Warren asks his readers to consider “what is ‘new’ about this virtual reality resurgence and which aspects are carried over from the previous attempts?”[8]

Where three decades ago, the reasons *why* the potential of VR is so important as a tool for exploring creativity were, on account of the technical limitations, largely speculative. Creatives today now have opportunities to designing the frameworks for *how* the potential of the virtual can become a reality. As Warren points out, “recent developments do not claim to revolutionize, rather to finally make good on the earlier promises of VR.”[9] Just as Warren argued about the value of the performing arts as a form of physical interaction, creatives from other artforms are now needed for designing how we use the technology. As Art Professor Brendan Kelley recently stated, “It is the artist, not the technologist, that may play a more pivotal role in VR development.”[10] The aim of the contextual background I am providing in this text is to connect the how of artmaking in VR with the cultural ideas initially proposed by artists and theorists thirty years ago, as these themes, despite the technological advances, continue to perplex us.

Embodiment as the key qualifier

A feature that distinguishes the current state of VR from that of the 1990s is that technological innovation has created new pathways for exploring embodiment. Embodiment in VR describes both the feeling of a lived experience as well as the sensations that make up what it feels like to be alive. Philosopher Helen de Preester calls embodiment a “comprehensive

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[8] (Warren, 2018)
[9] (Warren, 2018)
[10] (Brendan Kelley, 2019)

phenomenon"[11], in that it consists of both the feeling of ownership of the body as well as subjective feelings of the senses. In 1994, Morie described a future scenario for VR where the quality user involvement could be improved by through physical interactions. Morie specifically addressed the need for bodily movement in immersive environments to define "ways to manipulate things in these worlds, and to change them, if desired."[12]

The emphasis on physical embodiment is even more relevant today. Users in VR can now interact using physical movements of their bodies with a heightened degree of sensitivity and feedback. The technological advancements in VR mean that the types of manipulations Morie listed can now include recording the speed and direction of physical movements in virtual space. Embodied interactions are thus enhanced through features like the sensor-tracking and pressure-response of the hand controllers and the six degrees of freedom in the lightweight HMDs. The advent of these features helps in forming closer motor-sensory connections, effecting a convincing sense of immersion by making moving around in virtual space feel more natural and intuitive.

Since we engage in the world on a practical level through embodied interactions, physical movement is becoming an essential component in the "process of immersion"[13]. As Chan says, "Embodiment is integral to understanding the sense of being immersed and present within VR."[14] Warren proposes that the physical performance found in acting could contribute to how we learn to use physical interactions in VR, proposing that theatrical works could offer "specific

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[11] (Chan, 2018)

[12] (Morie, Inspiring the future: Merging Mass Communication, Art, Entertainment and Virtual Environments, 1994, p. 136)

[13] (Chan, 2018)

[14] (Chan, 2018)

techniques"[15] that help us communicate in virtual space.[16] There is a growing discussion about the use of VR for embodied games in the education sector. For instance, Mina C. Johnson-Glenberg of Arizona State University, lists embodied games as a category of video games that incorporates gesture into the act of learning. Embodied games are often designed to address topics that have been traditionally "tough to teach",[17] like science and physics, and make use of how the body moves to make concepts feel more real.

Sketching and embodiment

The advent of tactile controllers in VR have led to a flux of recent studies have proposed that another form of embodied language could evolve from the gestural motions of drawing, or specifically, sketching. The marks of sketching are commonly understood as being useful for the intentional design of visual representations. Tracy Hammond and Paul Taele of Texas A&M University recently conducted a study about sketching interactions for interfaces. Their research covers a broad spectrum of domains including education, artificial intelligence, science, and engineering. Hammond and Taele argue that sketching can be intuitive, as "a type of physical activity that we are able to perform in daily life naturally."[18] Hammond and Taele additionally point to the effectiveness of sketching as a form of ideation, that can "can then be reinterpreted in thinking, learning, and communication."[19]

[15] (Warren, 2018)
[16] (Warren, 2018)
[17] (Mina C. Johnson-Glenberg, 2015)
[18] (Tracy Hammond, 2019, p. 708)
[19] (Tracy Hammond, 2019, p. 709)

VR and drawing in context

In recent years, several artists have been turned to drawing a means to develop their own unique visual language for creating VR experiences. Laurie Anderson used drawings in the 2017 VR installation The Chalkroom, which she designed with her longtime collaborator, Hsin-Chen Huang. Using diluted chalk on traditional blackboard surfaces, Anderson and Huang projected hand-drawn gesture strokes as interactive elements inside the virtual environment. Anderson had initially rejected the idea of creating art installations for VR. “I didn’t like that visual language. That’s why I invented this other way to do it.”[20] says Anderson, referring to her use of hand-drawn media.

Recalling her initial impression of VR as having the cold, flat screen of graphical interfaces traditionally associated with video games, the use of chalk was explicit for its messy material qualities. The dust and grime of the medium so many of us associate with the classrooms of childhood served as a transformative contrast to the clean appearance of pixels. Having established her own way to bring the elements together to tell a unique story, Anderson later compared working in VR to be like creating an opera.[21] The Chalkroom showed how drawing could be applied to create an interactive, virtual performance of sorts in an entirely unique way. While this may have succeeded in enhancing the experience for participants of The Chalkroom, however, Anderson did not create the drawings inside VR, but rather on physical chalkboards that were projected programmatically inside the simulated environment. The significance of the work in this document is to point to the sense of agency employed by Anderson in the act of drawing. It established why drawing has value in a VR experience, but

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[20] (Anderson, 2017, p. 38)
[21] (Anderson, 2017)

not how it can be useful for the artist creating directly inside a VR environment. For that, I turned to the VR illustration work of Wesley Allsbrook.

Renowned for her art direction in the first made-for-VR hand-drawn film Dear Angelica, Allsbrook also expressed an initial aversion to VR as a creative medium. "I was telling all of my friends in private," says Allsbrook about embarking on the partnership with Oculus Story Studios in making the film, "I think I'm gonna have to quit this job because this looks really ugly. This is a problem."[22] Like Anderson, Allsbrook employed gesture drawing to develop her own visual language and found a way create virtual landscapes that exude the expressive strokes and dramatic colour palettes she is known for in her 2D artwork.

Allsbrook had successfully established a way of drawing with agency inside a virtual environment, but her collaboration with the engineering team at Oculus pointed to another challenge about drawing in VR: her visual language was made possible by the support of technicians. In fact, the collaboration resulted in a new creative application called Quill, which has a set of drawing tools that were initially designed around Allsbrook's techniques. Quill has since become the leading VR application for animation and other storytelling formats, and is the platform I focused on most in my own creative research. As I soon discovered in working with Quill, however, without an engineering team of my own to support me, I faced some daunting technical roadblocks. This was particularly the case when encountering the challenge of how I could draw VR 'worlds' that could be shared with audiences.

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[22] (Roettgers, 2017)

The misconception of embodied creation in VR

At first glance, approaching VR as a sketching tool can appear the solution for how we can most effectively communicate ideas, at least from within virtual workspaces. Sure enough, the marketing of creative VR boasts of the limitless creative possibilities, which at least from the images featured, seems to imply are possible thanks to how freely the artist can move, effectively turning the act of drawing, painting, and sculpting into a dance inside an infinite virtual canvas. The YouTube videos of Allsbrook painting in a VR headset all serve to articulate the point of her spatial freedom, where the gestural paint strokes that define her signature style encompass her dance-like motions around her studio.

Creative VR apps are often promoted for the expressive movement afforded by the tools.

Gesture strokes like this are fun to create but not optimal as artwork to be experienced by audiences. Artits must learn technical process to share work.

Allsbrook's dance-like movement for a documentary. In reality she finds this act "tiring" and works while seated at a desk.

Figure 1 Shows an image of VR Artist Estella Tse painting a stroke. Figure 2 Demonstrates the physical movement of VR painting in "Phelps Vs. Shark", a 3D painting by Wesley Allsbrook, 2018

The disconnection of the body

In my own creative research in VR, I was aware early on that there was a disconnect between my physical body and the space which surrounded me in a creative VR workspace. Chan describes a similar experience while creating with Tilt Brush, one of the leading creative VR applications. "The movements that appeared to occur in VR did not seem connected to my sense of embodiment in the world at large," said Chan. Allsbrook also echoes the experience of short-lived physical freedom, “Initially I would stand up and dance around,” Allsbrook recalls. “After a while, the dancing movements became “really tiring.”[23]

Allsbrook admits that she typically draws in VR while seated, as I soon learned to do as well. Allsbrook describes the struggle of working with space as “constantly pushing and pulling,[24] which resonated with the struggle I experienced in trying to orient myself and the objects I created in the endlessly scalable space. It became increasingly clear to me that there was a disconnect between my physical body and the space which surrounded me in a creative VR workspace. Chan describes a similar observation in creating with Tilt Brush. “The focus of my attention was on the enveloping blackness of the three-dimensional space generated by Tilt Brush and the creative opportunities within it.”[25]

What the marketing campaigns fail to address in the promotion of so-called ‘creative opportunities’ is how creators can share their work for audiences to experience the artwork in VR. While traditional viewing formats like 2D images and video are perhaps more accessible options for a creator working inside the virtual workspaces of creative VR applications, these formats fall short of reaching the potential of VR, specifically in the way that Morie had framed it in the early 1990s. According to Morie, the potential of VR has two components. First, it must be used to create works of art that would not be possible any other way or format. Secondly, audiences need to be able to engage with the artwork as an immersive experience.

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[23] (Oculus, 2017)
[24] (Oculus, 2017)
[25] (Chan, 2018)

The difficulty of sharing immersive work

The technical hurdles in devising creative workflows prevented me from designing shared experiences. Early on in my creative process, I came to loathe the term "optimization". It symbolized the impasse I faced in transforming works created inside the VR workspace applications I was using, like Quill and Tilt Brush, into the kind of virtual experiences Morie had outlined. I soon found that not only did preparing 3D content that in VR entail a fair amount of skill and strategy if it were to be exported to other programs or formats, like video, I would also need to grapple with the often daunting learning curve of software that is intrinsic to building immersive experiences, as in gaming platforms like Unity or Unreal Engine, and other 3rd party software like Cinema 4D or Houdini. I was forced to make a hard choice between using the studio time in my research for learning what I could of these applications or focus more on theory and acquiring hands-on technique inside the VR applications I was already working in. Not yet certain of which software would be the best use of my time, I opted to focus on the latter.

In a recent article, Morie acknowledged this challenge I faced as a creator facing a technical wall that blocked my hopes of sharing the work the way I wanted to. Morie writes, "No longer can a creative person have an idea and simply share it with traditional media from a distance. There are myriad aspects to consider in today's execution."[26] VR artist Rachel Rossin regards such challenging technical demands as being "analogous to any artmaking process."[27] The technical procedures are, as Rossin says, "somehow exacerbated when you're trying to pull something off that actually has to work."[28] What needs to 'work' for creators who are designing

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[26]

[27] (Gottschalk, 2016)

[28] (Gottschalk, 2016)

in VR is that the user must be able to interact in the experiences they create in an immersive way. If this goal was not already difficult enough, to meet the potential of VR, users must be able to experience these VR works with a sense of agency and in a state of presence. But before I could begin to approach how to make this process easier for creators, I first needed to address how to improve the sense of agency and presence for the creators in the immersive act of creating.

Chapter 2

Agency in context

I chose to make agency and presence the overarching themes of this thesis because I see them as the qualities that best describe the space where VR, drawing, and self-expression intersect. In the context of my research, agency in a VR experience implies that the user can assume the role of a creator by navigating an original path defined by their own unique set of actions. Presence, meanwhile, describes the willing suspension of belief. For presence to be achieved, whatever the user is experiencing in the virtual environment must feel like it is being lived in a way that feels akin to a physical reality, rather than a digital simulation.

Johnson-Glenberg uses the term agency "to connote the user has individual (self-initiated) control and volition over the individual virtual objects in the environment."[29] Some artists who were working with VR in its first run in the 1990s created immersive works that gave users the freedom to experience the environment in a unique way. This could mean the freedom to navigate freely, or it could consist of leaving a permanent effect on the environment. Kelley refers to this as "dynamically changing the landscape for future viewers,"[30]

In 1994, Morie wrote that the "truly interactive world (is) one where I can leave my mark; one that I can change to suit me."[31] In the same year, artist, and technologist Char Davies, expressed a vision for the technology of VR to show, through her immersive installation OSMOSE, that computer technology could be an expressive instrument.[32] Refuting the terms

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[29] **Invalid source specified.**

[30] (Brendan Kelley, 2019)

[31] (Morie, Inspiring the future: Merging Mass Communication, Art, Entertainment and Virtual Environments, 1994, p. 136)

[32] (Davies, Osmose: Notes on Being in Immersive Virtual Space, 2002)

"virtual reality" and "users", Davies referred to the medium as "immersive space" and those who experienced the space as "immersants". Davies sought to show how virtual space could be to a physical place, where artists could project their unique visions. Meanwhile, Morie co-created a VR application called Polyshop. Users of Polyshop were given the term "world builders"[33] to call attention to the agency of creating rather than simply navigating the environment. "Users should not only pick up objects," said Morie, "but also to stretch or shrink them, decorate them with textures or colours."[34]As a precursor to multi-user feature that is emerging in creative VR applications today, world builders in Polyshop could learn techniques from one another through a community made possible through remote networking. Through the support of a network of interactive learning, creators could explore agency by inventing new ways to use the tools for their unique creations. These artists underlined the significance of user agency in VR by designing technological tools that could be used to fabricate unique worlds and record autographical content in a sharable way. For more background and examples of artists who helped to define agency in VR, refer to Appendix 5: Agency in VR in context.

Agency in drawing

Agency is a key qualifier in the act of gesture drawing, articulated through the emotional experience and subjective expression. Art instructor Helen South defines gesture drawing as "a quick sketch to express emotion and movement."[35] South describes how the loose form of

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[33] (Morie, Inspiring the future: Merging Mass Communication, Art, Entertainment and Virtual Environments, 1994, p. 138)
[34] (Morie, Inspiring the future: Merging Mass Communication, Art, Entertainment and Virtual Environments, 1994, p. 136)
[35] (South, 2019)

sketching seeks to capture the basic form and expression of movement in a subject.[36] The act of gesture drawing activates a sense of empathy, a significant feature in subjective expression.

The study of life drawing, that is, the act of drawing a live model, is often recommended as a means of training the hand of the artist. Similarly, the creator in a VR workspace interacts with the pressure sensitivity of the controller to connect motor-sensory movements of the hand to the graphic responses of the stroke in real-time. The sensorial interactions of gestural movements are recorded over a lapse of time, increasing user agency through the motoric modality. Additionally, the inputs of VR controllers can be used for making the "individual gesture mark"[37] wrought with subjective expression and resulting in a unique autographical signature.

Reflecting on the comic book style of VR artwork he had created using Quill, artist Matt Schaefer articulates the significance of this skill with the controller, where the hand-gesture of the outline work "proved to be the most challenging and time-consuming aspect."[38] However, as Schaefer eventually discovered, the skill can become more intuitive with practice. As evidenced in his work "Alex's Sci Fi World", Shaefer's training resulted in a distinct quality that feels personalized and human. "Although this took a lot of time", Shaefer admits, before concluding with a statement that perfectly exemplifies manual drawing as a quality of agency in VR: "it gave me total control over how the painting looked. The result is organic and has a hand-crafted quality."[39]

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[36] (South, 2019)
[37] (Garvey, 2002, p. 303)
[38] (Schaefer, n.d.)
[39] (Schaefer, n.d.)

Matt Shaefer, "Alex's Sci Fi World". Illustsrated in Quill. Shaefer found that the hand-drawn lines gave the work a "hand-crafted quality" that came through in "all the mistakes and imperfections."

Figure 3 A still-frame from "Alex's Sci-Fi World", a VR project drawn in comic style by Matt Shaefer, from Quill's website.

In the widely acclaimed textbook, The Natural Way to Draw, Kimon Nicolaides advises students to draw not what a thing looks like, or even what it is supposed to be, but rather, what it is doing.[40] In drawing the weight and mass, we are trying to feel the effects of these forces in discovering the core motivation in the form. "All the senses" says Nicolaides, "should be used to feel and empathize with the subject."[41] His exercises focus on "contour gesture, weight, modeling, memory, analysis of contrasting curved and straight lines, predominating shapes and their design within the frame".[42] Such exercises are designed to help the student draw the subject with a deeper level of understanding and empathy.[43]

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[40] (Garvey, 2002)
[41] (Garvey, 2002)
[42] (Garvey, 2002, p. 303)
[43] (Garvey, 2002)

Geture drawing expresses the energy of the body through motion and force.

Figure 4 Gesture drawing, "Paris Ballet" by Glen Keane, 2015. Figure 4: Force and movement are demonstrated by Michael D. Mattesi, 2016.

Design Professor Gurt Hasenhutl describes drawing as a process of “self-cultivation”[44] similar to calligraphy, where through modes of perception, movement and introspection, the drawing hand is the direct input of the body.[45] Hasenhutl attempts to describe the peculiarities unique to the act, where “the drawing self gets dissolved into a self in the third person who is perceiving herself as drawing and herself becoming a tool.” In the following section, I will demonstrate how drawing on a digital graphics tablet is an example of how the drawing self becomes a tool, through the sensory inputs of the stylus pen and the surface of the tablet.

The agency of drawing on a graphics tablet

As a precursor to drawing digitally in VR, the design of graphics tablets is centred on sensory inputs. Creators rely on the sense of touch through the tactility of the tablet’s surface.

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[44] (Hasenhütl, 2020, p. 65)
[45] (Hasenhütl, 2020)

The tablet responds to the pressure of the pen tip and provides feedback that informs the artist how to respond intuitively. For example, Allsbrook, who had played an integral part in the design of Quill, was habituated to working with a Wacom tablet. Allsbrook ensured that Quill transferred the sensory experience from the stylus pen to hand controller. “I use the touch controllers”, says Allsbrook, in explaining how this process is transferred, “so Quill records my speed, my velocity, my position, and I can use the controllers to do anything that I might do with my Wacom tablet.”[46] Allsbrook also integrated the hotkey commands into the sensory inputs so that the sensory inputs of drawing were uninterrupted by menu selections. “I can scale infinitely,” she says, providing examples of the use of hotkeys while drawing, “I can colourize, and the feature set – there’s a user interface, and I use the controllers to interact with that.”[47]

As a digital drawing instructor, I cultivated methods for enhancing subjective qualities of drawing with the tablet. My classes often began with routine practice to develop motor-sensory training of gestural motions of the pen on the tablet’s surface. I paced around the room like a yoga instructor, coaching the students through exercises where they practiced slow, deliberate movement and quick gestural flicks of the hand and wrist. These sessions aimed to bring a quality of self-expression in the mark-making that could be recognized by each student on the first day of class, regardless of their drawing ability or technical aptitude with the software. It was a way to encourage them through the learning curve ahead by allowing each to look at the screen, like a child looking at their finger-painting, and think “That’s me.”

The drawing tablets being referred to here are not the kind we think of today, where screen technology has advanced to the point that we can now sketch on our phones. Earlier

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[46] (Oculus, 2017)
[47] (Oculus, 2017)

generations of drawing tablets (and still commonly used by creatives today) are a screenless, tactile surface. Learning to draw without looking (so the eyes are focused on the visual feedback on the monitor's screen) eventually becomes intuitive but involves some motor-skill training.

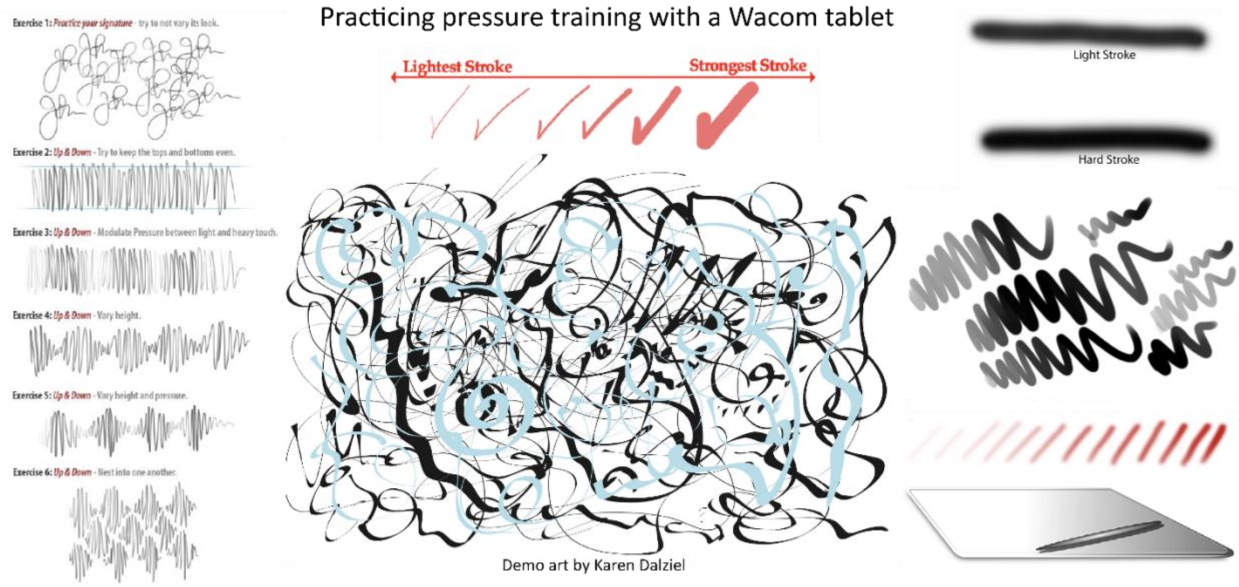


Figure 5 Examples of pen-pressure and dexterity exercises to develop motor-muscle training for drawing on a tablet.

A common first lesson in tablet courses is to practice writing one's own signature again and again, a slightly more evolved form of the individual autograph. In my own courses, I had students practice drawing their way through a maze, with the goal of getting from start to finish without the line of the pen grazing the sides of the maze wall. Throughout the course, I would introduce methods of working with the tablet that enhanced the quality of the mark-making while working in tandem with digital techniques, like those described by Allsbrook. The results were as encouraging for my students as they were for me, as they produced work that was often far beyond what they believed themselves capable of, at least when painting or drawing with traditional media.

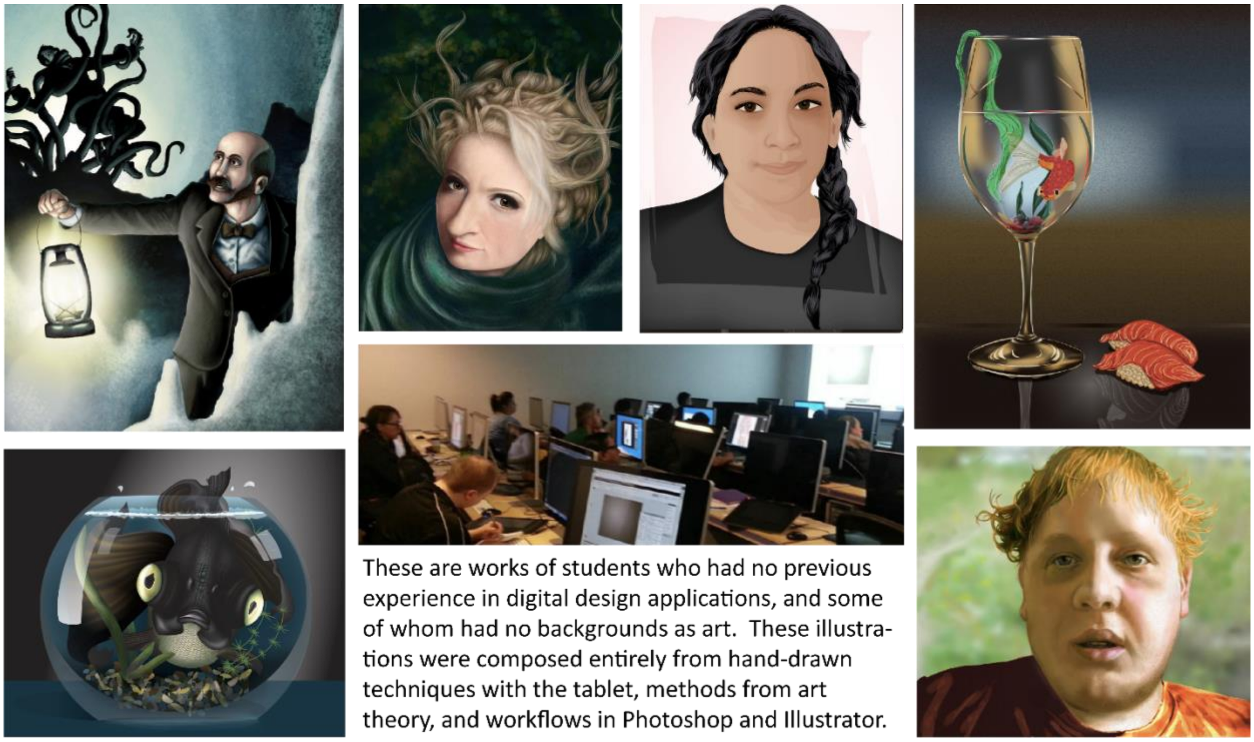


Figure 6 Examples of portraits drawn by students in the digital creation courses I taught. All examples shown are by students who had no prior experience with digital painting or drawing with a tablet.

In a similar way, I sought to rethink drawing, not just as an iteration of digital drawing on a surface. Because we live in a 3D world, visual concepts tend to come to us in 3D form. Sketching ideas on paper or on a tablet entails first cognitively transferring the 3D dimensions onto the 2D surface of an image plane. The first promise I saw in VR then, was that by removing that cognitive translation of 3D to 2D, creating in VR could give a lot more people access to the powerfully imaginative skill of drawing, and therefore, increased agency in the act of creating.

Finding agency: the challenge of translating drawing from 2D to 3D

Early on in my creation-as-research sessions in VR, I found early on that, as Shaefer said, drawing lines (gestural, freeform strokes) presented a challenge. I struggled to find a balance between the expressive quality of the sketching, that involved the fluid, impulsive and dance-like movement of my body, and the calculation involved in connecting the lines in accurate proportions and volume.

From years of practice in two-dimensional drawing, I can sketch with proportional accuracy while conveying the appearance of three-dimensional depth.

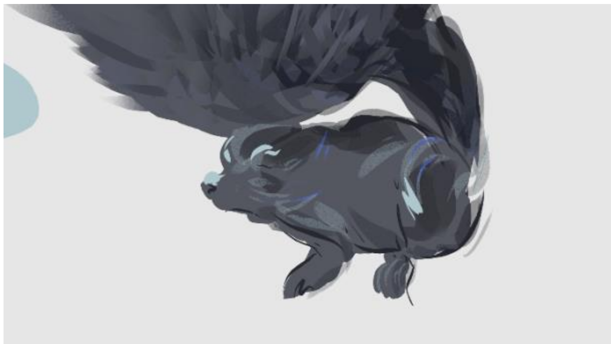
Figure 7 A sketch I drew in a park conveys a sense of 3D volume and depth with a few simple strokes.

The two modes of drawing

I began to differentiate between two modes of sketching. The first mode was more gestural and expressive, likened to a form of mark-making, or what philosopher Nelson Goodman refers to as the “authentic, personal, and situational aspects”[48] that often linked with

[48] (Hasenhütl, 2020, p. 57)

free-hand sketching. There is less reliance on accuracy of geometrical form and the focus is more on the quality of the strokes.



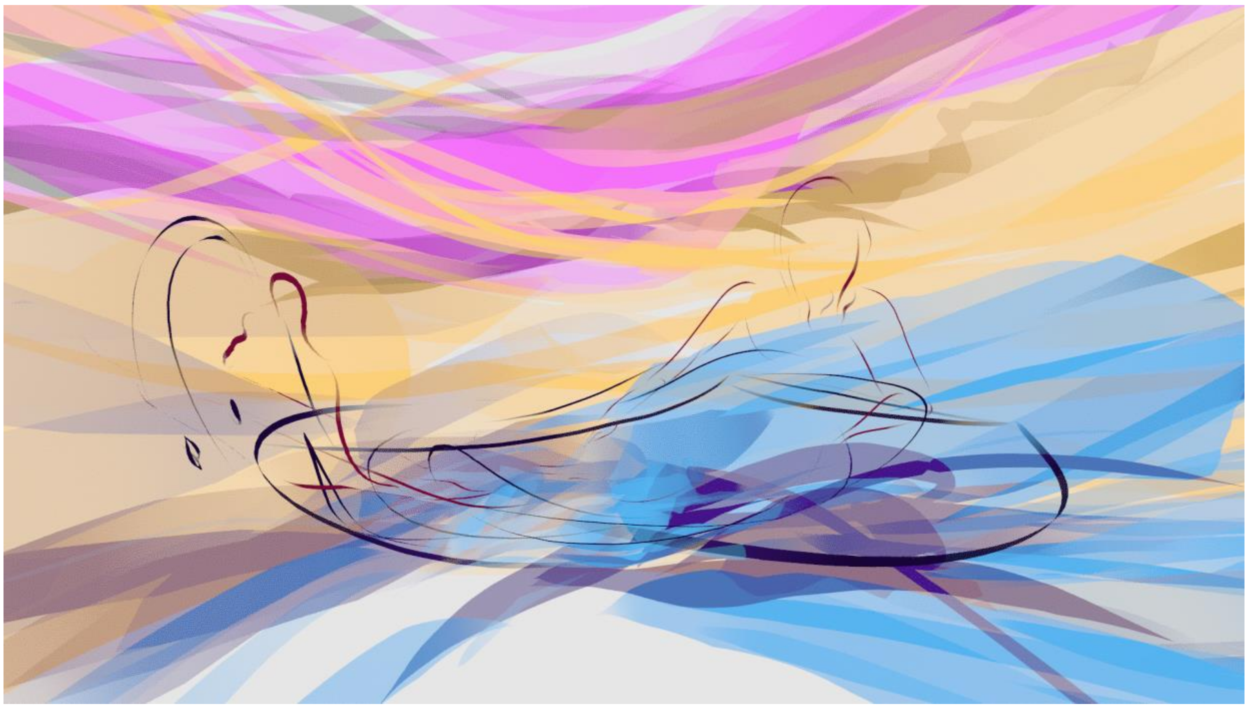


Figure 8 A quick sketch of a squirrel that I drew in Quill. Figure 9 The sketch fell apart when I changed the view. Figure 10 An example from a sketching exercise I did in Quill, exploring layered strokes to create atmospheric effects, along with a sketch of a figure. In these early sketches, I struggled to find harmony between the self-expression of gesture strokes, and the proportion and volume of the forms.

In the second mode of drawing, the spatial and proportional relationships of forms needed to be calculated in conveying an accuracy in volume. I associated this act with the scaffolding structure of a building undergoing renovation. This analytical approach results in the type of drawing more associated with drafting.

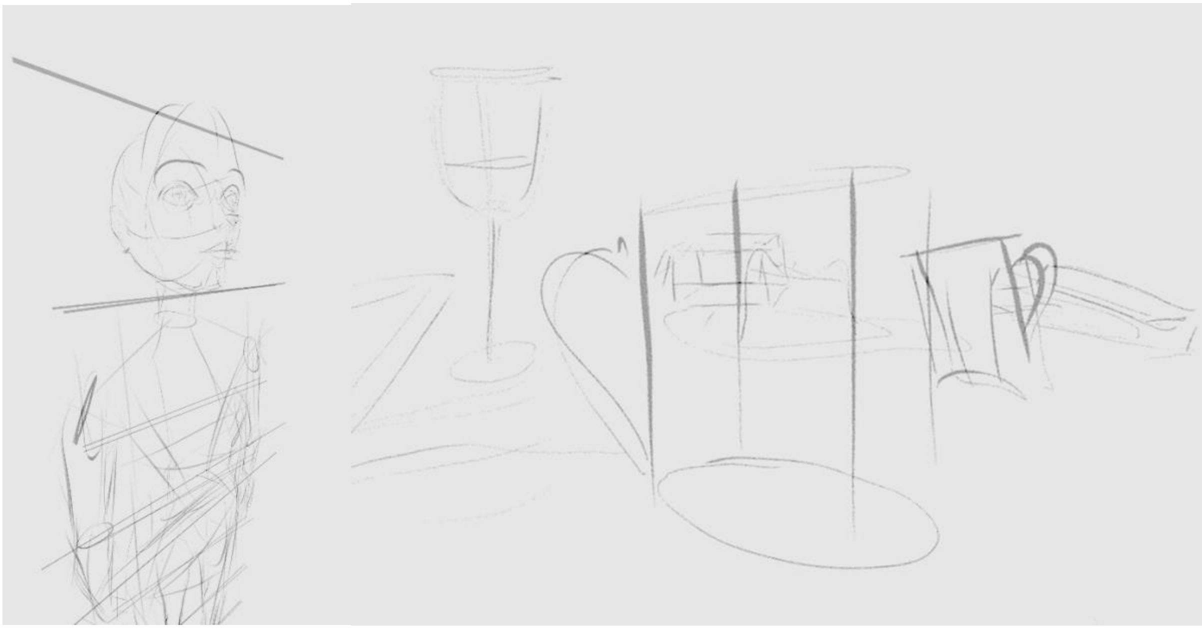


Figure 11 These sketches show my early attempts to find techniques for drawing volume and proportion while free-hand sketching in Quill.

When it got to the core challenge at hand, of translating this 2D skill to 3D space, the vocabulary simply just was not there. I was perplexed by this, as we live in a 3D world and must learn to translate it into a 2D frame. It seemed the major benefit of drawing in VR was that it bypassed that 3D-to-2D translation as the cognitive block, allowing us to create ideas just how we visualize them. At first, I had attempted (and failed) to work out a system for creating perspective lines to scale the infinite 3D space. Linear perspective is a method that artists use to construct what our eyes see on a 2D image plane. It involves the use of straight lines that converge together at what is known as a vanishing point on the horizon. The idea is that although the mind knows these lines never actually converge, they appear to do so the further they recede from our view. Perspective one of several depth cues we apply when perceiving visual space, and we use it to scale the distance between depth relationships of whatever is in our view.

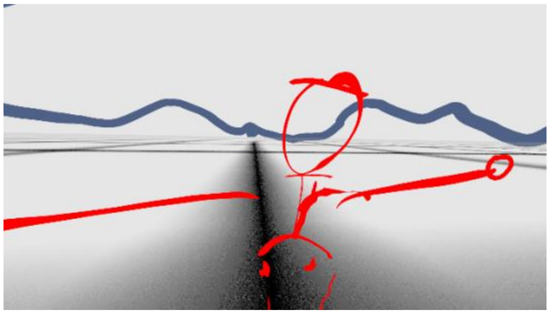
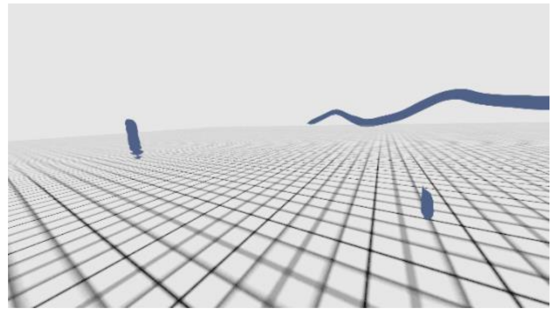



Figure 12 Using a sketch of a life-sized stickman version of myself, I tried to scale the distance of a far-off mountain range. Figure 13 I drew a grid as an attempt to integrate linear perspective.

Intuitively I understood the reason, but it would be through the extensive period of reading and reflecting that followed that I was able to spell it out. It simply made no sense to try to draw with linear perspective in 3D space, because I was already inside the method itself. I will expand on this problem in later chapters, as there are further considerations about the issue of drawing with agency in VR.

The surface shape of 3D geometry

I was also encountering an additional problem. Being able to see all the structural lines overlapping one another in 3D is both confusing and distracting. Our eyes want the interior space to be filled with a solid volume. In 3D modelling, that interior is known as the "mesh", and can be described in the most simple terms as a solid fill. Conventional approaches to 3D modelling involve a form of sculpting using a set of linear techniques and tools. Often seen as an intuitive advantage offered by VR, the sculpting process can be manually rather than with the clicking and dragging of a mouse. The technique is similar to squeezing out the contents of a paint tube while moving the hand through space. Sculpting the mesh shapes in VR with fluid gesture strokes does feel intuitive, results in shapes that appear more hand-made than what linear 3D modelling techniques can produce, and best of all for creators, a much faster process. However, I discovered early on that the benefits of sculpting in VR were far outweighed by one major disadvantage: the process is anything but optimal. Unlike conventional modelling tools and techniques, which implicitly address the requirements of the graphic software, VR modelling produces mesh shapes that are extremely heavy. This makes VR sculpted geometry not only very difficult to work with in the 3rd party software needed for sharing the work but also impose major limitations on the content being created in the original VR application.

Pre-fabrication and Post-production sculpting techniques

I followed countless tutorials created by VR artists that offered roundabout solutions to the optimization problem presented by hand-sculpting the 3D mesh. The solutions were divided into two approaches, one being in pre-fabrication and the other in post-production. An example of a pre-fabrication technique is building basic 3D geometry, like a sphere, a cube, and a cone, with techniques that reduce the mesh content. The artist then uses an additional set of tools to manipulate these shapes to push and prod the details of the desired form. A detailed synopsis of this process is available in Appendix 6: The "pre-fab" approach to sculpting the mesh in VR. While the process shares similarities to the hand-modelling of clay, it is also laborious and time-consuming – two factors which weigh heavily on a person wearing a VR headset to accomplish their creative tasks.

The post-production approach, conversely, prioritizes the fluid, free-flow of organic, hand-made sculpting. Once the desired forms are completed, an additional step is added, wherein the artist diverts to conventional modelling tools and techniques to rebuild the mesh in an optimized way. In traditional 3D modelling, the geometry of a mesh shape is defined by the vertex points, which is how the system design of 3D graphics can locate and position the objects in virtual space. When working in a desktop modelling application, the artist can manipulate the shape by adding, deleting or moving vertex points, edges or faces of the object. An example of a post-production method can be found in Appendix 7: The "post-production approach to sculpting the mesh in VR. In VR, this process is not only laborious and time-consuming, but it also raises the question of why this needs to be done in VR when it can be achieved in a desktop application. This question is challenged by the statement made by Morie in 1994, in that for VR to reach its potential, it must be used in a way that is not possible to achieve in any other format. My concern in this capacity is the use of VR as a design tool and the creators subjected to long hours spent wearing an HMD. While no concrete health concerns or hazards to vision have been proven, these factors weighed in heavily in my own time spent in the headset. For those (like myself) that work in VR, it soon becomes apparent that anything that can be achieved without having to wear the headset should be mitigated to avoid, among other factors, eye strain. I made careful documentation of the physical struggles encountered while working in VR throughout my creative research in this project. Through these recordings, a pattern began to emerge that narrowed down the key pain point of working in VR: the gaps in a process known as presence.

Chapter 3

Presence in context

Presence is arguably the most important factor in the quality of immersion in a VR experience. The term itself is broad is commonly used outside the scope of the technology, often attributed to any act that involves a state of being fully connected in an activity. Presence is about feeling completely immersed, and can be a state attained through conscious focus, like yoga or mediation, or as an unconscious biproduct of the concentrated focus of being fully engaged, whether the act be reading a good book or doing yard work.

Presence becomes a paradoxical topic where screen technology is concerned. A state of presence can be a kind of cognitive escape, where the mental focus is so great that the physicality of the body is forgotten. On the other hand, achieving a state of presence is also attained by connecting with the perception of the physical senses, like the rhythmic breathing in meditation. This paradox about the separation and, conversely, reconnection, with the body is a topic I was deeply affected by in my creative work in VR, and one I wrote about and researched extensively.

The concept of presence in VR can be loosely described as feeling involved in the immersive experience just as we feel immersed in our everyday reality. Presence describes the feeling of being inside a virtual world, causing the suspension of belief and convincing the senses that what they are experiencing is real. Sol Rogers, the CEO of REWIND, a production company that creates immersive experiences, offers this definition: “Presence is the magic of VR, the feeling that you’re actually *in* the virtual world. Presence will cause the user to suspend disbelief and believe they are in the virtual environment, reacting to stimuli as if they were in the real world."[49] By interacting with sensory inputs, the immersive VR experience becomes more relatable to how we navigate in the physical world. An immersive simulation can in this sense, trick the senses into feeling present in the environment, or that it is real.

In 1994, Morie attempted to define "the ultimate qualifier"[50] needed for presence, or a believable state of immersion, describing it as the "indefinable something that makes it come alive".[51] While predicting that technological advancements in the sensory inputs would help to increase the degree of immersion, the second quality of presence, that of willingness, is often overlooked. Morie suggests that the degree of presence could be enhanced by sensory inputs beyond those we experience in everyday reality. As one example, Char Davies designed the breathing-controlled vest as a mode of navigation in her immersive VR installations. Making the point that there could be alternative ways of moving in space other than erect on two feet, Davies sought to show how the ultimate qualifier in immersion could be the embodied experience. Davies describes this as a "sensuous, all-encompassing spatial quality."[52] Her works served to help reconnect participants to their own bodies as they permeate space.

Presence and creating for VR

As I learned in my own creative research in VR, current applications and tools could be doing more to improve the quality of the immersive experience. While the environment and the tools feel 'real' enough, my willingness to be creating in this space was constantly challenged. To really believe in the immersive state, a user needs to want to be there. This point addresses the

[49] (Rogers, 2017)
[50] (Morie, Inspiring the future: Merging Mass Communication, Art, Entertainment and Virtual Environments, 1994, p. 135)
[51] (Morie, Inspiring the future: Merging Mass Communication, Art, Entertainment and Virtual Environments, 1994, p. 135)
[52] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)

quality of the experience itself and can be compared to being fully engaged in a page-turner of a novel. To truly reach a state of presence in VR, therefore, relies on both the sensory experience as well as the desire to be present. Making art in VR is a thrilling concept when envisioned as dancing around in endless space, creating in the absence of scale. Once creating in VR becomes, as Rossin said, “something that actually needs to work,”[53] the willingness to present in that environment becomes more of an act of will, to stay in the headset to get the work done. Rossin, who had been working primarily in VR to create immersive experiences, eventually made the loss of physicality the focus of her work. Reflecting on her shift to plexiglass sculptures as a format to showcase her artistic investigations, Rossin writes: “I’m trying to find the link between the thing that feels impossible and the thing that’s tangible.”[54] By creating small sculptures in VR then printing them on sheets of plexiglass, Rossin used a blowtorch to soften the plexiglass then molded the shape of the plexiglass forms with her own body. “These pieces that were really physical, that released sort of false bodies,”[55] Rossin reflects, also referring to the works as “an artificial armour of a screen.”[56]

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[53] (Rossin, 2018)
[54] (Rossin, 2018)
[55] (Rossin, 2018)
[56] (Rossin, 2018)

Figure 14 VR artist Rachel Rossin sculpts with a blowtorch to mold plexiglass, an expression of the screen barrier between mind and body.

The screen separation of mind and body

The screen separation of mind and body was a central theme circulating about how we interact with technology in the 1990s. Cobb questioned our use of screen technology as a barrier that separates cognitive process from embodied engagement: “We enter through a flat, two-dimensional screen and engage primarily with our minds, leaving our bodies, for the most part, behind.”[57] According to Cobb, VR can be seen as an extension of this separation, having “a tendency to further the split between our minds and bodies.”[58]

The body of the working creator in VR becomes constricted, and the more complex the work becomes, the more sloth-like the body feels. To design 3D geometry in an infinitely scalable space in a way that can be exported out of the creative software demands a level of concentrated focus that renders the body, except for the arms, nearly catatonic. Furthermore, continuous sessions or prolonged lapses of time spent in this state of focus can lead to headaches and eye strain. Creating in VR being such a new phenomenon, we have no idea whether it could lead to vision damage.

[57] (Cobb, 1998, p. 186)
[58] (Cobb, 1998, p. 186)

The strain on vision

Danni Bittman, one of the leading VR artists whose tutorials I followed throughout my research term claims the risk to vision damage is real. Midway through my research, Bittman became a whistleblower in the creative VR community when they announced their departure from VR after being diagnosed with not one but two eye diseases. Bittman attributed VR as the culprit of both, and through a series of posts on Twitter, explains the science through captioned diagrams. What I found most alarming was that Bittman sites the practice of 3D modelling in VR as being the most destructive.

Bittman had specified that 3D modelling techniques had played a part in the damage to his vision, writing that "excessive VR 3D modelling"[59] had been contributing to the problem since 2016. Bittman offers an extensive, thorough and well-created series of tutorials about 3D modelling in Tilt Brush, which they had launched prior to experiencing vision damage. Having followed these tutorials myself and invested quite a bit of time modelling in Tilt Brush, I could relate to what Bittman had alluded to about the eyestrain of 3D modelling in VR from my own experience in my creative research.

The potential of the Hull Brush

In one of my first major projects in VR, I had focused on sculpting with the Hull Brush. This had been a process of creative experimentation, whereby I ambitioned to sculpt a human figure without much planning, allowing myself to figure out techniques through trial and error. I had initially been enamored by the functionality of the Hull brush, finding it to be as intuitive as it was efficient. I imagined that through practice, I could become highly proficient with this tool,

[59] (Bittman, Twitter, 2020)

using its capabilities to create highly complex 3D geometry while also evoking expression in the organic forms.

The brush seemed to inherit the properties of traditional 3D graphics software, in a way that distinguished 3D modelling in VR from conventional approaches in desktop 3D applications like Maya or Blender. With these inherent properties, it seemed possible to figure out techniques that included optimization strategies while also feeling more natural and expressive. The subjective expression is evidenced in the work itself. I had wanted the figure to appear to be swimming through space. Sculpting the geometry through gestural movements enabled me to create in a way that felt like the practice of life drawing, where the mind focuses on not what a thing looks like, or even what it is supposed to be, but rather, what it is doing.[60]

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[60] (Garvey, 2002)

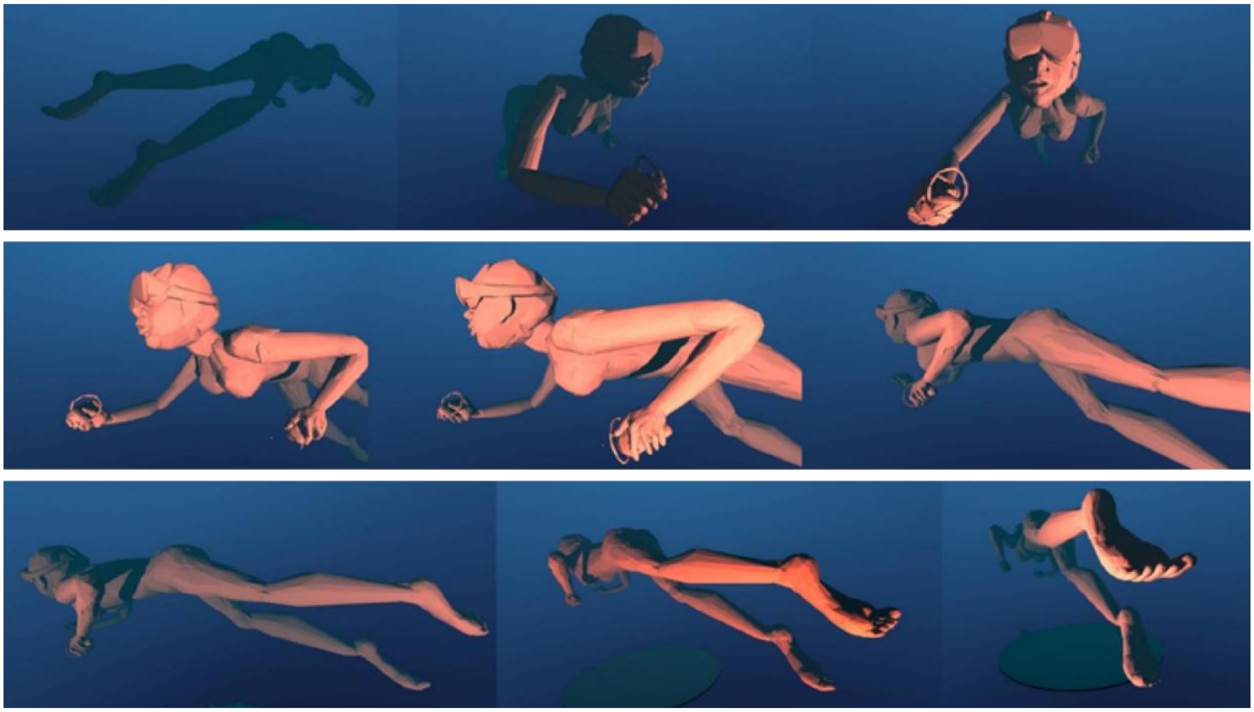

Figure 15 "The diver": A sculpture I made in Tilt Brush, using only the Hull Brush. By Catherine Reyto, 2020.

The reality of the Hull Brush

In my documentation logs, however, I tell a very different story. In the live video recordings and written entries that followed these sessions, I described how I felt like a combination of a welder and a car mechanic. I took frequent breaks from the headset to mitigate the eyestrain, in a way that felt like I was coming up for air. Though I could easily move and scale the sculpted figure in virtual space however I liked, I eventually found it most comfortable to maintain a life-size scale and positioned directly above me. I would go 'back in', leaning as far back as I could in my office chair, as though I were sliding on a wheeled platform underneath a car. Though these physical adjustments enabled me to prolong the sculpting sessions, the physical strain on my eyes and body played a major factor in my eventual decision to abandon the project.

In an industry like animation, where creatives are already subjected to long hours and high-pressure deadlines, a transition to VR could be seen as having tremendous gains on the commercial front. Content can be created and animated in real time in VR, expediting previously time-consuming and tedious production pipelines. But it could also prove to be detrimental to the vision of the animators, as but one example. Alternatively, the risks imposed on creators may result in a resistance to this technology. Given the potential of VR as a creative tool, that would be a tragic outcome as well. It would have been enough to assume that future advancements in graphics software and the HMD lenses would resolve these issues. But the more I learned about the issues, the more it became apparent that the task of finding solutions would come from the hands-on experience and subsequent documentation of creators.

Drawing and presence

Presence can be understood as a pathway of sensory connections that connect the mind to the physical senses. When this pathway is seamless, a state of presence can be attained. Any gaps in this path, an obvious example being when an audio track is out-of-synch with a video track, will prevent or interrupt a state of presence, even if these gaps occur in minutely subtle ways. The challenges creators face in working in VR in a state of presence are examples of such gaps. Eye strain, for example, is the result of a gap in the sensory process of creating 3D geometry in a digital simulation of a 3D environment. These gaps, and how they connect the sensory inputs of vision and touch through a state of presence, can be better understood in the context of drawing.

Drawing, especially the practice of life drawing and that of drawing from observation, involves being in a state of presence. According to famed drawing instructor Dr. Betty Edwards, drawing is a skill made up of component skills, each representing an aspect of visual perception.[61] Edwards takes the approach that learning to draw means learning how to see. Learning to see perceptually the way artists do, Edwards insists, is a skill can be learned by anyone, as learning to draw opens access to "skills you already have but are waiting to be released".[62] Learning to draw well, says Edwards, is simply a matter of learning five component skills of perception. The first four skills must be taught then acquired with practice, and the fifth is a "clicking" of the first four, in an act of simply getting it.[63] Edwards calls this fifth skill the "Gestalt"[64] and compares the learning process in drawing to that of riding a bike, implying that once this global comprehension occurs, the skill of drawing will remain for life.[65]

Michael D. Mattesi, author of the instructional book *Force: Dynamic Life Drawing*, explains that learning to draw perceptually means entering a state of presence.[66] The heightened focus is achieved by learning to draw what the eyes see, in an act that connects the sensory perception of vision with the motor-muscular activity of the hand.[67] Mattesi breaks down the process of perception, thought and physical act in drawing into three simple steps: "seeing, thinking about what we see, and then using our hand to draw it."[68]

The gaps in presence

According to Matessi, the issues that occur, like interruptions in a fluid process, derive from gaps that occur between these steps.[69] This most often takes place when, in looking at

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[61] (Edwards, 2012, p. xviii)
[62] (Edwards, 2012, p. 3)
[63] (Edwards, 2012)
[6464] (Edwards, 2012, p. xviv)
[65] (Edwards, 2012)
[66] (Mattesi, Force: Dynamic Life Drawing, 2017)
[67] (Mattesi, Force: Dynamic Life Drawing, 2017)
[68] (Mattesi, Force: Dynamic Life Drawing, 2017, p. xvii)
[69] (Mattesi, Force: Dynamic Life Drawing, 2017)

something, we form a mental picture of what we saw that is based on our own version, or assumption, and we draw this rather than what our eyes perceive.[70] The gap between the eye and the mind is the most crucial in drawing, and in order to close it, says Mattesi, the mind needs to believe what it actually sees.[71] Mattesi describes this as “feeling the power of drawing in flow, in the moment.”[72] When this second gap in perceptual flow has been closed, or as Matessi puts it, when “you focus on your hand moving at the speed your eye sees and your mind thinks”,[73] drawing becomes a state of presence.

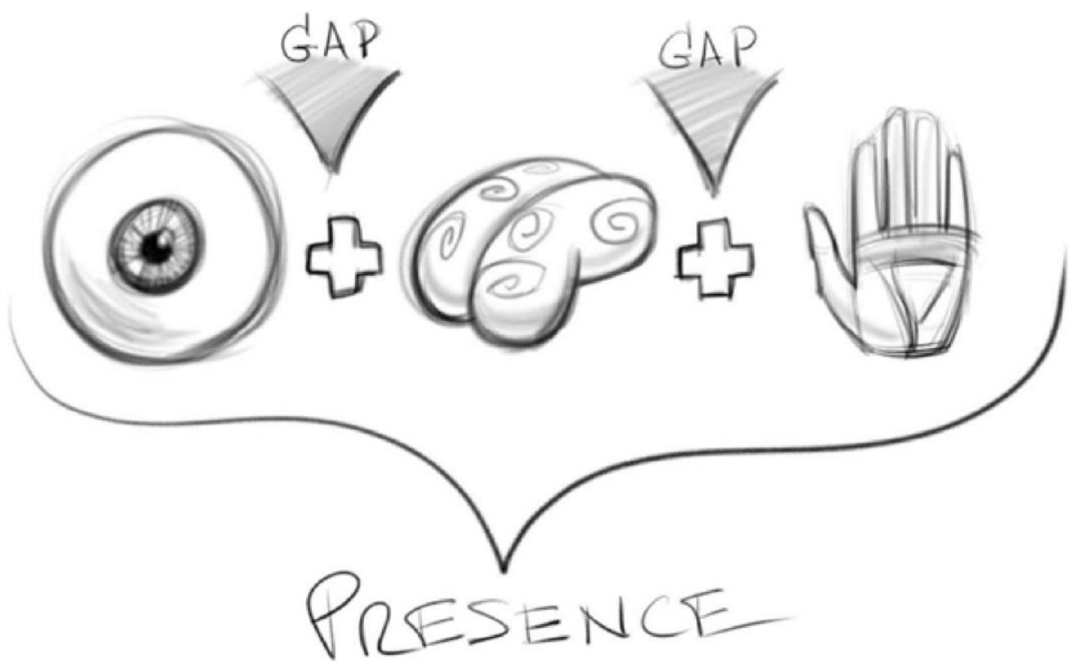

Figure 16 This sketch illustrates the sensory path of presence in drawing.

The disparity between the speeds of the hand moving, sight and thought, could be a contributing factor in the gap in presence when sculpting, rather than drawing, 3D geometry in

[70] (Mattesi, Force: Dynamic Life Drawing, 2017)
[71] (Mattesi, Force: Dynamic Life Drawing, 2017)
[72] (Mattesi, Force: Dynamic Life Drawing, 2017, p. xvii)
[73] (Mattesi, Force: Dynamic Life Drawing, 2017, p. xvii)

VR. I investigated studies about visual perception conducted by neurobiologist Sir Colin Blakemore to find out whether there could be a correlation. I had felt, on an intuitive level about 3D modelling long before VR, that the practice of sculpting the shape of the mesh was inconsistent with the mechanics of visual perception.

The hierarchal steps of visual perception

According to Blakemore's studies, our eyes distinguish the surfaces of objects by first distinguishing the edges of their shapes.[74] In discerning the shapes of objects in our periphery, our eyes first recognize the edges, followed by the surfaces, then finally the shapes.[75] To read more on how this works, refer to However, 3D models are sculpted in a reverse order, where shapes are used to sculpt into recognizable forms. The contours are only formed once the object has been sculpted into the intended shape. This reverse ordering (of perceiving the shapes before the edges of forms) may be counter-intuitive to the natural way our eyes perceive objects. 3D modelling techniques in VR could thus be causing gaps in presence and contributing to eyestrain.

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[74] (Blakemore, 2019)
[75] (Blakemore, 2019)

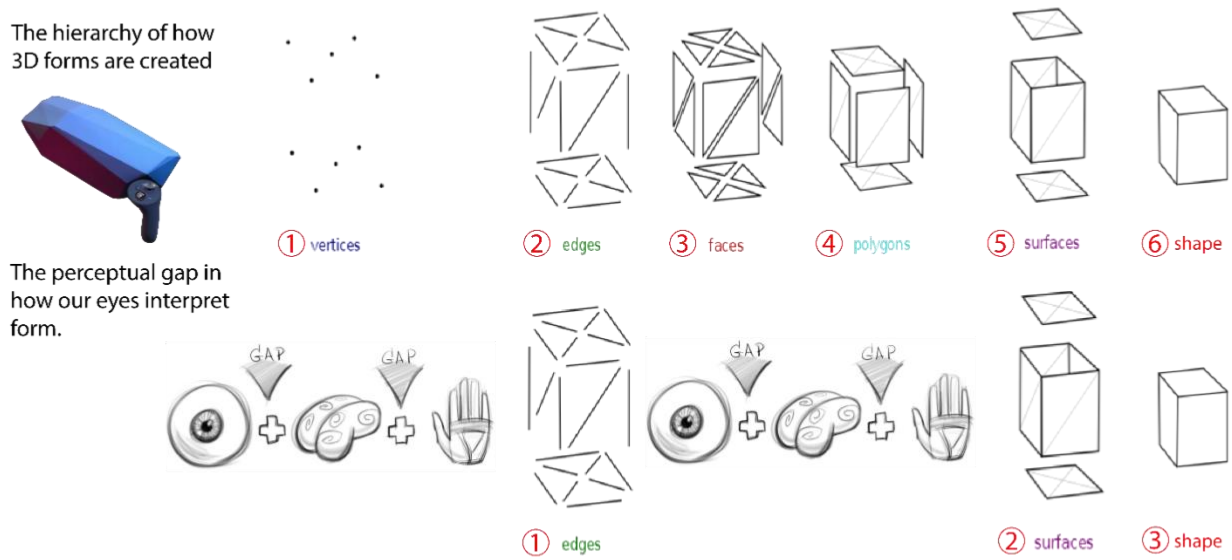

Figure 17 The top row of the diagram shows how the first step of creating 3D geometry begins with points. The second step, lines connect the points to form edges. This order contrasts with the second row, which shows that our visual perception recognizes the edges first. The points of 3D modelling that precede the edges may be causing gaps in presence.

Drawing as an increased state of presence

Drawing a form by hand, by comparison, begins by first defining the outer contour of the shape. Lines define the edges of the form. This means the edges of the shape are drawn first, as a series of hand-sketched lines. These lines will eventually define the both the shape of the form, as well as describe the volume and mass of the object being drawn. By first drawing the edges, or lines, that define the form of the shape, the speed at which the hand draws these lines matches the speed of sight and thought. The second gap in presence, the connection between the eye and the mind, is thereby closed. By prioritizing drawing, rather than sculpting techniques, creators can work in VR in an increased state of presence.

The elevated state of presence of drawing over sculpting is recognized by sculptors who work with material mediums. The faster connections between thought, vision and hand movement allow for faster iteration of ideas. As famed sculptor Henry Moore puts it, “Drawing is a means of finding your way about things, and a way of experiencing, more quickly than sculpture allows, certain tryouts and attempts."[76] Sculptures often begin with hand-drawn sketches. The compounding forces of the model can be felt through the physical expression of weight and mass in the gesture strokes. By beginning with sketching rather than sculpting in VR, creators can focus their attention on what their model is doing, rather than what it looks like. Rather than think about what the model is supposed to be, the mind can focus on feeling its core motivation in real-time through gesture strokes.

Chapter 4

A drawing method for 3D forms

While working on The Diver, I had developed a technique that later became the foundation of the method I designed for spatial drawing in VR. The technique had come to me by recalling life drawing exercise called "cross-contour" drawing. This mode of drawing describes the volume of a form using lines that travel across the form. Cross-contour drawing is a way of drawing proportionally while conveying a sense of mass and depth. When cross contour drawing is done with expressive gestural strokes, it becomes an "attitude and approach"[77] in reflecting the eye movement in and around what is seen. The cross-contour technique in drawing a human figure in 2D, for example, is about feeling the force and mass of the shape through spiral lines, like overlapping springs or Slinkies. By drawing what the eye sees, rather than thinking about what a thing ought to look like, the gap between the hand and the mind is closed.

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[76] (Francis D.K. Ching, 1997, p. 262)
[77] (Fry, n.d.)

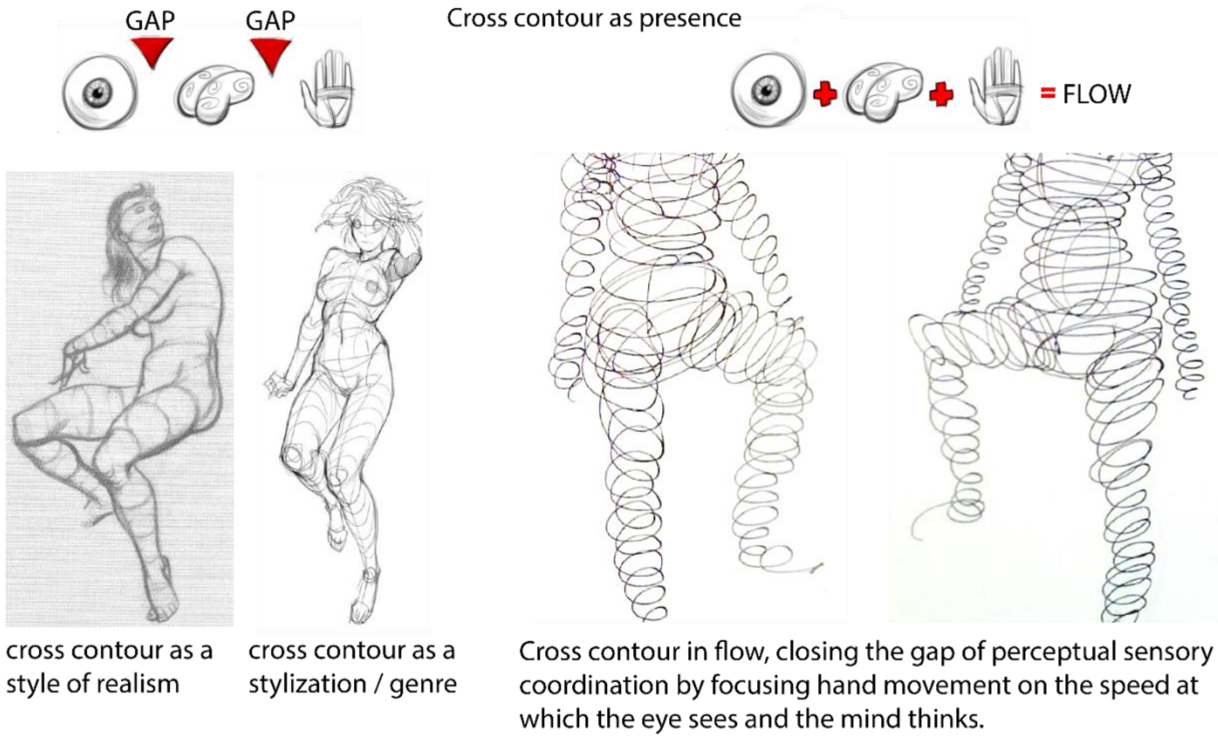


Figure 18 Comparisons between stylized sketches of a figure using the cross-contour technique vs. using the cross-contour spirals to feel the force and mass of the figure through gesture. The first approach uses cross-contour as an aesthetic, whereas the second approach uses spiral-like gesture strokes to help close the sensory gaps in presence.

The shoulder as a surface support

When drawing in VR, however, where there is no surface plane to support (and stabilize) the forearm, it becomes rather challenging to retain a consistency in the rhythm of the spiral lines. I found that by extending my arm in front of me and ‘locking’ it in position at the shoulder joint, the rotational axis of my shoulder could become a substitute for the surface plane. I would then apply pressure on the controller’s trigger to “release” the 3D mesh shape. While doing so, I slowly bent my elbow, bringing my hand towards my eyes in a rhythmic, circular motion. Because of the spiraling rotation, I began thinking of it as the “corkscrew” technique, which I would later evolve into the design of a method for spatial drawing.

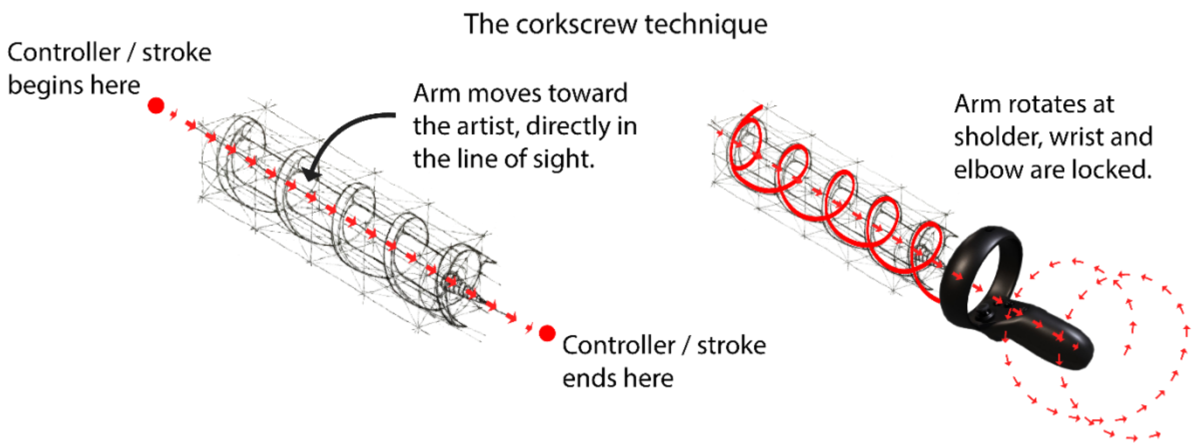


Figure 19 This diagram illustrates the spiral motion of the arm. The rotation begins at the shoulder joint, while the elbow slowly bends, directing the drawing hand closer to the eyes. With the support of the shoulder, the drawing hand can remain locked in the line of sight.

The arm as a mechanical tool

It became most effective to sculpt the diver as though I were a mechanic lying under a car for the same reason Michelangelo painted the Sistine chapel while lying on a horizontal platform suspended beneath the ceiling. Just as it likely had in these examples, I had thought it might mitigate the duress of prolonged work sessions that required concentrated mental focus and rhythmic, operational precision of my motor muscles.

The gravitational force was absorbed by the supporting muscles of my back, while my shoulder blade had instant access to relief from the material surface of the back of the chair. The position converted my arm into a mechanical tool, the physics of which I could improve on through practice. By relying on my arm to provide functional support, I was able to remain in the flow of presence. My drawing hand could move at the speed of my eyes, while through memory and imagination, my thoughts were focused on the feeling the mass and force of the model, empathizing with the movement.

The spiral motion and visual perception

I later realized that the Corkscrew method had, through the experimental act of trial and error, inadvertently established a way of modelling that was more natural to visual perception while also being aligned with the requirements of 3D graphics software. The corkscrew method compensated for the absence of edges sought by my visual perception as the first step of my eyes defining the shape of the form. By bending my arm at the elbow and brining my hand towards me while drawing the continuous spirals, the vertex points of the mesh followed the spiral motion as it moved towards me through the depth of space, otherwise known as the Z-axis.

The Hull brush was designed by Google engineers in the 3D gaming engine Unity, so the properties of the brush inherently responded to the 3D coordinate space of the XYZ axis. I had learned fairly quickly that the Hull brush is unable to calculate curves. Unlike the 3D brushes in Quill, which can follow the C and S shaped curves of a gesture stroke, the Hull brush follows the cubic grid of the Cartesian Coordinate System.

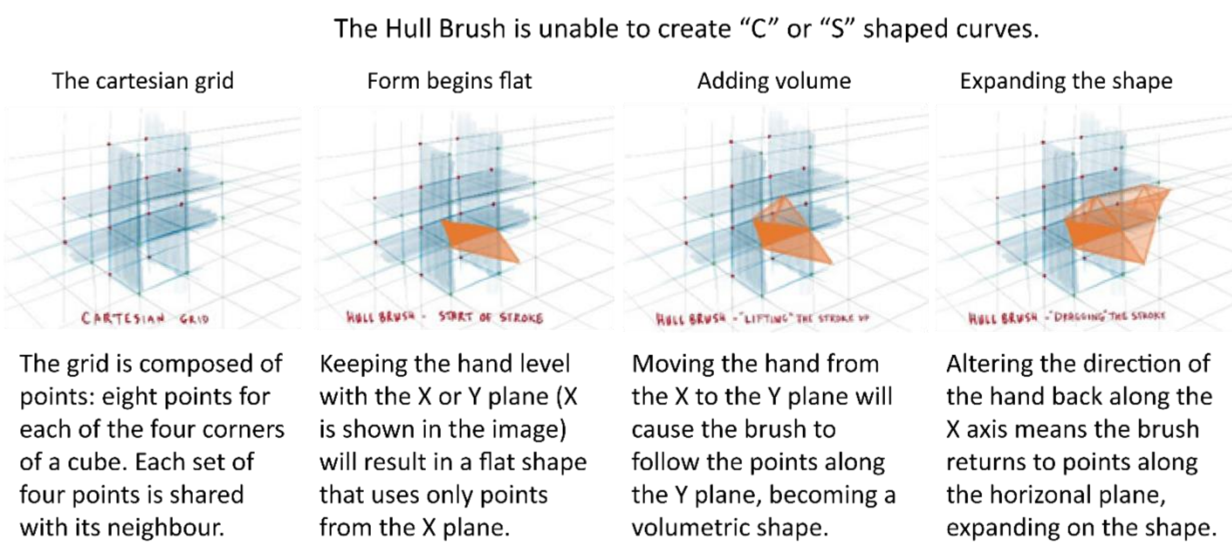


Figure 20 A diagram I sketched in my process log illustrates how I broke down the steps in the functionality of the Hull Brush.

The resulting behaviour of the mesh was that it dynamically recalculated the vertex points from circular edges that followed the spiral motion, to linear planes, or in 3D modelling terms, faces. Because of my previous experience in conventional 3D modelling in Maya, I had intuitively known that the linear faces being recalculated by the brush was making my model far more optimized by reducing the complexity of the mesh.

The corkscrew and tapping techniques were used to create the contours and volume in the form.

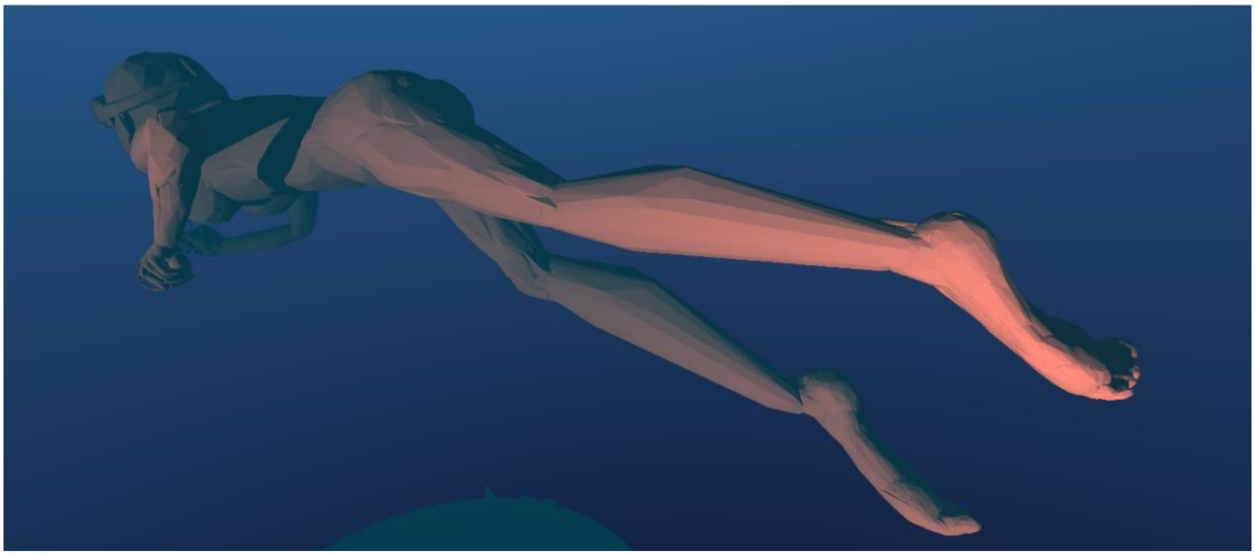


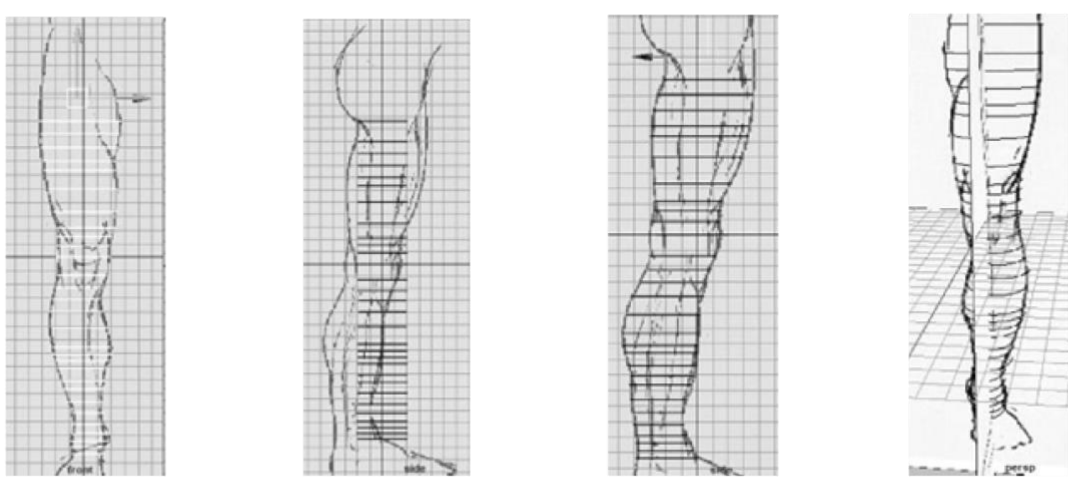
Figure 21 The corkscrew technique worked with the properties of the Hull Brush to transform the spiral contours on the mesh into elongated faces, resulting in a more optimal design.

The qualities of life drawing in 3D Modelling

I later discovered I was not the first artist to attempt to infuse techniques of life drawing into 3D modelling, nor a way to do so while aligning with the requirements of the 3D graphics software. I came across a paper by Gregory P. Garvey from 2002, summarizing a workshop he had hosted on this very topic. Garvey was concerned that the sudden shift in the animation industry from hand-drawn figures to computer-rendered 3D models was ebbing out the subjective expression of drawing. Garvey sought out approaches that brought something about the nature of life drawing into 3D modelling techniques, using a human figure as an example of the natural curve of shapes in organic forms.

Garvey used NURBS (Non-uniform rational basis spline) modelling rather than the polygonal modelling that is commonly used in animation. Unlike polygonal models, which create shapes based on individual vertex points, NURBS geometry averages out the points along prefabricated curves, or splines. Referring to a photo image of a human figure, Garvey used ellipse shapes to follow the curving form of the muscles. By placing circles close together, Garvey had illustrated regions of the form where there was more detail, such as the knees of the figure, and fewer circles where there was less, like the smooth planes of the thighs.

Garvey’s 2002 workshop: cross-contour technique with circular shapes



Beginning with a 2D image of a human figure, the “circle tool” is used to follow the topography of the form.

Each circle is adjusted to align with the contours, with more circles where there is more detail, and fewer where there is less.

The predetermined points of NURBS ellipses are ad-justed to follow the curves to align with the natural curves and indentations of the human figure.

The technique is resonant to life-drawing, in terms of finding the form and grace, and what Nicolaides refers to as the “force” of the body.

Figure 22 Images from Garvey's workshop show the use of NURB circles to follow the topography of the human leg. Manipulating the shape of the circles to follow the curves of the muscles brought some qualities of life drawing into 3D modelling.

The hull in context

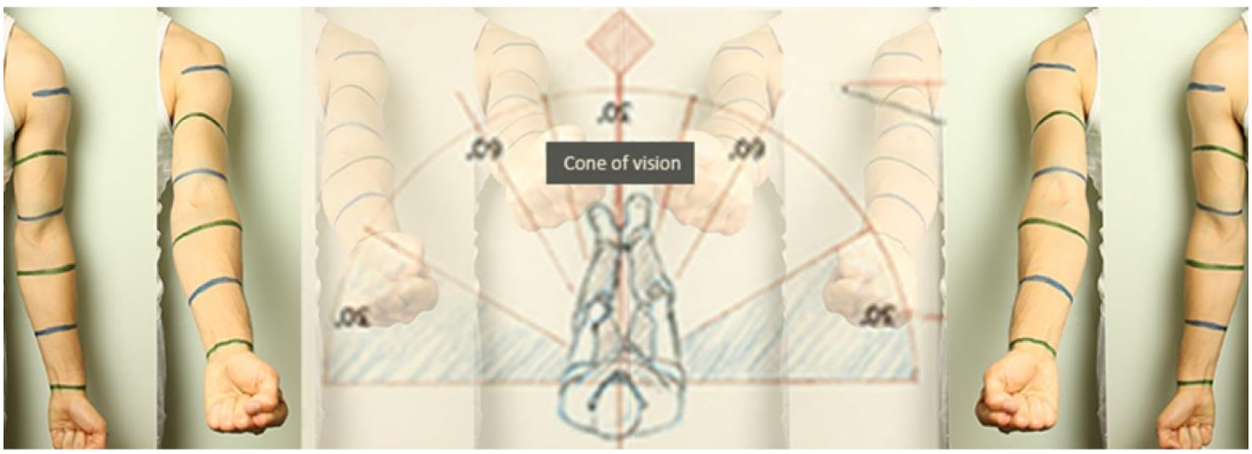
Interestingly, NURBS modelling finds its origins in the drafting techniques that were used long before computers. Drafting tools like protractors could not be applied in the rendering of freeform curves, like that of the hull of a ship. Shipbuilders used flexible strips of wood, known as splines, which were shaped into the desired curve by a series of control points. The elasticity in the strip of wood contorted to the curve of the control points, in a way that resulted in the smoothest shape possible. The shape of the spline could be dynamically adjusted by moving the position of the control points.

Although I could find no documented correlation between the Hull Brush and NURBS modelling, the namesake of the tool and the origins in the drafting tools of shipbuilders seems more than coincidental. Though I went on to research the many iterations of VR tools, the Hull Brush continues to show the most potential for creating optimized 3D geometry while in a state of presence. In at least a very primitive way, the tool combines the ordered points of polygonal modeling with the drafting techniques used to create freeform curves. In doing so, its functionality attempts to meet the needs of the human designer while also adhering to the requirements of the software.

Promising though it may be as the leading tool in VR creation, the Hull brush still has a ways to go in closing the gaps in presence while reconciling with the mathematical principles inherent in 3D graphics. As my goal in this project was to suggest approaches for creators to apply in VR rather than design new iterations of the tools, I focused on how to translate the cross-contour drawing technique as a method for spatial drawing in VR.

The Corkscrew method

I eventually made a correlation between Garvey’s method and the technique I had applied when sculpting the figure with the Hull Brush. The corkscrew technique is essentially the same as the perspective technique known as ‘foreshortening’, for drawing an object that falls directly in front of the line of sight. The closer to the centre of vision, the more accurately we can interpret the angle and depth in space.



The closer that objects move into the direct line of sight, the more they become foreshortened. While this concept is challenging to grasp in 2D drawing, I found it the most intuitive way of drawing in 3D space.

Figure 23 An overhead diagram illustrating the cone of vision is overlaid to show how it correlates to the foreshortening effect when objects are directly in our line of sight.

The line of sight

Reflecting on this observation led to an insight about how to significant a role that the line of sight plays in perceiving depth relationships in the virtual environment. I observed that forms were more easily drawn when they remained within the line of sight.

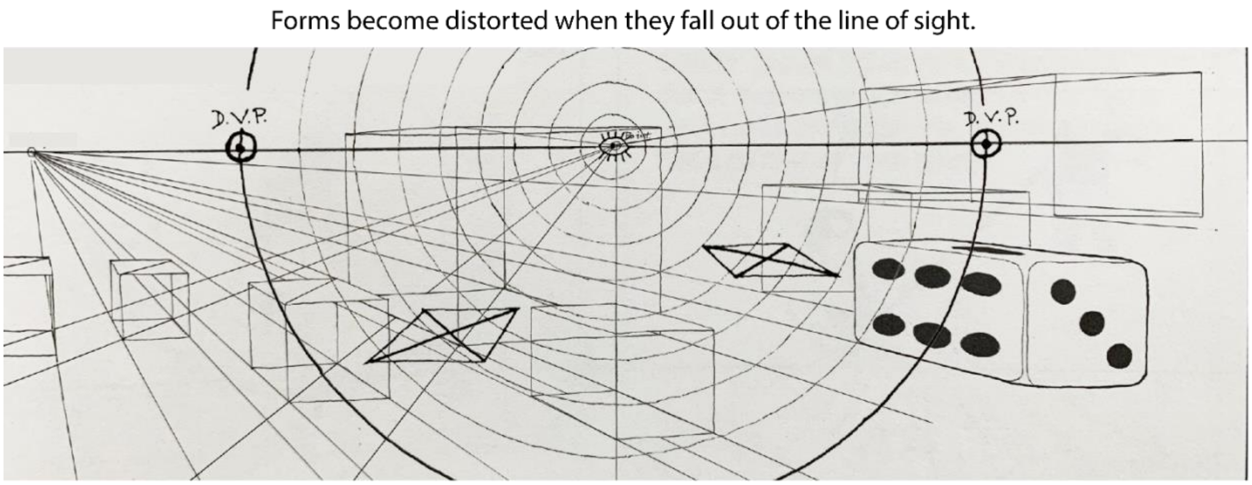


Figure 24 A diagram of the line of sight is overlaid on a drawing of objects drawn in perspective, to illustrate the distortion that occurs in the field of view in VR.

The fixed, rotational axis of the arm provides a mechanical method for effecting the volume of forms while freeing the artist to focus on the expressive gestural shapes and strokes that make up the contours.

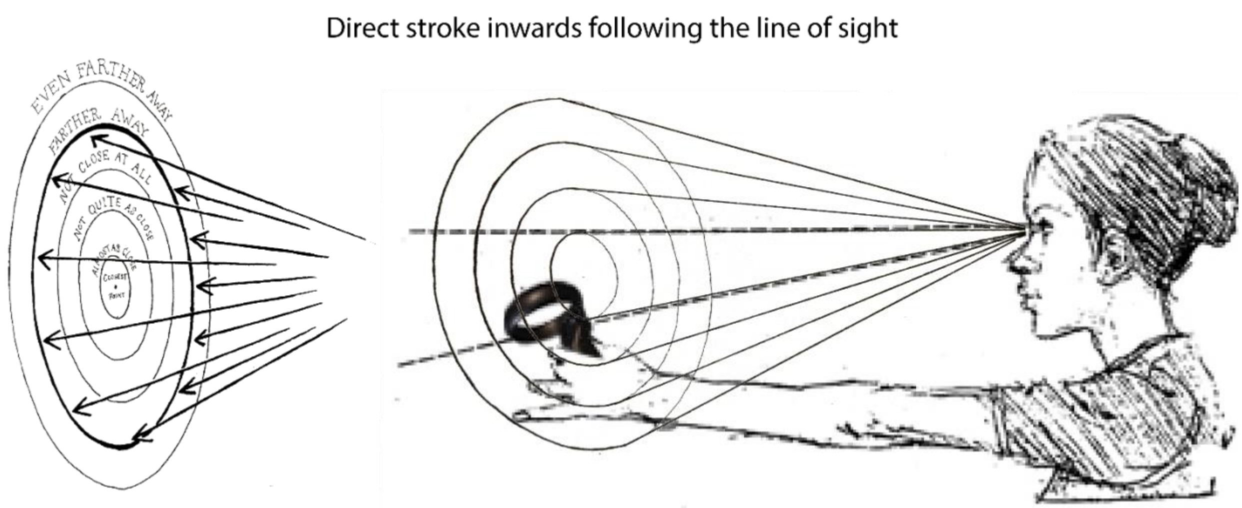


Figure 25 The diagram on the left illustrates how our visual range diminishes the further objects are from our direct field of view. The illustration on the right demonstrates the line of sight as a work area for the Corkscrew method.

Spiral growth patterns in nature

Inspiration that led to a new method came while out walking one day, when I came across a tree that struck my eye. There was a distinct spiral curvature that ran up the form of the trunk. It led me to research geometric patterns in nature, soon discovering that the spiral was a characteristic of the classic proportioning systems in geometry that date back to Antiquity. The spiral pattern is a type of visual relationship referred to by Kimberly Elam as "the essential qualities of life",[78] that describe the growth patterns in nature that are characterized by a spiral. In her book, Geometry of Design, Elam writes that these patterns can be interpreted in sequential mathematic formulas, such as the Fibonacci sequence.[79]

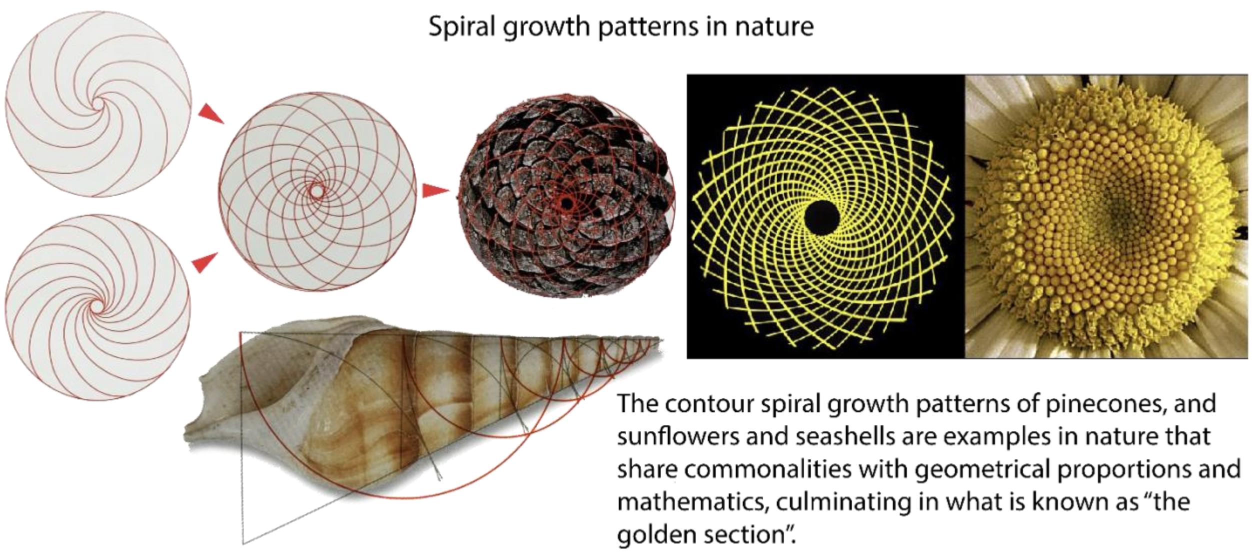


Figure 26 These images illustrate the correlation between spiral patterns in geometry with those of various forms in nature - in this case a pinecone and a seashell.

[78] (Elam, 2001, p. 9)
[79] (Elam, 2001)

The subjective expression of forms in nature

It occurred to me that the spiral pattern of the tree did not form a perfect sequence. The pattern of the tree had been influenced by a particular set of characteristics, such as its location, how it had been pollinated, and the effects of weather. This meant that the pattern was a unique expression, and the spiral was the result of the individual life experience of the tree. I connected this to the agency found in drawing.

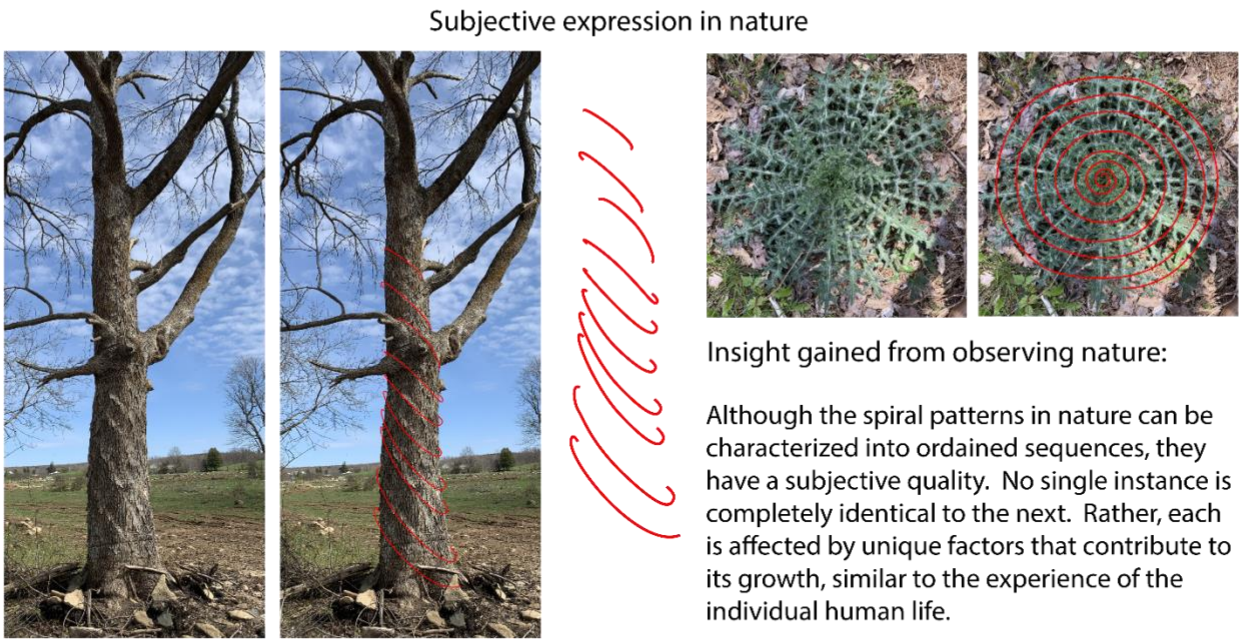


Figure 27 The spiral pattern of a tree and a forest weed are examples of how nature produces unique designs.

The cross-contour technique in 2D drawing

Cross-contour drawing with curved, or spiral lines is a technique for drawing objects from observation while also expressing the individuality of the artist through the gestural quality of the outlines and the unique composition of the form. The subjective quality in spiral patterns in nature made me realize that the cross-contour method was also a way of mediating between systematic patterns that makeup the geometric shapes of forms.

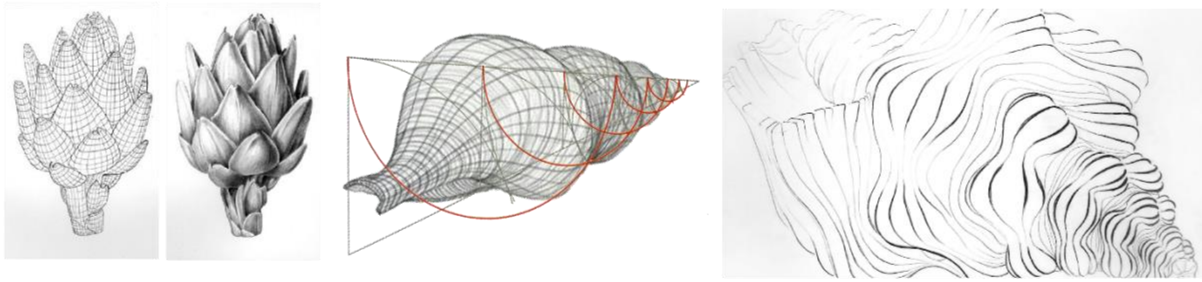


Figure 28: The images of the plant and seashell on the left demonstrate the cross-contour technique for drawing objects with precision and realism. The sketch on the right shows how cross-contour drawing can enhance the qualities of force and mass through the subjective expression of gesture strokes.

I compared the use of cross-contour drawing of objects with precision and realism to the same technique applied expressively with gesture strokes. The comparison led me to the insight that cross-contour drawing is very similar to the wireframing of mesh surfaces in 3D graphics. As a method of drawing forms by hand VR, it could prove to be a means for artistic, personal expression and the math of 3D graphics to use similar functions in structuring forms. I will expand on this topic in the discussion section of this document.

The spiral shape produced by the shape is about drawing how a thing feels, rather than what it should look like. The corkscrew shape will define the mass and movement, but additional structure may be needed in defining the force in the form. To execute this, expressive gestural strokes can be added along the length of the shape. With the curvature in the shape already formed by the Corkscrew method, these linear strokes can be drawn with physical force and energy. The linear strokes may become the part of the linework that remains even once the mesh, as they can possess an aesthetic strength, while defining the edges of the form. The physicality of the linear strokes here becomes the autographic quality of the work, as the personal signature of the creator is expressed in the gesture. In defining the form by its edges, through gesture strokes, rather than by the points or faces of the surface mesh, the final gap in presence is closed. The state of presence is increased for the creator working on the piece, and the finished work will be viewed by audiences in a way that follows the hierarchal order of visual perception.

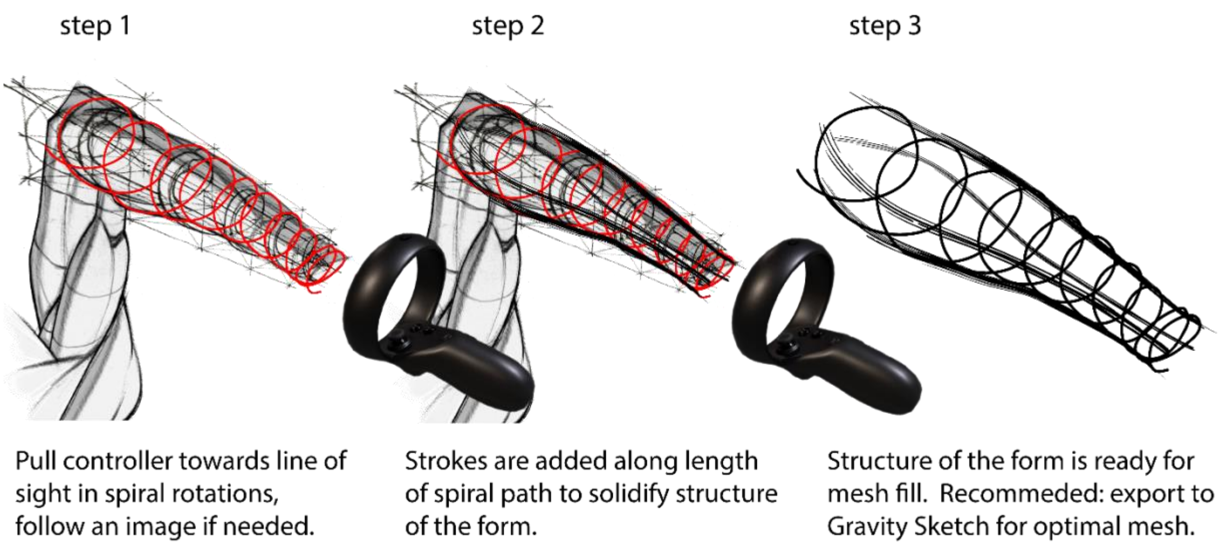


Figure 29: This three-step diagram demonstrates how the Corkscrew method is done in a state of presence,in how the eyes, mind and hand work together to feel the shape. The linear strokes are added as a final step, to add edges to the form with unique expression.

Relieving eye strain with the Corkscrew Method

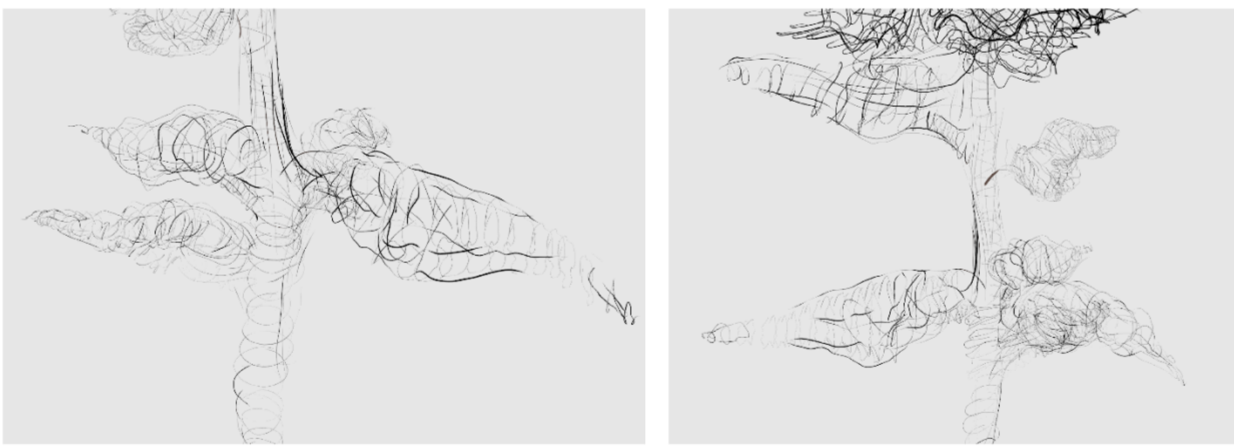
The Corkscrew method, in how it involves feeling out the edges of shapes through gesture lines, presents a possible solution for the eyestrain experienced with 3D modelling. The freeform nature of gesture drawing relieves the eyes from being focused for long periods on fixed position, which is often the case when using 3D sculpting brushes to form shapes. The steps of spiral gestures and structural lines and are alternated as the form is created, in a fluid process of shaping the volume and finessing the structure with gesture strokes. Shaping tools can be employed to easily manipulate the spiral strokes in a way that, unlike working with a mesh, will not effect change on the remaining area of the form. The eyes are thus additionally relieved from the intense focus on the line of sight, while the body is freed from the physical constraint required in precise movements.

Locking the arm at the shoulder has the added benefit of engaging with the pressure sensitivity on the trigger button of the VR controller with increased motor-sensory precision. By varying the degree of pressure applied on the trigger, the stroke shape and weight can be dynamically adjusted in real time. Once the form begins to take shape, additional gestural strokes further define the form by iterating and eventually refining the form of the object. This method is only as time-consuming as the creator desires it to be, as it can be applied for rapid iteration of ideas in 3D forms or to sketch the details of a finalized structure over several sessions. Additionally, by making use of other tools typically offered in creative VR applications for warping shapes, the gesture lines can be easily manipulated at any point in the process. Unlike the complications that can arise in working directly with the mesh surface of a model, structural lines can be altered without risk.

The Corkscrew method in action

I tested the corkscrew method by drawing a tree in Quill. I used no image reference and sketched perceptually from memory and imagination. Instinctively I worked facing downwards, with my back arched and head directed toward the floor. I felt that my body was physically engaged with the form of the tree in an empathetic sense, in bringing it to life by literally growing it upwards from its roots. I used the shape tools to shift the direction and shape of many of the circles, while imagining the natural bends and bumps in the trunk. As I moved upwards and into the branches, I shifted back and forth from the corkscrew method to Garvey’s method of duplicating circle shapes, often finding they worked best when in an interlocking rhythm.

Locking my arm at the shoulder helped me engage with the pressure sensitivity on the trigger button of the controller to enable variety in the stroke shape and weight. I began adding structural lines in the form of loose gesture strokes, more as a method of ideation than any deliberate strokes that would remain as outlines. In doing so, I was sketching the volumetric structure of the form through hand-drawn gestural lines. Nothing was permanent nor tedius to edit, and the overall process was as satisfying and expressive as drawing on paper.



I used the corkscrew method to draw this tree from memory and imagination in Quill.

Figure 30 The image on the left shows how I used the Corkscrew method to 'feel' the shape of the tree, while giving me the enough structure to add linear gesture strokes. These expressive strokes give integrity to the form. The image on the right shows the combined use of stacked circles (top left branch), which were then shaped with the warp tool.

“Filling in” the mesh

What is essentially taking place with the Corkscrew method is the steps of 3D modelling are being broken down into more manageable tasks. The Corkscrew method is the initial step, where the lines become the edges that will form the contours of the desired shape. This step prepares a scaffolding structure for the second step, where the mesh is ‘filled in’. For this step, there is yet no alternative to the aforementioned methods of pre-fabricating the mesh with primitive shapes or building the mesh with conventional 3D modelling techniques. What it does succeed in doing is providing a way to render 3D geometry in any VR application, as freehand sketching is a feature shared by all platforms. The hand-drawn mesh can be exported as an FBX file and is therefore not software-dependent. This frees the creator at hand to fill in the mesh using whichever application or tools that best suits level of experience and the requirements of their project goals.

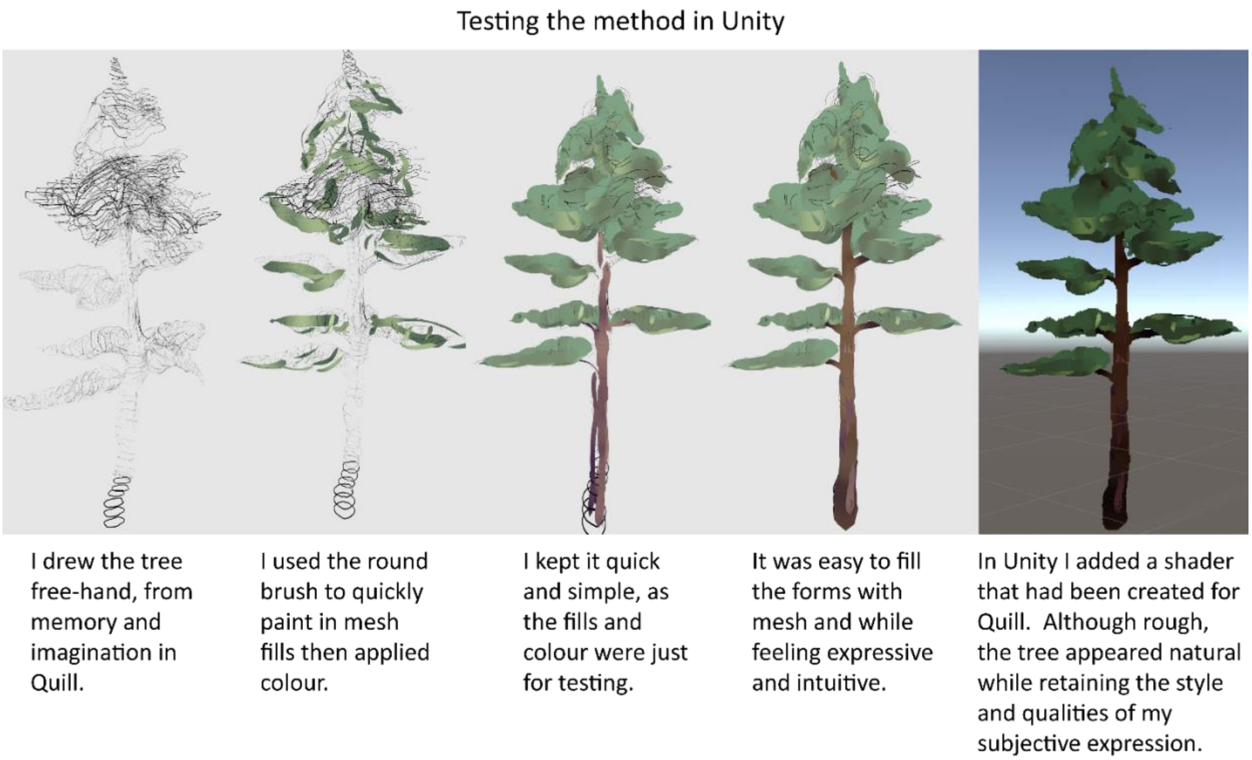


Figure 31The five-step process of sketching the tree with the corkscrew method, filling in the mesh with a 3D brush, then importing to Unity and adding a shader.

The Corkscrew method is an approach to drawing spatial forms in VR in a way that increases agency while closing the gaps in presence. But this method alone did little to resolve the problem of how works created in VR could be shared in an immersive way. A common link between all formats of visual composition, be it painting, film, photography, or even sculpture, is the relationship between form and space. The Corkscrew Method had provided a way to translate 2D drawing skills to 3D forms. But to consider VR an art medium, what remained was the design of a method for representing 3D space.

Chapter 5

A drawing method for 3D space

The relationship between form and space is as important in VR as any other form of visual composition, but 3D space, and how we understand it, is a very complex concept. My lifelong acquisition of drawing skills had helped me translate drawing on a 2D surface to a method for drawing 3D geometric structures in VR. But when it came to translating the concept of 2D space to 3D space, the vocabulary was simply not there.

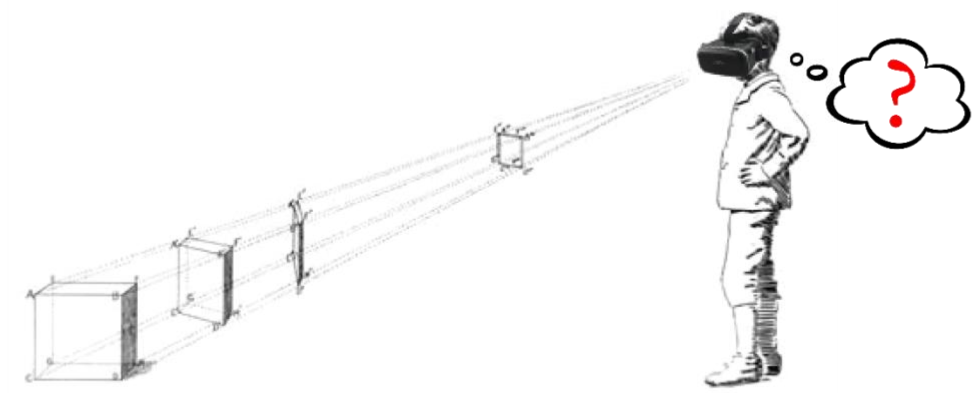


Figure 32 This image illustrates the challenge of translating the concept of drawing 3D geometry on a 2D surface into that of drawing inside 3D space.

As I previously mentioned, I had initially attempted to work out a way to impose a scale system on the infinite space of VR by recreating linear perspective. It was all I knew to do, in attempting to relate my methods of representing depth in 2D drawing. I spent many months going through cycles of prototype iteration, reflective writing and researching a vast array of topics spanning from art history, metaphysics, astronomy, scientific studies about vision, and the works of artists and theorists about VR. Eventually, the ideas began to synthesize and coalesce into an approach to immersive virtual space that could be of service to creators working in VR. Like the Corkscrew method for drawing spatial forms, this approach is conceptual by design for creatives make use of independently from what features may or may not be available in current creative VR software. The Corkscrew method is designed to enhance agency and presence in rendering 3D forms in a way that caters to optimization requirements. Similarly, the qualities of agency and presence form the core of this approach to 3D space while suggesting a method for sharing the environment as a contained world. This method translates art principles dividing the scale of depth into layers on a 2D plane that is typically used when drawing or painting landscapes. I have termed this method “Worldscaping” to emphasize the immersive quality of a shareable, virtual world as the key qualifier that distinguishes the relationship of form and space in VR from that of a 2D image.

I will begin explaining how this method works by describing the key insight I came to after many months of research: the XYZ axis is the link that connects the body to virtual space. In the following sections, I will break down the key factors that led me to this insight, all of which are rooted in the concept of Perspective.

Perspective is challenging enough a concept to teach, but deconstructing it, both in rejecting it as a mathematical model of our vision, and as a political ideology, can feel like trying to explain the way out of room full of mirrors (aka “infinity room”). In this thesis project, it became the most crucial point for me to attempt to get across to creators who are either currently or considering working in VR. I believe it is the most powerful feature about creating in VR as an artistic medium. The most fascinating insight of my research was realizing the extent to which the literal methods for working in visual perspective and the philosophical interpretation of perspective, are essentially the same thing. By breaking with the rules of perspective, creators are empowered to invent them in new ways. VR a tool that can be used by creators to create alternative perspectives, both as literal methods of scaling space, as well as cultural views. The Worldscaping method I designed is but one example, and one that I propose in hopes of inviting other creators to either build from, or redesign in their own unique way. To understand how the Worldscaping method presents an alternative method for drawing in Perspective, as the saying goes, the rules need to be learned first before them. I have adopted the approach taken by Betty Edwards, in breaking down the skill of drawing into five components, each representing a perceptual skill. I present here the five components of drawing in 3D space: The tilt movement, perspective, vision, and scale. Like Edwards, I consider the fifth component the Gestalt, the result of the four components working together.

Component 1: The Tilt Movement

Translating the skill of drawing from a 2D image plane to a 3D world is a paradoxical concept. Drawing in VR entails both being embodied inside the mathematical model of perspective and rejecting Perspective as a method outright. To understand what was taking place in this translation, I needed to break down the steps, and did so according to my own subjective experience in artmaking and digital creation. I formed a link between three key events in the evolution of the translation of drawing perspective on an image plane to drawing with embodied perspective in VR. Those key events are the practice of creating digitally with a stylus pen on a graphics tablet, the VR navigation system designed by Char Davies, and the first drawing application created for VR. The link that connects these events is the concept of tilting, or rotating, in an embodied way.

Tilt in the stylus pen

“Tilt” is an integral feature in Wacom’s design of the stylus pen, wherein the drawing hand tilts the pen with a physical motion that the tablet responds to as a sensory input. The intention of the pen tilt is to be able to draw not just with the tip, but the sides of the pen as well, to simulate the sensation of drawing with material tools and media. Wacom promotes the tilt as a feature that produces "lighter but more organic strokes"[80] that can feel more natural to the drawing process. The tilt functionality provides a fluidity akin to gesture drawing, or as described on Wacom's website, the "gesture-like approach to sketching".[81] The tilt enables the hand to access the tips, edges and sides of the pen, or paintbrush, while pushing or pulling it horizontally across the tablet, making the resulting artwork feel more alive.[82]

Tilt in the Breathing-Controlled Vest by Char Davies

Davies integrated the tilting motion of the body to navigate space in her immersive VR installations. Sensors in the vest were used to measure the rotational degree of the spine, enabling participants to move horizontally through the space in whichever direction they chose to tilt.[83] The tilt allowed for free motion in any direction, which, when coupled with the vertical movement that was directed the expansion and contraction of breathing, kept the body connected to its surroundings. Davies describes how the tilt navigation helped participants be "aware of their body functions of breath and balance."[84]

Tilt in Tilt Brush

The tilting action first appeared in VR in Tilt Brush, and the significance of this feature is apparent in the name of the application. The brand name was derived from the earliest iteration of the software, several years before other creative VR apps had emerged. Before it was possible to draw or paint dynamically in depth, or three-dimensionally, the first prototype involved

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[80] (Park, 2019)
[81] (Park, 2019)
[82] (Park, 2019)
[83] (Davies & Harrison, 1996, p. 27)
[84] (Davies & Harrison, 1996, p. 26)

drawing on a two-dimensional surface. This 2D drawing could then, in virtual space, be tilted in any direction.[85]

Tilt and the Gimbal

In all three cases, the tilt rotation is taking place on the horizontal plane, and the point of origin of the tilting mechanism is centred on a joint of the body. The tilt rotation of the stylus pen is activated at the wrist, whereas in the case of Davies' immersive installations, the tilting navigation is rooted at the root of the spine. In the first prototype of Tilt Brush, the tilting motion is based in the shoulder. I finally began to see a connection to a feature of 3D graphics applications that had, while working in creative VR software, been literally in front of my face for months: the gimble. Also known as the Gizmo in the animation industry, this small but immensely powerful tool is the predominant feature of 3D graphics software. The gimbal in VR is made up of three ellipses that cross one another perpendicularly through the horizontal plane, forming the shape of a sphere, with three arrows that originate from the centre of the sphere and point outward to the surrounding invisible coordinates of virtual space. Both the ellipses and the and the arrows are marked with the respective colours of XYZ space.

The tool can be used in many ways, the simplest being to move, transform, or rotate a single object, a selected group of objects, or the contents of an entire environment. I began to see that the tilting motion was the correlation between the rotation in the joints of the body and that of the gimbal tool. Each of the joints was acting as a gimbal, and though the motion of the joint is limited to the constraints of anatomy, it can be imagined as rotating within a sphere of 360

[85] (Ungerleider, 2016)

degrees. It occurred to me when thinking of the sphere shape, that our eyes function in the same way.

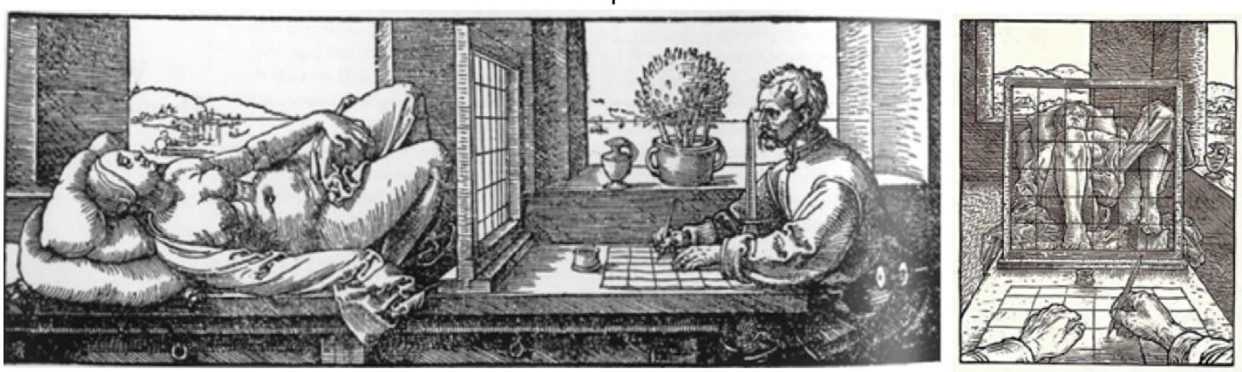
The gimbal tool, I realized, can also be used as a representation of the mechanics of vision. The spheres of our eyes tilt on a horizontal axis, which, in the terminology of art principles, is known as the horizon line. As those who are familiar with the techniques of drawing perspective are aware, the horizon line is situated wherever we fix our point of view.

To clarify the significance of the gimbal in how it relates to the eyes and bodies of creators working in VR, I need to first explain the other factors that led me to this insight. The first and most fundamental factor is the discord between the mathematical model of perspective and visual perception.

Component 2: Perspective

The use of the XYZ axis as a method for working with depth and scale in 3D space traces back to the Renaissance, with an invention called the 'perspective device,' created by artist Albrhet Durer.[86] The device consisted of a square grid of strings that were held together by a frame. The points at which the strings overlapped were each given a numeric value. By placing the framed grid between themselves and their subject, artists could use these numeric points to translate accurate proportions with a realistic sense of depth.

Durer's Perspective Device



A screen divided the artist from the subject. A mathematical grid on the screen's surface enabled the artist to plot the subject out on paper in points. This resulted in a convincing representation of depth.

Figure 33 The image on the left demonstrates how the Perspective Device was applied, shown in profile to illustrate the actual distance between the artist as the viewer, and beyond the screen, the subject, as the viewed. The image on the right shows how the points on the grid were used to translate the depth relationships of the figure, a technique known as "foreshortening". Images retrieved from "Drawing on the Right Side of the Brain", by Betty Edwards, 2012.

Perspective explained

This invention became the groundwork of phenomenon that was as valuable in fine art as it was in architecture, as until then, there existed no formula for representing three-dimensional depth in a way that appeared accurate. It also would become the foundation for the science of

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[8686] (Edwards, 2012)

vision until very recently. The formula, called Perspective, evolved from a mathematical grid into a simple concept so effective that it continues to be taught to art students today. The concept is to imagine that there is a 3D version of the grid device imposed over the world, so that the grid squares become cubes of equal proportion. The horizontal side edges of these cubes begin to converge together the further they recede in space, while the vertical side edges remain equally spaced apart. The edges of the cubes are like the rows of string on the device, which in 3D, become straight lines that eventually meet at a single point. This point, which represents the depth at which objects in the scene are so distant that they fall out of view, is aptly named 'the Vanishing Point'. A third set of lines horizontal lines is added, which represents the front and back-facing edges of the cube. These lines remain parallel to one another, but the spaces between them decrease as they get closer to the vanishing point. The line that meets with the vanishing point is called the horizon line.

Perspective deconstructed

The concept is extremely difficult to teach, and I have attempted to several times, in various courses, from storyboarding for film to illustration. What is so difficult to grasp is this intersect of the vanishing point and the horizon line. The intersect represents the point at which the scene falls out of view, or the furthest our eyes can see, and so it is the literal representation of our 'point of view'. Two factors contribute to making the concept so challenging to digest. First, it means accepting that the lines converging together towards a point on the image plane never actually meet. However, these lines never converge at all but go on in equidistant parallel. Secondly, the vanishing point is in fixed position on the image plane, and in constant motion in reality. The constant position is fixed at the centre of our view, which constantly moves to wherever we shift our visual focus. In art history, this became immensely powerful because established the concept of the image plane, where a representation of a scene could be rendered with a fixed viewpoint.

When transitioning this viewpoint from the 2D image plane of a piece of paper or a monitor scene to that of the 3D scene of VR, something very complex takes place in our vision that we haven't quite figured out. This is because our vision is largely a neurological process of the brain, which we are only just beginning to make sense of. What was so effective about perspective as a method was that it enabled a way to reduce our field of view into a simple mathematical construct. The method was so influential that it became the basis for initial scientific studies of vision. The premise was that our eyes worked like little cameras, where the retina was assumed to be a like a flat projector screen that compressed all the 3D data of the world around us onto a 2D image plane. Until very recent studies about the neurobiological processes of vision, this premise was the foundation for how we thought our eyes worked.

Perspective as a political ideology

Inside the museums, Infinity goes up on trial.

- From "Visions of Johanna", by Bob Dylan, 1966.

The concept that the way we see the world is founded on the mathematical construct of According to Char Davies, artist and theorist Brenda Laurel and others who have discussed cultural themes surrounding computer graphics, Perspective entails philosophical ideologies that have had immensely political ramifications. For one, the cubic grid imposes a scale that spans the world, making it possible to measure earth with coordinate points in the same way that artists had initially used the Perspective Device. The idea of a global coordinate system is rooted in

Western thought, in assuming that it exists objectively and is something that we discovered, rather than created. When the concept is extended to the Universe, the vanishing point from the art method comes into play. Perspective is a method for representing depth with straight lines that recede until they converge at a point. These lines never actually meet, but rather remain in parallel and extend to infinity.

Linear perspective, and the mathematical system that evolved from it eventually led to the invention of photography.[87] The still photographic image in turn gave way to film, which then led to computer graphics, to cinematic effects and video games.[88] Davies argues that linear perspective contributes to a distinct concept of space, where the metaphor of the grid, as the screen of Durer's device, forms a separation between us as viewers, and our surrounding space as what is viewed. As Davies points out, the early scientific studies about the perspective-based operatives of vision are credited to Descartes, who also happens to be the founder of the Cartesian Coordinate system that underpins computer graphics. Descartes is also the author of the philosophical view of Dualism, which separates mind from matter. The ideology of dualism is that through the power of intellect, man can ascertain order over the chaos of nature. Davies argues that the domination of Western Man over nature was but one of many examples of how dualities are integrated in screen-based formats, including 3D graphics. Her VR installations aimed to show how technology could be approached as a tool for reconnecting these divides, or as Davies puts it, healing the fractures, by creating conditions that enabled participants to reconnect the mind with matter, where the breathing-controlled vest becomes the body and virtual space as the natural living world.

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[87] (Edwards, 2012)
[88] (Pepperell, 2020)

Perspective and the Infinite Void

Davies writes that the concept of a lifeless, infinite space is inherent in conventional 3D computer graphic techniques.[89] She quotes Roger Jones in Physics as Metaphor in describing how the laws of perspective summarize our "normal experience of alienation, unique identity and un-relatedness."[90] The virtual environment of creative VR applications implies creating within the infinite, mathematical void that Davies had observed. what Jones describes as an "abstracted, externalized, and synthesized into the cold, empty void we call space".[91] This view is echoed in in one of my earliest blog entries, long before I had read articles on the topic. I describe the sensation of intense lethargy that increased throughout my creative session in VR, to the point that needed to put down the headset and go immediately outside to sit very still while gazing at trees.

Component 3: Embodied Space

The virtual environment of creative VR applications implies creating within the infinite, mathematical void that Davies had observed. what Jones describes as an "abstracted, externalized, and synthesized into the cold, empty void we call space".[92] Davies suggests that only by eluding the conventions in the technology, such as linear perspective, can the "medium of immersive virtual space"[93] be used to create alternative perceptions and worldviews. She emphasizes that space has a transformative potential for reconsidering our "conventional attitudes towards our own being and becoming in the world."[94] To shift the concept of viewing

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[89] (Davies & Harrison, 1996, p. 25)
[90] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)
[91] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)
[92] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)
[93] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)
[94] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)

space as an abstract, empty void, the creator would need to become, as Davies describes, "a perceiving subject at its centre".[95] This could transform the concept of working in empty space into one of being embodied within a place, which suggests having a body.[96]

Space as embodiment

Davies emphasizes the importance of the sensory experience of the body in feeling enveloped by the space. She uses the term "cognitive absorption"[97] to describe the feeling of being "bodily-enveloped or encompassed"[98] in the interaction of the body with its surrounding space. Davies suggests that we shift our conventional concept of an external, abstract space and try to imagine space as we experience it subjectively. By sensing how we inhabit it, and by understanding that we live within space, the concept of an abstract void is transformed into a that of an encompassing place. The body becomes involved as a present, living being within this place, since, as Davies puts it, "Being in place suggests having a body."[99] Challenging the conventions of the fractures imbedded in the graphics of VR therefore begins with the immersive role of the creator because, as Davies quotes from Bachelard, "we do not change place, we change our nature."[100]

Space as embodied perspective

The reflective methods in my creative research had led me on a metaphysical pursuit that seemed to coalesce well with what Davies described as a shift in our conventional concept of

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[95] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)
[96] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)
[97] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)
[98] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)
[99] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)
[100] (Davies, Rethinking VR: Key Concepts and Concerns, 2003)

space. I had, in one audio recording, described a concept of reality that involved a layered system of spheres.

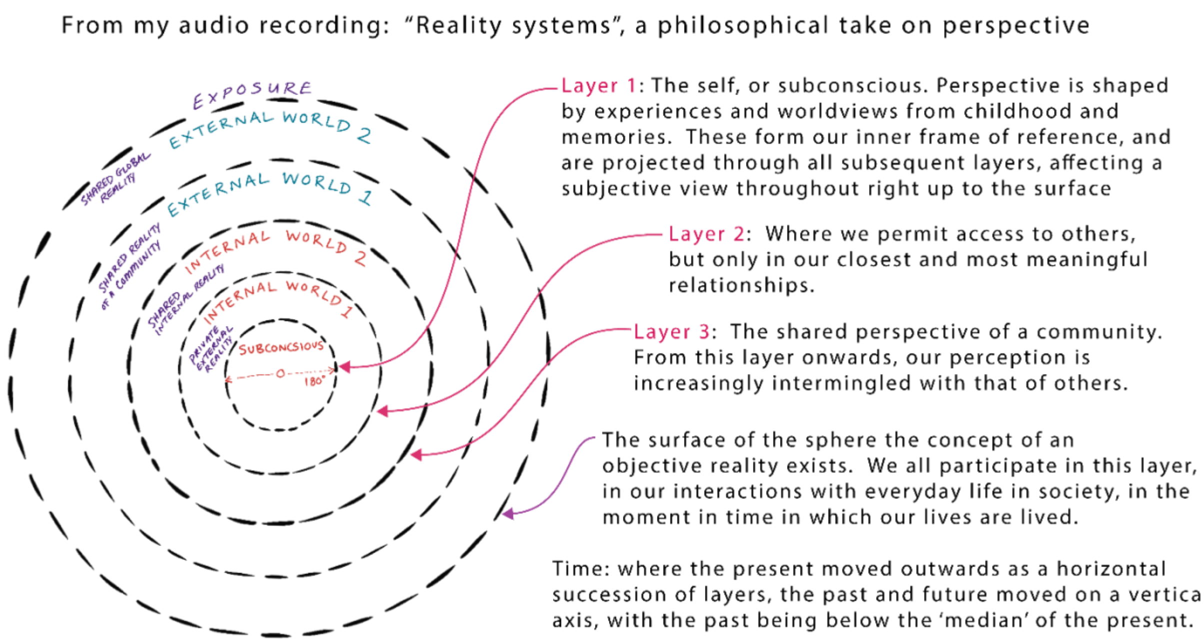

Figure 34 Diagram of my own concept about the layered perspectives of reality

This recording led me to the writing of theologist Tehard de Chardin, which in turn gave way to a method for scaling depth in VR in an embodied way. When I later came across Davies' writing about space being a place that implies someone perceiving at the centre, I formed the connection to a spherical reality surrounding the inner reality of the self.

De Chardin writes about a spherical model known as the "Noosphere,"[101] in describing his vision of humanity. The analogy described by De Chardin helped me form a link between the metaphorical spherical perspective and the literal use of visual perspective that used space as an art element. I soon discovered that Morie had also referred to De Chardin's concept of the

[101] (Krüger, 1997)

Noosphere in describing her vision for the future of VR. Morie applied the concept of the Noosphere as a way of describing a network of creators working together in VR, an early iteration of what we now know as social VR hubs where users can meet and sometimes create together online. It was the first of several significant coincidences I would come across in my research, which I would come to appreciate as not at all coincidental, but rather, different perspectives about the same problem. The problem in this case being, how we can use VR as a tool to help us evolve and come together in a spiritual sense, as De Chardin had alluded to in his Noosphere analogy. Davies focused on the healing potential in how immersive experiences, such as her 1994 installation OSMOSE, could help reconnect our minds with our bodies, and our bodies in turn with nature. Morie, meanwhile, hoped that a ubiquitous future form of VR, that is, a shared virtual space that spans the globe, could help us work together to reach our creative potential. My own perspective of the problem creating in VR was very literal, in that I needed to find a method for representing visual depth inside a virtual simulation of depth.

Space and visual perception

My investigations into linear perspective were the result of feeling I had reached an impasse in my creative work in VR. While inside the 3D workspace it became suddenly very apparent to me that the method no longer applied, and that without it, I had no system for working with scale and proportion. I became keenly interested in the workings of my own eyes, a path of study that began with recordings of what I perceived while looking out at the world. I recorded my observations from different vantage points, like the night sky on a clear night, the long horizon line of Lake Ontario, and various cityscapes. These findings led me to compare the differences in visual fields between humans and other animals, like rabbits, horses, and flies, who on account of the variances in their physical formation, see the world drastically differently than we do. The observations I had made all pointed to one common denominator, which happens to underpin the technology of VR: stereoscopic vision. I felt I could not progress any further without gaining an in depth understanding of how we see. My research about visual perception led to a key insight about 3D modelling in VR: the techniques of 3D modelling could be inconsistent with the natural process of our vision in distinguishing the appearance of objects.

It was through researching studies Blakemore's studies about visual perception Blakemore's research that I was led to a key insight about an alternative method for working with perspective in VR. Attributing the work of visual artists as having made significant contributions to the study of vision in western science, Blakemore delves into the history of linear perspective. With substantial evidence, Blakemore argues that linear perspective neither explains the whole story for how artists represent depth on an image plane, nor does it fully explain how we see depth in the world around us. Blakemore points out that while the realism that artists of the Renaissance had mastered with this method did not accurately replicate reality, it could be used to manipulate how we perceived it.[102] Artists could use the method, for instance, to direct the viewer's eye to a focal point that did not necessarily exist in the real-life version of the artist's representation.[103]

Artists and the Science of Vision

Since the Renaissance, many artists have made observational recordings what their eyes see through representational paintings and drawings that do not rely on linear perspective. These artists were less concerned with achieving a mathematically correct representation of reality than

[102] (Blakemore, 2019)
[103] (Blakemore, 2019)

a subjective interpretation that appealed to the "natural" appearance of visual perception.[104] Though this method had been widespread and deeply ingrained in art training since the Renaissance, artists like Vincent Van Gogh have since invented alternative methods and devices for drawing the perceptual depth of space.[105] These observational studies have often lead to the patent of new methods of drawing perspective.[106]

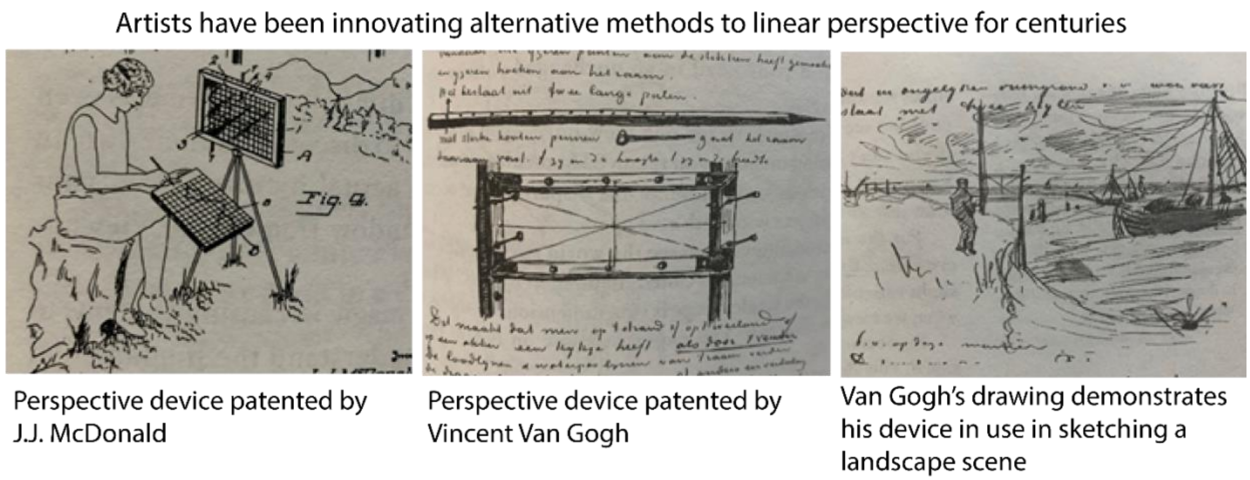

Figure 35 These three images show examples of devices that artists have invented as alternatives to linear perspective. These artists, and many others, felt that linear perspective inherently failed to represent what they observed in natural landscapes, because there are no straight lines in nature.

I had intuitively done exactly this in my own investigative prototyping. While looking up at a ring of tall trees I had just drawn in the virtual workspace, I impulsively tilted the tops of the trees inwards, so that the trunks fell in towards each other, forming a dome around where I stood. Standing inside the circle of trees towering around me, I observed that the treetops appeared noticeably more pleasing to my eyes. The effect somehow appeared more real to how appear in

[104] (Pepperell, FOVO: A new 3D rendering techique based on human vision, 2020)
[105] (Edwards, 2012)
[106] (Edwards, 2012)

nature, in standing erect and upright. Without understanding how or why, I felt intuitively that my something about the construct of my own vision was influencing the effect of feeling like I was standing in a "real" forest.

Motivated by this discovery, I researched the work and methods of artists who have studied spherical perspective as a style of representation. I eventually came across the research of Dr. Robert Pepperell and his colleagues, who have been studying the effects of spherical, or hemispherical influences on visual perception. Like Blakemore, Pepperell argues that linear perspective is not necessarily representing 3D space the same way as we experience it through visual perception.[107] According to Pepperell, this is especially the case in images that have, like VR, a wide field of view.[108] The extensive research and prototyping that Pepperrell and his colleagues have invested in the 3D rendering process has led to the conclusion that these systems should not begin with the modelling of incoming light, like cameras, but rather with the structure of visual perception.[109] Pepperell explains that our vision is influenced by the spherical structure of our eyes: "Our light sensors are not arrayed on flat planes but on hemispheres."[110] Pepperell concludes that the current 3D graphics technology, including VR, must reject linear perspective and, like the observational studies made by artists, begin with the structure of visual perception.[111]

Learning about the contributions that artists have made to the science of vision and visual perception inspired me to believe that my research about visual perception in VR could be of

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107 (Pepperell, 2020)
108 (Pepperell, 2020)
109 (Pepperell, 2020)
110 (Pepperell, 2020)
111 (Pepperell, 2020)

value. Both Blakemore and Pepperell, from the prevue of their respective disciplines, neurobiology and fine art, make the point that artists have made significant contributions in many other ways. For example, Blakemore demonstrates the work of Alex Coleville to show an adaptation of perspective to represent a wide field of view of an open landscape. Pepperell provides additional examples, listing John Constable, Van Gogh, and Cezanne as all having deviated from the rules of perspective, employing direct observation rather than geometrical principles to represent the visual field in their paintings.

Reading about the research achievements of Pepperell and his colleagues gave me confidence in the insights I had been recording through my creative process in VR. I was further motivated by the fact that like Davies and myself, he had a background as an observational painter. Coupling this knowledge with the claim made by Blakemore about the contribution artists have made in the science of vision, I finally reached a breakthrough in my research. I felt overwhelmed by the task of having to overhaul the conventional assumptions imbedded not just in the 3D graphics and VR, but the conventions long ingrained in my own training in visual art. As daunting as this prospect was, it was also exciting: I could suddenly appreciate the gravity of what it meant to approach science as an act of creation rather than discovery. If scientific truths, like linear constructs of depth, are created rather than discovered, then they can be recreated in new ways.

A preference for spheres

The theme of sphericality had been consistently reappearing in my explorations. My first prototyping session in VR where I had impulsively drawn a dome around myself as though to insulate myself from the looming void of the infinite space.

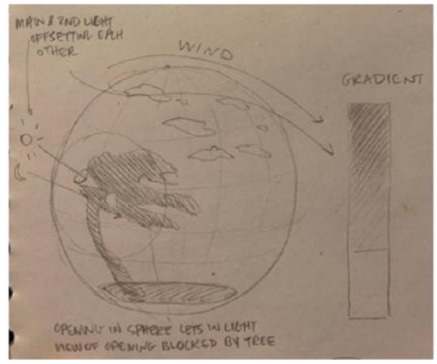
The attempt to create a dome was led by an eagerness to recreate the feeling experienced in diving of being immersed in space in a freeing way. With the intention of creating the "surface" look of the ocean when looking up from beneath, and in contrast, the sense of dark depth below, I explored vertical space first.

Figure 36 : Images of my first session creating in VR (Tilt Brush).

When I moved onto my first "world" project, I had attempted to be more strategic about the design of a spherical surrounding 'place' in which I could centre myself within the environment. I had challenged myself to create an immersive replica of a scene in a 19th century Japanese woodblock print. I had investigated design strategies about the atmospheric qualities that were integral to the print. I sketched out ideas for how I could enclose the space in a spherical structure, hoping to find ways to use the tools provided in the program to be able to achieve this enclosure in the design. I soon learned that creative VR applications are not designed for the creation of enclosed environments. The expectation is that atmospheric qualities will be mostly managed in a gaming engine, where the scenes will be exported.

The print I intended to recreate in VR

I intuitively remapped the print as a sphere



planning strategies for working with atmospheric properties of light and weather

Figure 37 From left, "Sankeieni Garden", Kiyochika Kobayashi (1847-1915), woodblock print, Japan, date unknown, my concept sketch of how the image could be assembled in virtual space, and my attempt to visualize how the 3D layout of the scene could accommodate atmospheric elements.

I had noticed a spherical structure in the map Davies had documented of the immersive world of OSMOSE. I had drawn diagrams connecting my own metaphysical ideas about reality as layered system of spherical perception that tied in with the spherical concept in de Chardin's analogy about the layers of Earth, from the core to the stratosphere. I had recorded my own observations about the improved appearance of tress curving to form a dome in the wide field of view in VR, and I had come across artists who had eschewed linear perspective for a hemispherical perspective.

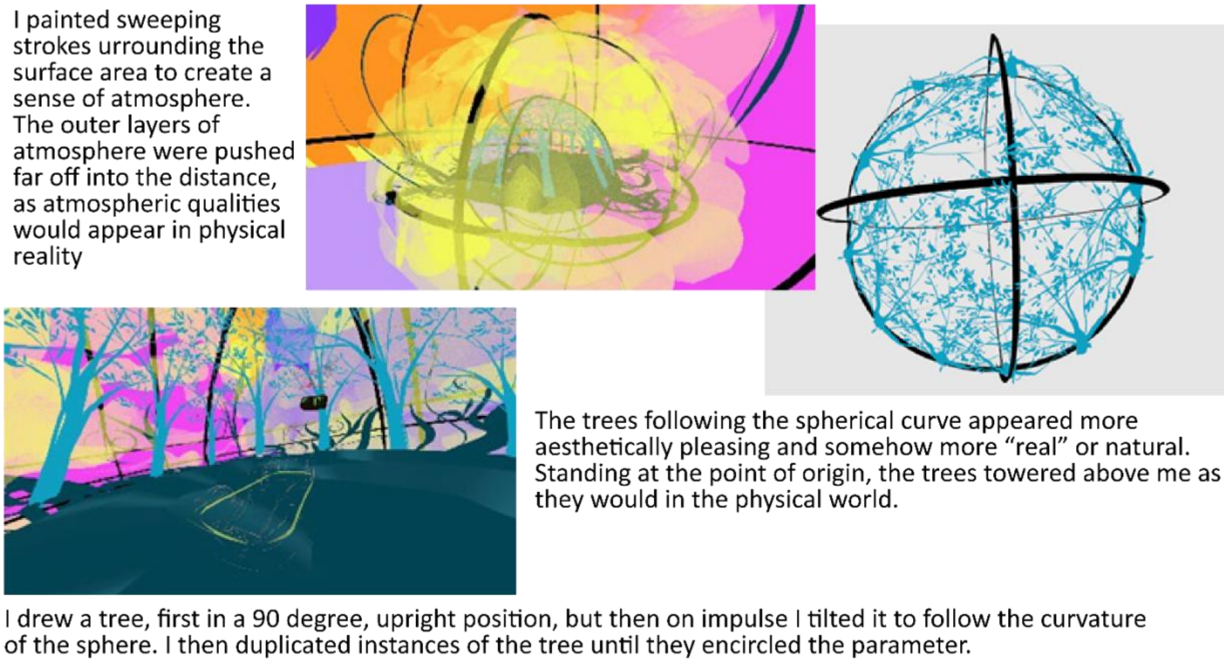


Figure 38 Images from a prototyping session in which I inadvertently discovered the more pleasing appearance of curvature in virtual space.

Now I had the support of the research evidenced by Pepperell about our how our preference for spherical phenomena could be attributed to the physiological and the spherical shape of our eyes.

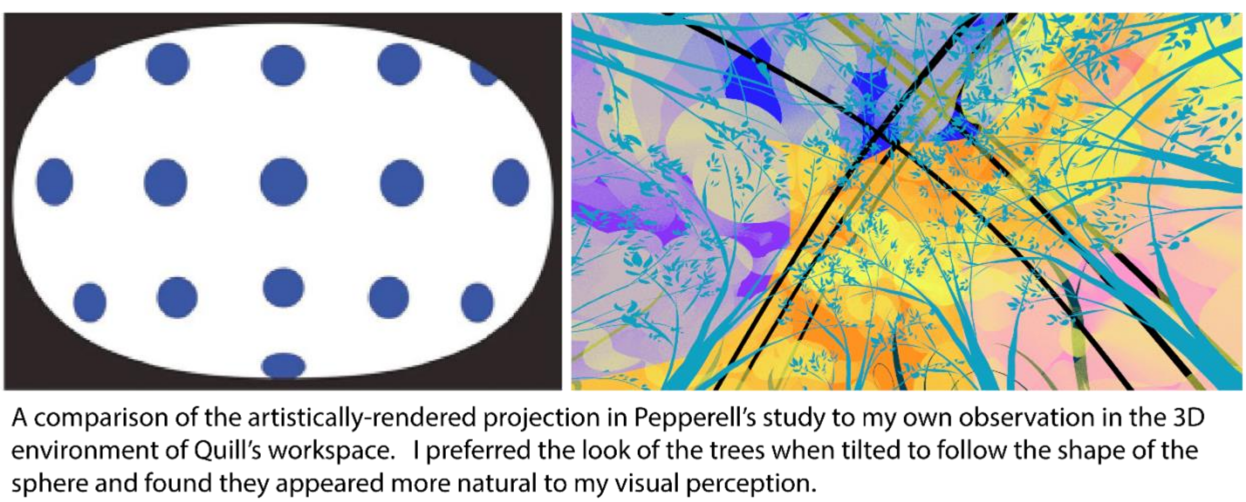


Figure 39 Left: image retrieved from "Comparing artistic and geometrical perspective depictions of space in the visual field" by Joseph Baldwin, Alistair Burleigh, Robert Pepperell, 2014. Right: an image from my own prototyping of a spherical perspective.

The spherical influence on human vision led me to texts about some of the earliest recorded discoveries about astronomy, when people looked out at the depth of space and reasoned that the universe was a dome and we, on Earth, lived at the centre, then gradually, I made my way back from there till I could grasp a theory that was tangible. All I had to do was adapt the spherical tiered system to the art principle of diving depth into layers: the foreground, the midground, and the background. This concept was sufficient for creating what I call a 'buffer' for creators working within the infinite void of 3D space: a way to contain it within a layered sphere.

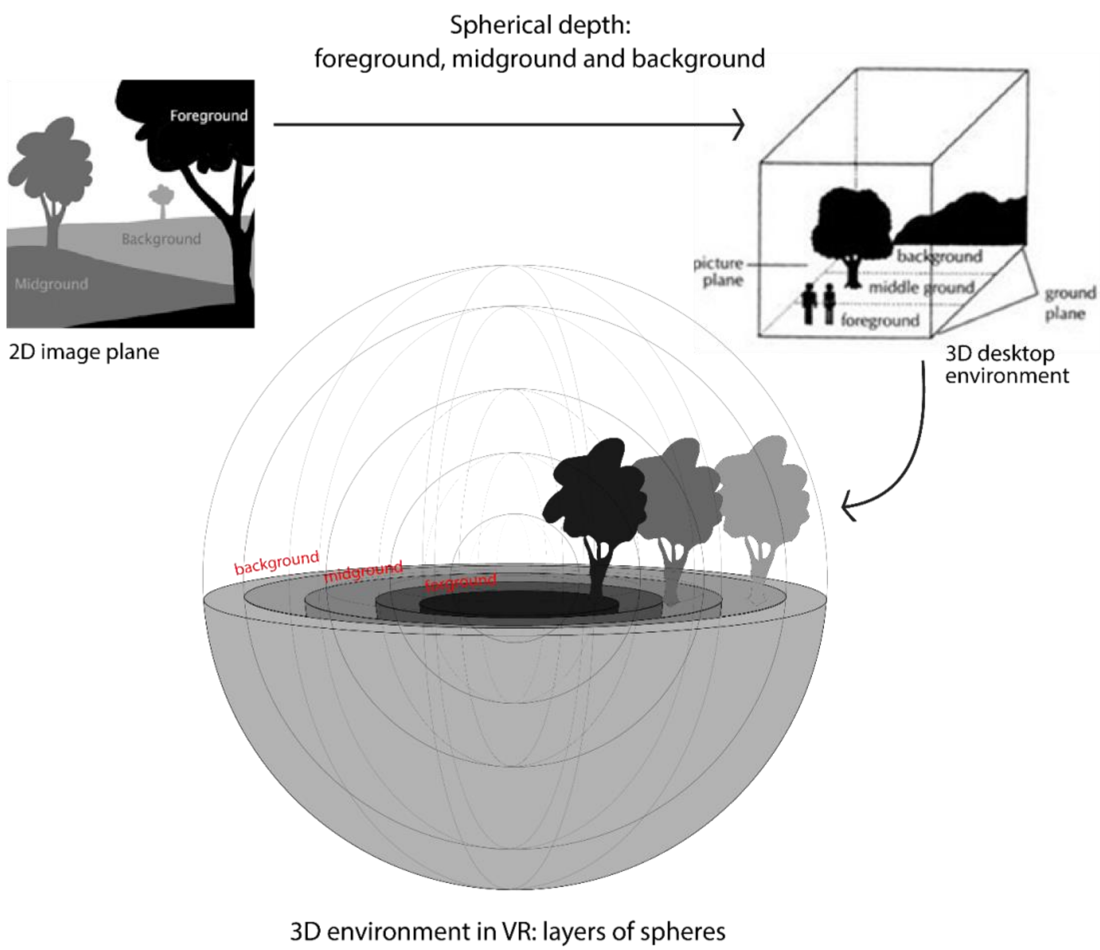
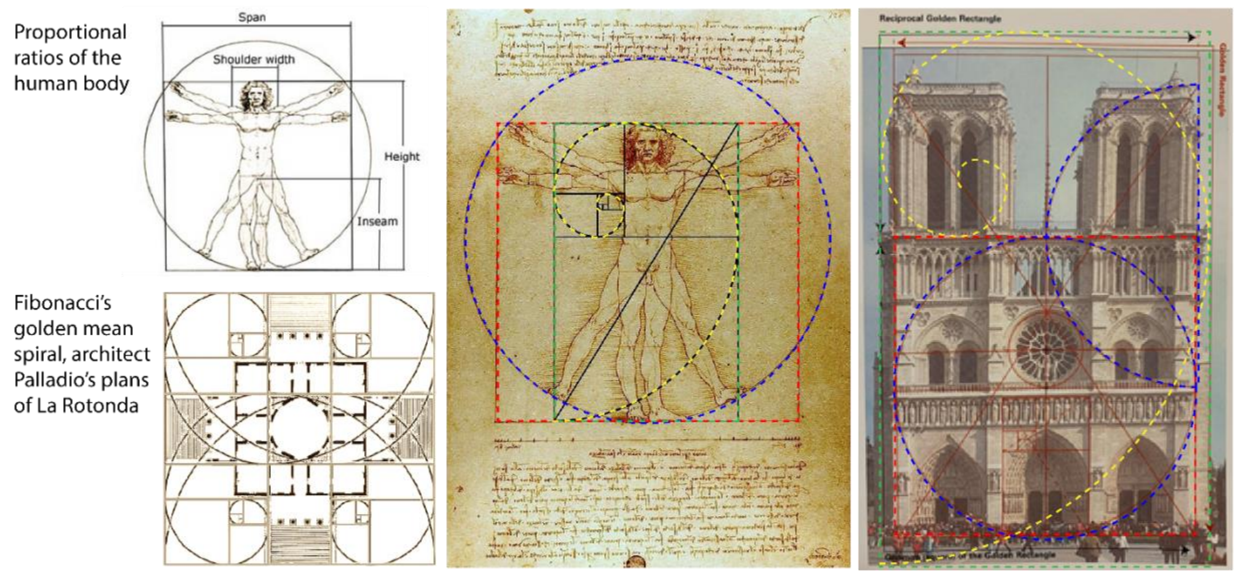


Figure 40 Translating the layers of depth from a 2D image plane to 3D space, then as a spherical enclosure.

I compared the spherical patterns we find in natural phenomena (described earlier in this document in how I prototyped the Corkscrew method), to the proportional system drawn in the famous image by Leonardo Da Vinci. The diagram is called "Vitruvius' Canon," in refence to the original author of the diagram, the Roman scholar and architect Marcus Vitruvius Pollio. The sketch shows how the proportions of the human body can form a perfect circle. Vitruvius had recognized a harmonious aesthetic between human proportions and the geometry in the design of their edifices.[112]



The Vitruvian Man, from the notebook of Leonardo Da Vinci, c. 1490.

The golden ratio in the design of the Notre Dame Cathedral, Paris, 1163 - 1345

Figure 41 These diagrams demonstrate the geometric forms found in the proportion relationships of the human body: the circle, the square, the rectangle, and the spiral. The image on the right shows how these four shapes are used in architectural design.

It occurred to me that throughout history, or at least, Western history, we have quite literally been seeking out spherical patterns for the simple reason that our eyes are spherical. Not only that, but like the early philosophers looking out at the universe, we perceive our

[112] (Elam, 2001)

surroundings as spherical, with ourselves at the centre. I wondered how much of what we have discovered, about the spiral sequences in nature, the proportions of our bodies, and our observed preference for the Golden Ratio in architectural design, was rooted in the spherical influence of the two globes nested next to one another in the human skull.

Seeing is believing

Neuroscience has established that the visual processing system is largely the work of the brain, rather than the eyes. In her book Visual Intelligence, Amy E. Herman quotes neuroscientist Dr. Sebastian Seung to underline the extent to which the retina is *not* like film in a camera. “It’s definitely not film,” says Seung. “The retina’s such a complicated structure that it’s not even a camera. It’s more like a computer.”[113] This computer is responsible for what we think we see just as it is for all subjective thought. “Studying the retina is our easiest way into the brain,” Seung goes on to say, “because it is the brain.”[114] And yet, just as Blakemore purports that linear perspective does play a part in visual perception, our sense of sight is still at least somewhat associated with our eyes. Specifically, I deduced from Herman’s summary that the visual processing system engages 25% of our brain and over 65% percent of all our brain pathways, the eyes could arguably still be responsible for 10% of how we see. It seemed plausible to me that the subjective thought that plays such an influence on what we think we originates from the stories we created while looking out at the world through the lens of spherical organs. The spherical influence of that lens could have in turn, been responsible for how we have sought out spherical and spiral patterns our perception of the world. We could be projecting our human

[113] (Herman, 2016), p. 7
[114] (Herman, 2016)

identity in space by finding relatability in how we distinguish form – by searching for, and preferring, all that aligns with how we see.

Component 4: Embodied scale

The fourth component that contributes to the worldscaping method is the concept that transforms this synthesis of ideas into a practical application: the human body as a base unit of measurement. To create in VR with an embodied sense of scale, the person standing at the centre of the virtual environment can scale the space based on their own proportions. The virtual world created in that environment can thereby be a projection of the identity of the person creating it. This insight came to me from a study conducted by Blakemore about how we perceive depth relationships. Blakemore states in this study that our ability to measure the distances of between depth relationships of objects in our view breaks down as these objects recede in distance. While this may seem evident, the results of the study evidence the extent to which our perception of scale is derived from subjective knowledge rather than visual observation. The studies conclude that we are good at guessing the distance between two or more objects up to a limit of 80 cm. After this point, a mechanism in the brain begins to slow down our ability to measure these distances, at a rate that accelerates the further we project our view. To emphasize the point of how shockingly small an area falls within that limit, Blakemore states that 80 cm is roughly the length of a human arm.

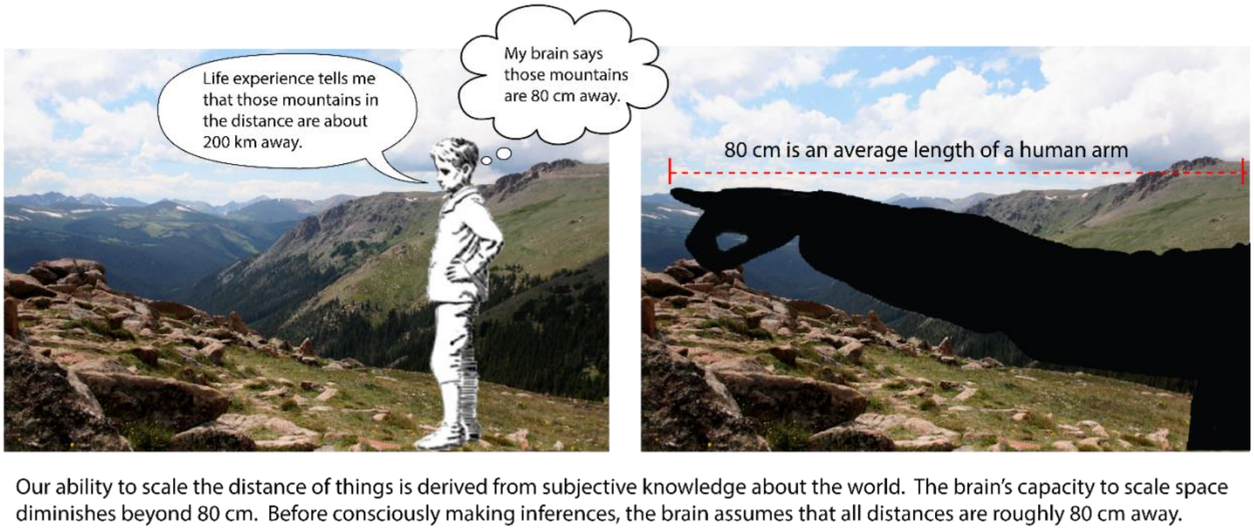


Figure 42 Left: illustration of how we 'guess' the distance of depth by inferring to previously acquired knowledge of the world. Right: This image illustrates the concept that by outstretching the arm along the same depth of visual field, we can plot out the distance between depth relationships of the objects within the scene with greater accuracy.

The length of my own arm roughly measures 50 cm, and I stand at 5’4”, compared to Blakemore’s evident stature as a tall man. I thought it made for an interesting example of Western Man’s imposition of himself on the world, Blakemore being after all, a knighted scientist. But his proportions also correlate to those of the figure in the Canon of Proportions by Vitruvius, of a tallish western man.

Component 5: The Gestalt

The ideas began clicking together when I thought of that figure of perfect proportions, who’s arm span equated to that of his height. The ellipse formed by those proportions in a 2D image becomes a sphere in 3D, where the span of the arms equates to the width of the diameter of the sphere.

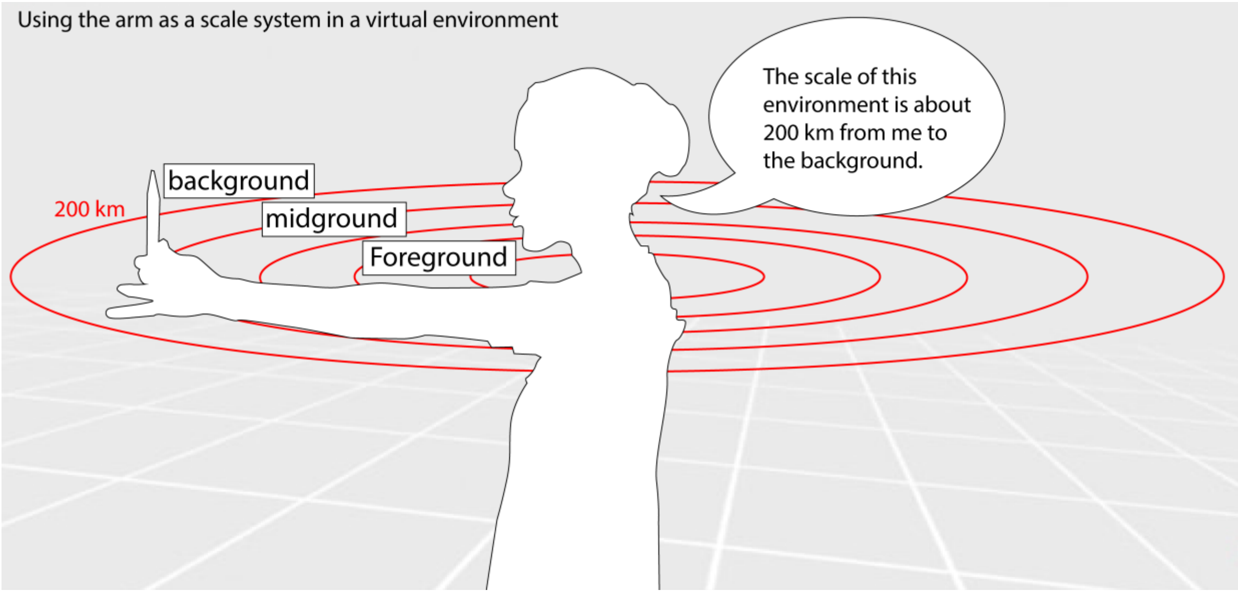


Figure 43: A figure stands in the 3D environment of a VR application, extending her arm with the sighting technique from drawing.

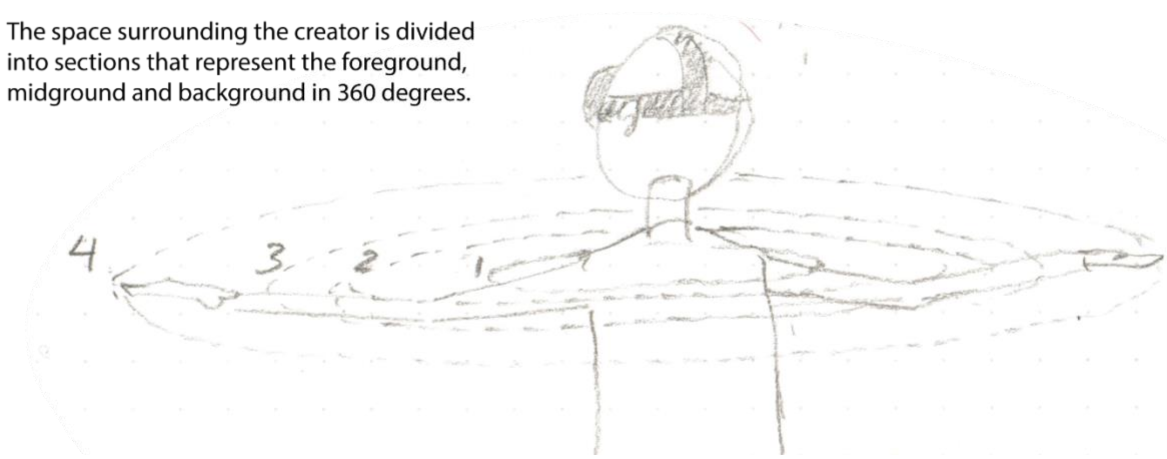


Figure 44 This image illustrates how the length of the arm can be used to divide sections of depth in VR.

The sphere therefore encapsulates the human body, with the sphere aligned with the anatomical centre of the body, known as the transverse plane, located roughly around the belly button. I connected this idea to the audio recording I had made, describing a tiered system of spheres, with the self at the core.

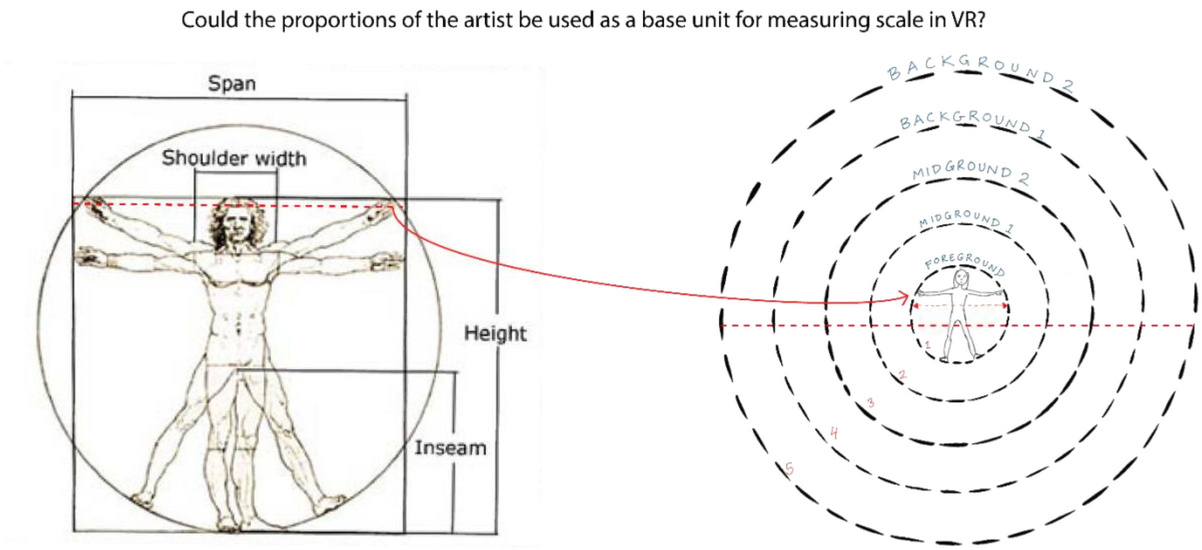


Figure 45 Left: the Vitruvian Canon, by Leonardo Da Vinci. Right: The physical propotions of a VR user as a 3D Vitruvian Canon within the first of five spherical layers

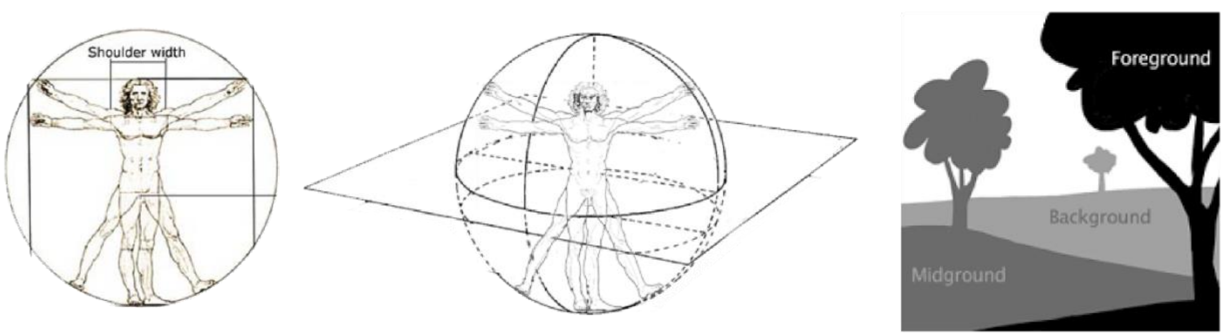


Figure 46 The proportions of the user fall within the first spherical layer.

If our ability to perceive the scale of all that falls in view decreases past the limit of our extended arm, then it made sense that our perspective of the world, both in terms of visual depth as well as our individual subjective experience, fell within the scope of the sphere incapsulating the body.

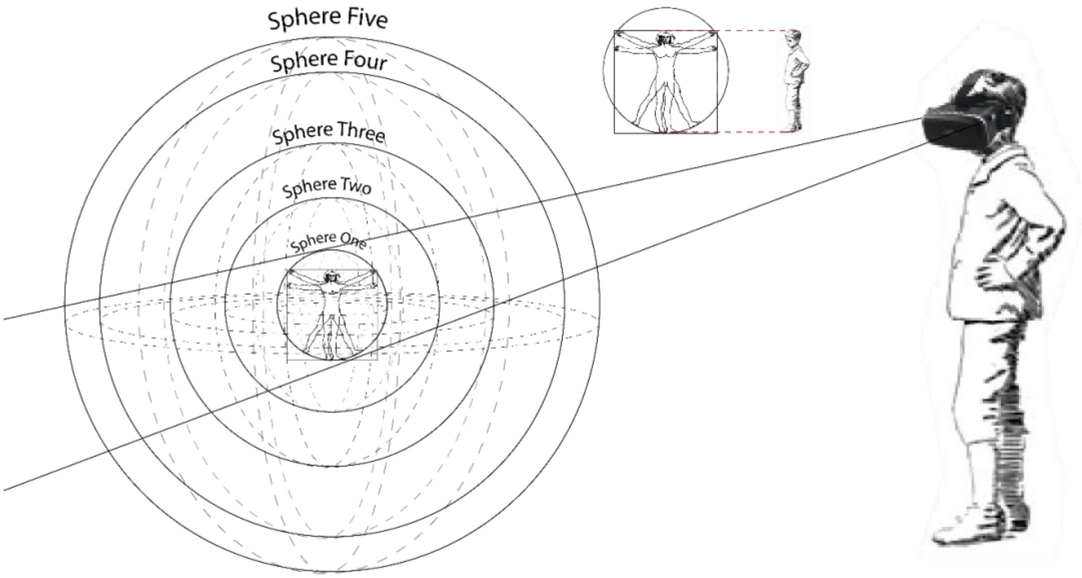


Figure 47 The creator can apply their own physical proportions to transform the VR workspace into an embodied, spherical 'place'.

The Worldscaping method in context

I theorized that by creating a VR world at the scale of this body-sized sphere, we would, according to Blakemore's study, have the most effective model for the scale of that world. As the entire environment falls within the limit of the arm span, our ability to visually perceive the distance between objects in the scene would have the best conditions for compositional arrangements in the scene. For example, it could make deciding how far mountains are in the background from a farm field in the midground, and a scarecrow in the foreground, much easier and efficient. The world scene can be sketched out in a scale that aligns to the range at which we best guess the distances between objects.

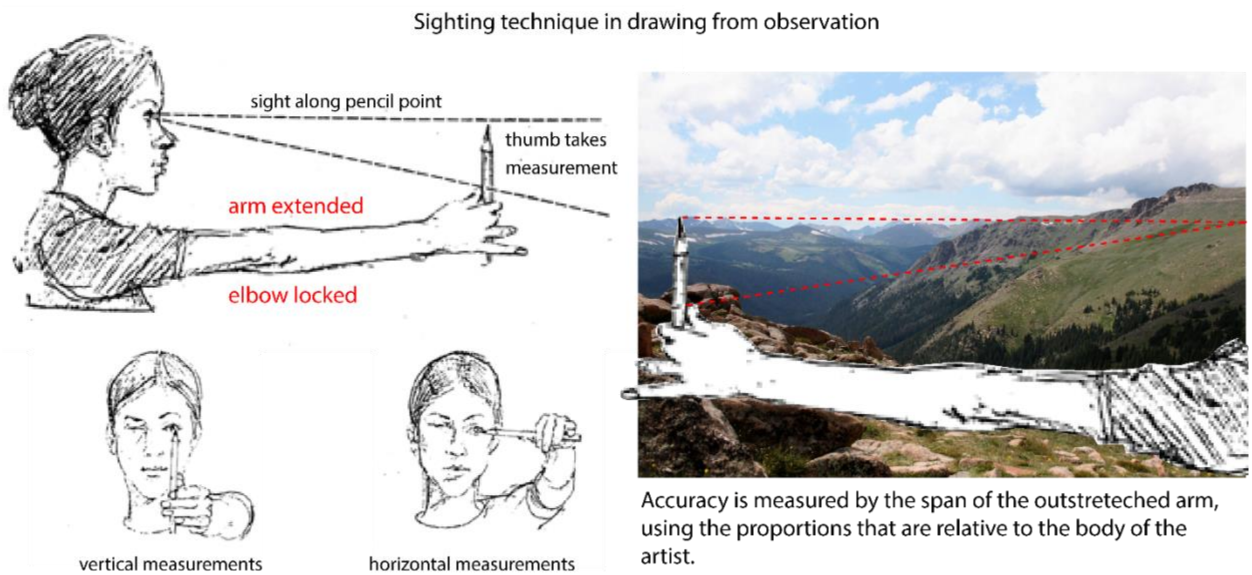


Figure 48 The images on the left demonstrate the sighting technique from traditional drawing, which also makes use of the outstretched arm. In sighting, the artist uses a pencil to mark distances. The image on the right shows the sighting technique in practice.

An additional feature of this system is that it can be used to upend conventional associations of navigation, as the median of the sphere is not at our feet, like the traditional ground plane, but at the centre of the body. The body is thus situated inside the centre of the world, rather than standing on its surface. To create a ground plane, the creator must consciously draw one, and could just as easily decide to place it above, below, beside or in front of them, or omit the concept of a ground plane altogether.

The steps of worldbuilding using these methods

The steps are introduced here as a general workflow and order is up to the creator and tasks of the project at hand. I will summarize the steps then explain each one in context.

1) Draw a circle in VR and scale it to the width of outstretched arms.
2) Duplicate the circle and position the copies to form a sphere around the body
3) Staying within the sphere, sketch the position of elements that will be in the scene, organizing them within the foreground, midground, and background.

4) Duplicate the sphere (not the sketched environment). Keeping the original in position, scale the second sphere, along with the environment sketch, to the desired "human-sized" scale. For depth that resembles how we perceive distance in natural settings, scale until the perimeter of the sphere starts to fall out of view.
5) Import the world-scene in Unity and set up the project to match the scale and view in the VR application.
6) Draw the scene elements can be drawn in detail. Use the Corkscrew element to begin spatial sketching each element as a 3D form.
7) Sculpt the mesh of the forms using pre-fab or post-production technique of choice.
8) Import and position the now-complete 3D models into the scene in Unity.

Step 1: Initializing the body in virtual space ("Hello, World!")

To apply this concept in VR, the first step is to draw a circle, then scale it out till the radius reaches the tips of the outstretched hand. Doing this requires one hand to physically feel the other hand where it hovers in the "real" world and mark a position for it in the virtual one. This not only serves as a way to add measurements, it also brings the physical body into the virtual world, and does so as the very first step in the creative process. Like the exercise common to all those learning to code, or programming a new application, it is the "hello, world!" of the body, being initialized, or spawned, into the virtual world. Once this ellipse is positioned at the scale of the arm span, it needs to be duplicated and positioned vertically to align with the head and toes.

Step 2: Scaling the world with embodied proportions

Once the world has been sketched out, the human body of the creator of this world becomes the base unit of the intended scale of the environment. How large the world is intended to be is subject to the project at hand. Whether the world is intended to be 20 km or 200, the base unit of the human body can equate to 1 km or 20 km and can be decided at any point. The fixed variable of the scale is the same as the one we apply when looking out in the natural world: the horizon line. If the intention is to create a world that simulates our natural field of view of vast areas of space, then this world need simply be scaled out in VR till the radius line (a hand-drawn ellipse that forms a ring at the centre of the body) falls out of view. To scale the world, the initial sphere must be duplicated, so that the duplicate is what is scaled out in virtual space. The initial sphere always encapsulates the body, at the centre of the world, at all times. The reason for this is that the body within that initial sphere becomes the gimbal.

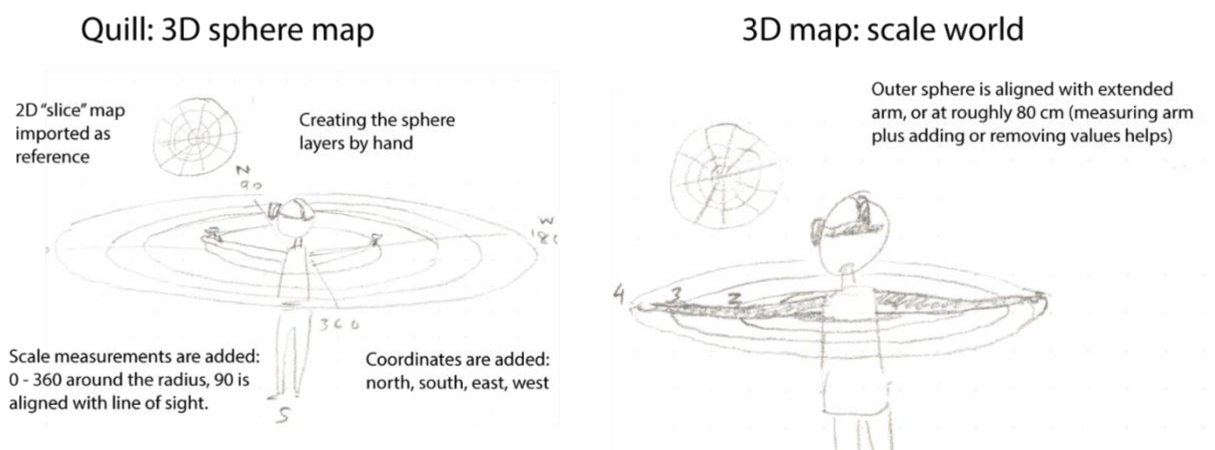


Figure 49 These sketches show the intial steps in setting up a foreground circle (left) at the scale of the outstretched arms. Additional layers are added as the divisions of foreground, midground, and background.

Step 3: The body as the gimbal

The body as the gimbal circles back to the first component in the method and can now be put into context. If the human eye is not a camera, and VR is a simulation of our visual perception, then there is no reason for a camera in VR. The immersive environment is where live-action film and animation as storytelling formats end. Because the view is first-person, there are no cuts in the scene, only things that appear and fall out of view. The first-person view is that of a real person, using camera moves to control where they look is negating their sense of agency.

To create in VR thus becomes an immersive theatre, where the background sets, atmospheric elements, set props and actors are choreographed to align with the view of that human at the centre. Whether the project situates the viewer as a passive audience member, or as a player navigating in a game, this principle remains the same. The elements in the scene align to the viewer, who always remains at the centre of the world.

This does not entail that the scene must remain static, but rather, the opposite. The concept of camera moves still exist, only there is no camera, but rather, a human-sized gimbal at the centre of the larger sphere of the greater environment. By rotating this gimbal, the whole world rotates, along with all the contents within it. The human-sized gimbal becomes the controlling parent of the environment, but the view of the human is unaffected. By tilting the gimbal, the view can change from a busy cityscape to the bright sky and sun, without the viewer turning their head upwards or looking up. The important point, however, is that the viewer is free to turn their head, or look around, if they so desire. The viewer is therefore able to engage with the scene with agency.

The creator of the scene is, through the Corkscrew method, able to draw with personal expression, and share this experience with viewers from their first-person view. Because the world space integrates the natural operatives of visual perception, the drawing hand moves at the speed of sight, which in turn, follows the speed of visual thought. With the perceptual gaps closed, the creator of the scene can work in a state of presence.

Step 4: Building the pipeline

Once the world has been scaled out, with all the elements in the scene having already been sketched into position, this model can be exported from the given creative application. It can then be reproduced at scale in Unity, Unreal engine, or whichever 3rd party platform is required for the project goals. Because my own experience falls within the scope of animation, I use Unity, and will refer to it as the given 3rd party application going forward.

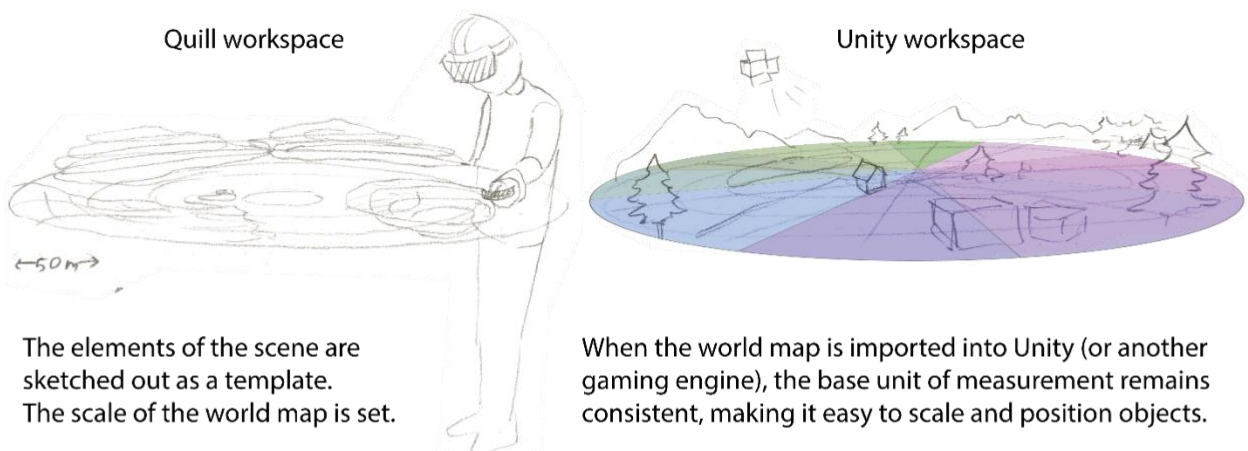


Figure 50 Sketching out the objects using the base of the spherical structure as a ground plane. The scale, proportions and relative distances of the objects in the scene remain consistent when the elements are imported into Unity.

From this point, the process becomes interchangeable. An animator may choose to work out the major sequences, like the rotations of the parent gimbal and more complex movements, such as parallax rotation of the elements that fall within the foreground and midground, and background. These sequences can then be exported to Unity, to test them while also establishing the naming conventions, preparing the project directory, and scene timelines. Or it may make more sense to address the scene assets first, and for this the Corkscrew method comes into play.

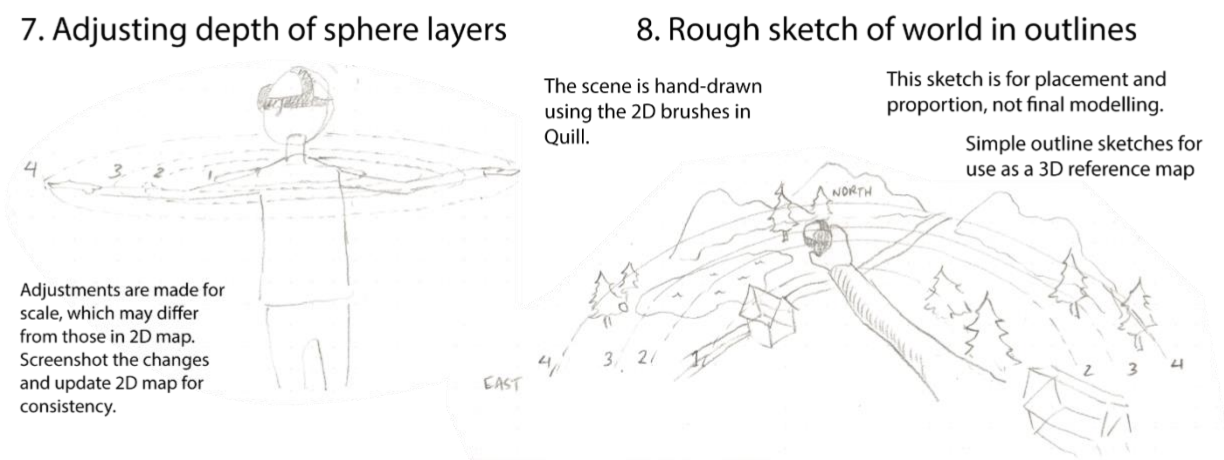


Figure 51 Once the depth layers have been plotted, the scene can be drawn out while the spherical structure is scaled to the proportions of the outstretched arms.

As I had mentioned, the corkscrew method is but the first step in the 3D modelling process. It results in hand-drawn structures that define the form of the model and can achieve a high degree of detail. But the mesh will need to be dealt with as a separate step. I feel that this is up to the individual and can vary depending on the needs of the given project. One example would be to use the VR application Gravity Sketch, which combines conventional tools and techniques of desktop 3D modelling with new tools that are designed to enhance the sculpting process in VR. There is a learning curve to this program, albeit not as intensive as that of becoming proficient with desktop modelling with software like MAYA or Blender, I am unable to say whether it would be more efficient. Alternatively, the mesh can also be modelled in Quill, Tilt Brush or Adobe Medium, though some system for pre-fabricating with primitive shapes and subsequent testing in Unity is recommended.

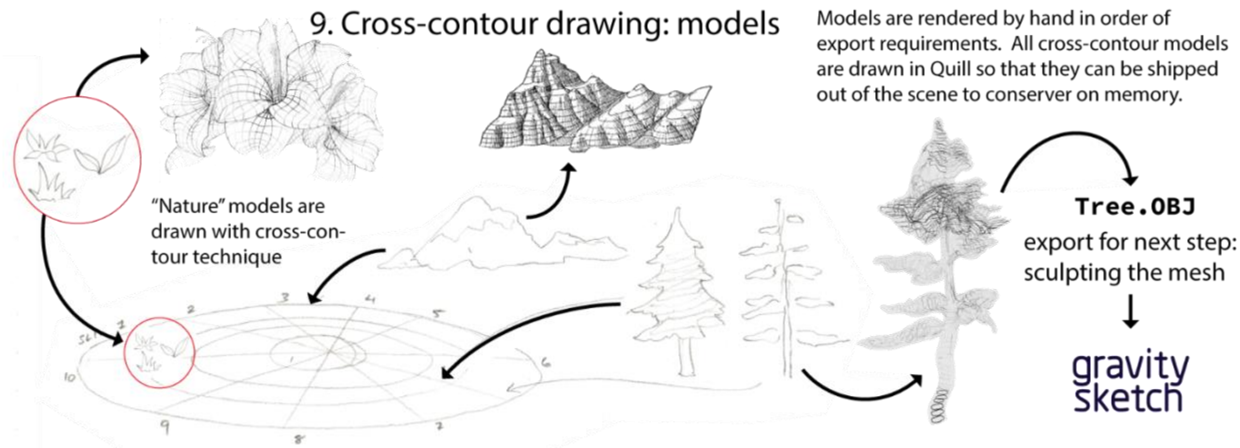


Figure 52The cross contour-drawn forms are exported to Gravity Sketch for sculpting the mesh with greater efficiency and optimization.

Summary

The Corkscrew method is designed to enhance the qualities of gesture drawing to make the experience of drawing with a hand-controller in VR feel more intuitive. At the same time, the method integrates mechanical operatives of the body, like the rotational axis of the shoulder, to draw the mass and volume of 3D forms. The Worldscaping method offers a way to scale virtual space that is founded on the natural qualities of visual perception. The method implicitly transforms the infinitely scalable space into a self-contained world with the creator at the centre. Both methods mitigate the implications that working in VR has on vision by balancing visual tasks with motor-sensory tasks of the body. In the Corkscrew method, the strain on the eyes is relieved by being able to rest in a fixed position that feels natural. Meanwhile the rotational axis of the arm alleviates the effects of gravitational forces imposed by the lack of surface support.

These methods break down the steps of creating forms in space by transforming the body into mechanical tools. By isolating the physical qualities of creating in 3D, creators can develop motor-muscular skill of spatial drawing through routine, physical practice. The technical support of the body provides a solution for the challenges presented by translating the perceptual components from 2D drawing on an image plane to 3D drawing in virtual space. By developing physical skills through motor-sensory practice, creators can focus on perceptual skills of drawing. These methods therefore create conditions for learning to draw spatially that enhance the sense of agency, in an increased state of presence. I have presented these methods in a context that speaks to creators, offering suggestions for how spatial skills can be honed for creating virtual worlds in VR. In the following section, I will shift the focus from creators to the broader spectrum.

Discussion

Addressing an audience of cultural theorists, educators, computer scientists and product designers, I will present some examples of how this research can contribute to advancements in VR tools and software in a variety of ways. Traditional methods of drawing were transformed in digital drawing on a graphics tablet, through pressure sensitivity and graphical response of the sensory inputs. The design of methods for spatial drawing in VR could contribute to the digital drawing tools of future technologies. Hasenthütl writes that “The next step is the gestural design directly in 3D via augmented reality tools.”[115] The tools being designed for VR today, and the way creators learn to work with them, will likely evolve with the technology. Hasenthütl predicts, “the next step is the gestural design directly in 3D via augmented reality tools.”[116] The tools of spatial drawing for what Hasenthütl describes as “crafting a real object in virtual space with hand gestures,”[117] are already underway. I will expand on some of the developments taking place, then suggest how the methods designed in this research could contribute to the design of new 3D tools.

Wacom has wisely chosen to, as the saying goes, to look not where the puck is, but where it’s headed, by designing a VR pen. Though promoted on the company’s website, the promise of such a tool may be well ahead of its product development. The brand has partnered with the VR creative application, Gravity Sketch, a collaboration that will provide ample data for user-led research and development.

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[115] (Hasenhütl, 2020, p. 66)
[116] (Hasenhütl, 2020, p. 66)
[117] (Hasenhütl, 2020)

The VR Pen

The predicted transformation of manual drawing from digital screens into virtual space is evidenced by recent innovation in the technology of the tools. Wacom has announced the upcoming release of a VR pen and has partnered with Gravity Sketch in streamlining workflows between graphics tablets and virtual space. The pen is designed to improve the experience of drawing in VR by integrating a superior quality into the sensory response of the trigger inputs and use of the ergonomically positioned buttons. The pen is designed to nest comfortably in the palm and weighs less than the standard controller, with aim to improve the intuitive experience.

The VR workflow

Meanwhile, in partnering with graphics tablet technology, Gravity Sketch enables the immersive workspace to be but one of many tools in a pipeline. With the intention of reducing the number of disruptions in the creative workflow, the brand positions the headset as “an additional input device, like your mouse or Wacom pen.” Their website provides an example of a workflow like the one I have proposed in this document, where VR is only utilized for design that is impossible, or at least difficult, to achieve in any other way. The specific need for VR is explained: “the designer will then reach out for their VR headset and seamlessly dive into their sketch and begin pulling their 2D strokes into 3D splines.”[118] It is worth noting that the process of transforming 2D strokes into 3D splines is an alternative approach to drawing 3D objects with the corkscrew method. However, where the corkscrew is most effective for organic forms, this method is suitable for hard-lined geometrical design. This comparison can be seen as an

[118] (Wacom VR Pen: Deliver "Natural creating experience" in VR environment, 2020)

example of how, just as in traditional drawing, multiple tools and techniques are used in the design process.

As promising as these tools are, the design is inherently product driven. The industries that these brands cater to could become integrated into the tools, prioritizing the workflows of product design over the agency and presence of the creators using them. The methods designed in this research could inform the design of 3D tools for, as Hasenhütl suggests, "crafting a real object in virtual space with hand gestures".[119]The corkscrew and worldscaping methods are powerful tools for ideation. The combined implication of these methods can transform VR into a three-dimensional sketchpad. Used conjunctively, creators can ideate and structure entire virtual worlds with gesture strokes.

The Corkscrew Method as a 3D drawing tool

The Corkscrew method has the potential to become the blueprint for the design of a new tool for 3D modelling in VR or Augmented Reality (AR). One of the key attributes of this method is that it separates the drawing of lines as edges of form, from the sculpting of shapes. The underlying principle is that hand-drawn lines are the central feature in ideation and creative iteration, while the mesh is a technical byproduct that needs to be optimized for the software. This is not to say that sculpting the mesh is not a creative process, but rather that it can be tedious and complicated in a way that diminish the agency of sculpting and effect gaps in presence.

Digitizing the mesh

The strategic assembly of the mesh can perhaps become mitigated by algorithm-based features in the software design. If the optimization requirements of the mesh were delegated to

[119] (Hasenhütl, 2020)

programmatical tasks integrated in the software design, the creative qualities of sculpting can be enhanced, like manipulating the surfaces with intuitive expression through feeling, memory, and imagination. In this sense, this vision of a 3D tool is an adaptation of the vector-based hand modelling suggested by Garvey in is 2002 workshop. Current technology may already be capable of such a development, by combining the tilt feature of Wacom's stylus pen, the Bezier paths of the vector pen tool in Adobe Illustrator, and the dynamic averaging of vertices of the Hull Brush tool in Tilt Brush. The 3D graphic software of 2002 had limited Garvey to the mouse-click manipulation of vector-based ellipses. The motor-sensory response of a stylus pen could now enable vector-based gesture strokes to draw the edges of 3D geometric forms along curved paths. In his first method of the workshop, Garvey had used these ellipse shapes to build a series of "ribs" to create the scaffolding of the 3D shape, using the example of a human leg. In the second method, Garvey used the same reference of the leg, this time duplicating, then manipulating the points on the surface curves of a NURBS cylinder. The first method is similar to the "post-production" approach to 3D modelling wherein the structure of the 3D geometry is formed by connecting the edges of a polygonal shape using conventional 3D modelling techniques. The second method resembles the "pre-fab" approach to modelling by combining primitive shapes then manipulating the surface mesh with additional tools. While not explicitly stated, Garvey may have needed to establish two methods, the first to address the scaffolding and the second to address the mesh, because the software didn't allow a way to "fill in" the scaffolding with a surface mesh. In the 2D graphics software Illustrator, shapes can first be created as vector-based "strokes" and provided the stroke forms a closed path, the "fill" of the shape can be auto-selected, rather than drawn in manually. If this feature were adapted to VR software, the hand-drawn lines that form the scaffolding of the form could be auto-filled with a surface mesh. The mesh surface would follow the frame of the scaffolding. The mesh would then be updated with the manipulation of the vector points in the hand-drawn lines.

The hand controller reimagined

If the tilt feature of the Wacom pen were added to this design, it could lead to an AI-driven mesh that calculates the surface based on the rotational motion of the joints in the human arm as it traverses through YXZ space. The mesh would then be added dynamically as gesture strokes are drawn, using the Corkscrew method. The creator could impulsively alternate between drawing and sculpting the scaffolding of the form and making surface adjustments to the mesh. Including a feature that enables the easy toggling of the mesh appearance would allow for isolated focus on the gesture-stroke based frame of the form and the mesh-based surface shape.

The Corkscrew method as a foundation

The auto-filled mesh seems a likely feature in near-future iterations of VR applications for

For the curves that are so essential to the self-expression in drawing by hand, however, the Corkscrew method is a fundamental component. It seems likely that near-future iterations of VR-based creative applications will offer auto-filling of the mesh when drawing forms with straight lines. It would enable the frame of an object to be plotted out by the pen by connecting the vertex points. The straight lines that connect the points would result in angles that are simple enough for the polygonal triangles to be calculated. For the curves of gesture lines to be hybridized with the digitized calculation of triangles, the key attribute may be found in the design techniques that are already inherent in both human-made forms and those of computer graphics.

Mediating between hand-drawn and machine-made geometry

The corkscrew method is adapted from the cross-contour technique common to sketching the contours of form with a representation of volume. Cross-contour lines are used to define the shape of surfaces in complex 3D geometry in 3D graphics. In the comparisons exemplified in the image below, the similarities between cross-contour drawings and the wireframe of digitized 3D geometry becomes evident.

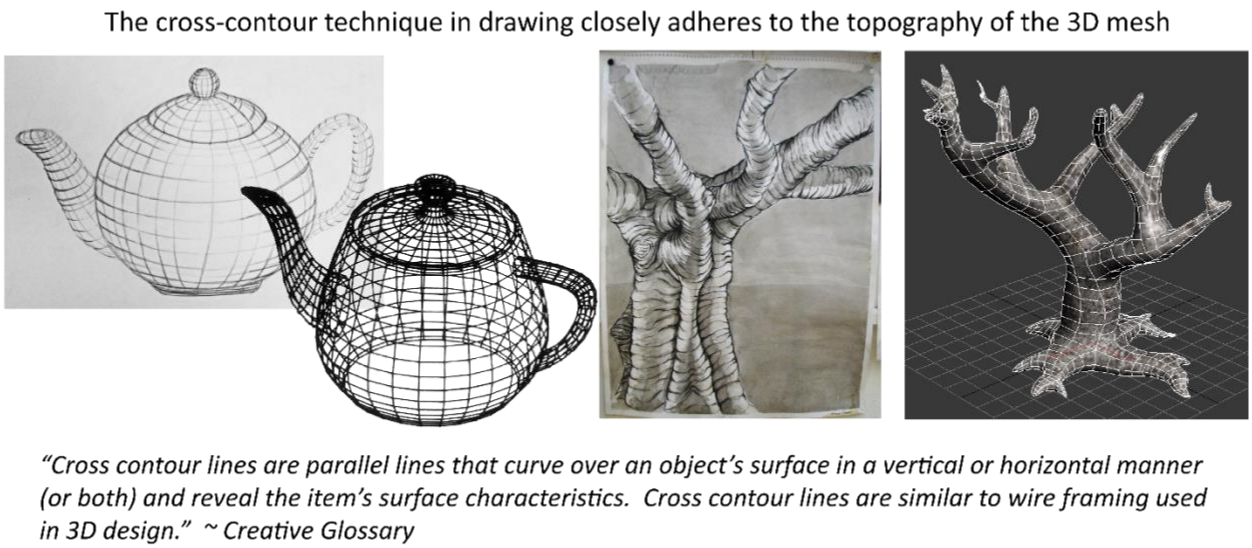

Figure 53 These images compare two examples of hand-drawn cross-contour lines and machine-made cross-contour lines to form the wireframe of 3D geometry. The comparison on the left compares a drawing done using the cross-contour technique for objective representation of a teapot, to a 3D model of a teapot, also as a representation of objective realism. On the right, A hand-drawn image of a tree using the cross-contour technique to articulate the form through subjective expression. This drawing is compared to a 3D model of a tree, also sculpted with a sense of artistic expression.

Coiling

The spiral motion in the Corkscrew method is the feature that mediates the translation from 2D drawing to 3D spatial drawing, but it also shares a common property with computer-based geometric assembly of 3D forms: coiling. The corkscrew method integrates cultural traditions in artmaking as well as technical process. While drawing in VR with the Corkscrew method, I was reminded of the coiling method in pottery that I had learned as a child. At the same time, I likened the mechanical rotation of my arm to the design the digitized arm of a 3D printer, which produces 3D material forms with a similar coil rotation.

Clay coiling and 3D printing

There may be some common ground when comparing the cultural history of clay-coiling with the design of 3D printers. Coiling is a method for clay sculpture that has been in use for thousands of years in countries like Africa, Greece, China and New Mexico[120] Coiling has been used for shaping clay into many variations of both functional forms, like bowls, pots and other practical containers. It has also been used for artistic purposes to create original works infused with subjective expression in the variations of the shapes. By comparison, recent iterations of 3D printing can apply algorithms to produce both industrial forms as well as organic forms.

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[120] (Milne, 2021)

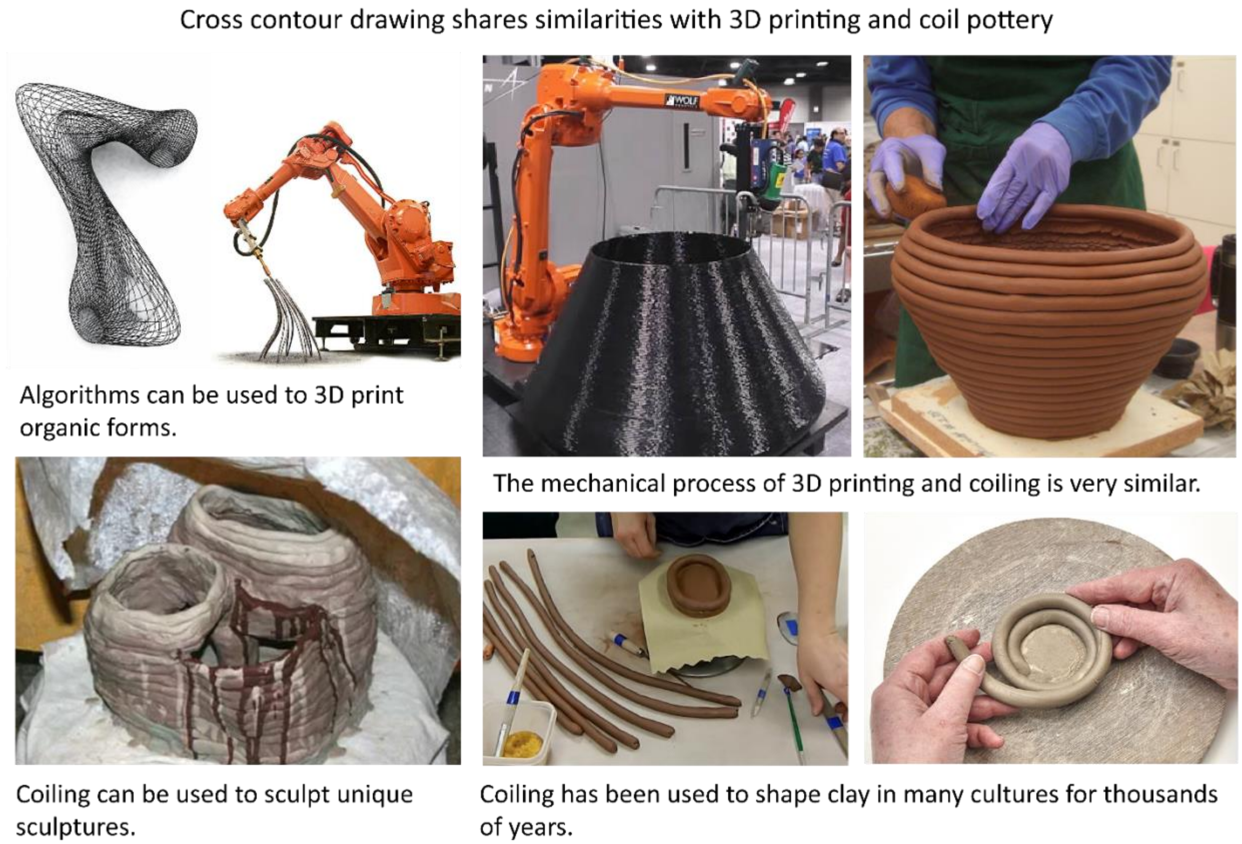

Figure 54 Two comparisons are made between 3D printing and clay-coiling. On the left, the comparison shows how algorithms in 3D printing can result in unique forms, and below it, how clay-coiling can be a tecnhnique for original works of art. The comparison on the right shows the use of a 3D printer for industrial design, in this case, a vase-like vessel. The vessel is similar to that created by hand using coiling as a ceramic technique. The images below demonstrate the cylindric clay strips, which bear a strong similarity to those produced by the 3D printer (visible in the image in the top right).

The corkscrew technique can be seen as a continued tradition of clay coiling, while the mechanical operative of the human arm can be interpreted by the software as an imperfect arm of a 3D printer. The automation of mesh surfaces could potentially do more for hand-drawn geometry in VR than fill in the scaffolding. Like the algorithmic process in 3D printing, the AI integrated in the mesh could help in guiding the creator with ways of improving the physicality of the technique. This is a feedback loop that can be compared to an athlete making corrections to their form through dynamic observation, for instance, the direction and velocity of a golf ball following an adjustment in the golfer’s swing.

The element of surprise

The algorithmic properties of the mesh may also result in surprising results, adding an experimental quality to the act of creating. The element of surprise can in turn enhance the trial-and-error of art-making that makes digital creation more human. In a VR tool that hybridizes hand-made ideation and machine-predictive processes, this could perhaps lead to the creation of 3D forms with interesting and unique outcomes that could not be produced by hand alone.

The Worldscaping method and the navigable 3D environment

The Worldscaping method could also suggest ways 3D graphics software could be improved for the creation of VR experiences that utilize first-person navigation. The method is founded on the premise that linear perspective is but one feature in the natural operatives of visual perception. By assuming the human body can be understood as a living version of the gimbal tool, the XYZ axis at the root of linear perspective is integrated into a spherical enclosure rather than an infinite void. The method therefore takes what works about Perspective but adjusts it to the biological makeup and functions of vision as it is understood in neuroscience today. The method takes as a property the claim that artists have made significant contributions to the scientific study of vision.

Visual Perception and 3D graphical systems

With similar views contributing to a decade of research, Pepperell recently announced a new 3D rendering technique based on human vision. The technique is called FOVO, which stands for Field of View Opened, implying that the expanded field of view we experience naturally. This meaning is distinguished from the limited field that is produced by linear perspective. To "achieve the widest, deepest and most immersive image," Pepperell writes, "it turns out (as we have discovered after years of experimentation) that you have to throw away the linear perspective rule book (originally invented by artists) and start again." Though FOVO was invented for flat-screen technology, Pepperell points out that the constrained field of view that results from linear perspective affects VR as well. "Even VR headsets have severe limitations in this regard," writes Pepperell, suggesting that those working in VR technology may want to consider how to integrate the findings of his research in future iterations of the technology. Pepperell claims that FOVO should be of particular interest in game development, explaining that the technique includes what he terms a "highly flexible geometry manipulator" in the place of linear perspective. This enables 3D space to be navigated in a way that updates dynamically with moving view of the player, in ways that, according to Pepperell, are not possible with current projection techniques.[121]

A template for creating a navigable world

Where Pepperell's focus is the rendering of the graphics, the Worldscaping technique could offer a template for integrating the manipulation of immersive geometry in a VR game from the foundational design of the environment. The human-sized sphere in the method represents the area of the most foreground elements in the scene. Meanwhile, the sphere that is scaled to the VR version of the horizon line represents scene elements too distant for the eye to access the depth relationship of objects with any level of accuracy. This could inform the design of navigation paths, enabling the designer to apply more depth information to elements in the scene that fall within the scope of the player sphere, for instance. The template could be used as a constant variable in all stages of the pipeline through to rendering, as geometry could be updated and compressed depending on the position of the spheres.

[121] (Pepperell, FOVO: A new 3D rendering techique based on human vision, 2020)

Combining the methods for world-building

The combined use of the Corkscrew method and the Worldscaping method can be used as a workflow that makes the design of virtual worlds more efficient for optimization requirements. Although optimization is always a concern, this is especially the case with platforms where users can upload and share immersive worlds of their own creation.

A strategy for creating an optimized world

Platforms like VRChat, for instance, the polygon limit of uploaded worlds is 70,000, though the recommended maximum count is below 32,000. The number of polygons increases with every instance of 3D geometry added to the environment. When the geometry is hand-made, the limit on polygons becomes an immense challenge for creators. To remain under the 70,000 K limit in VRChat entails significant strategic planning as a preliminary step in the world-making process, while the 32,000 recommended limit assumes an environment with minimal geometry. The Corkscrew method handles the creative iteration in the design of the form, resulting in a scaffold that serves as a detailed mold of the finished geometry. This creates optimal conditions for modelling the mesh surfaces with low polycounts. If the creator in question has some experience with 3D modelling in desktop software like MAYA or Blender or has a 3D modeler on their team, the polycount can be further reduced with scripting features in these applications.

An efficient way to test world elements

The worldscaping method offers additional ways to keep the polycount low, by providing a testing ground for importing the geometry into Unity or Unreal Engine. Importing the assets (3D models) into the scene together will provide the creator with the polycount of the scene in its entirety. The testing of imported geometry enables decisions to be made about what affordances can be made, to either reduce the polycount of assets already made or how to maximize the remaining number of polygons available with geometry yet to be created. The combined use of the Corkscrew method and the Worldscaping method, in conjunction with a testing template in a 3rd party application therefore presents a workflow for the creation of immersive worlds in an optimal way.

Collaborative world-building

This workflow, in how it results in optimized world spaces, can potentially be used to create overlapping worlds. Creators could apply the workflow to divide a polycount limit, each using their fraction of the count to create their own unique world. The Worldscaping template of each creator could be imported into Unity with the templates of the other creators involved in the project. When shared as an collection of immersive worlds, VR users could navigate through one world to the next, experiencing each with the subjective expression unique to the creator. In future versions of VR hubs, we may see the polycount increasing, along with additional factors that ease the world-building pipeline for creators. The vision of an endless virtual world made up of individual worlds, where participants could navigate freely through the imagination of one creator to the next, is what kept me motivated in the most trying moments of this project. It is this vision that resonates with me most about the potential of VR. When worlds can be created with a sense of agency and in a state of presence, built in collaboration with other creators in the same way, and shared as immersive worlds for audiences to experience, again, with agency and in a state of presence, the technology will have finally reached its potential.

Conclusion

There is, unfortunately, no avoiding the learning curve implicit in combining several applications. But this is often the case in digital creation to attain the desired results of the project. Like most of what I have learned in the many iterations of creative software and tools over the years, I became proficient with Quill only by enduring a long and often painstaking process of trial and error. It was only towards the end of my research that I began doing the same with Unity, and even then, attempted to keep most of the production in Quill. That, I came to realize after what I can only really chalk up to a learning experience (wasted time), was only because I found Unity too daunting. Overwhelmed by the fear of the learning curve, I tried to stick with what I was comfortable with, and this was to my detriment. I eventually learned the lesson I have relearned countless times: take it slow and focus on accomplishing one small task at a time. Unfortunately, in a studio project there is often no room for the patient, mediated approach to adapting to new software. I have found myself subjected to this pressure with VR creation in a professional context, despite having initially devoted myself to this research because I hoped to find easier paths for creators. In concluding this writing, I have become aware that my research goals were not to offer concrete design solutions or to improve the conditions for digital creation in highly competitive and demanding industries. What I did accomplish with these methods is a way to create worlds in VR with a sense of agency in personal expression, and, by perceiving virtual space as an extension of the body, in a state of presence. It may only be one step in the greater process of what creators will encounter in working with VR, but it is a big one. I have offered my own creative iteration of methods as a way of leading by example, hoping to encourage other creators to reach past the implications of working in a headset, to the tangible ways it can help us to reconnect. Through drawing, VR offers us ways to reconnect with ourselves as form, through self-expression, and to space, by embodying the 3D environment as an extension of our physicality. Through VR, drawing can help us reconnect with one another through the sharing of worlds of our own, and hopefully one day soon, collaborative creation.

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Appendix

Appendix 1: My professional background

I entered the Digital Futures Graduate program as a mid-career graphics professional. My research pursuits and design goals were informed by the culmination of my experience as a graphic artist to date. I use 'graphics' as an umbrella term to account for the many hats I have worn till now, all of which having found their way into this research in one way or another. While my educational path in animation did not lead me into the animation industry, it gave me the foundation needed for the freelance digital artist and educator that I remain to date. For the past decade, I worked with Wacom Americas, the leading brand name in drawing tablets, as a demo artist and workshop host. I was the first digital drawing instructor in the Design Program George Brown College. I designed the curriculum for Continuing Education courses in traditional and digital illustration. I've taught architects and animators, costume designers, pool table makers, bankers, high school and college students, new immigrants, and retirees. The diverse range of experience forced me to figure out methods of teaching, and techniques of making, that could apply to everyone.

With a desire to one day have a hand in improving the design of the creative tools I both used and taught, I returned to school to learn how to code. I spent four years working in the field of Interaction design, during which time I led a team in the design of e-learning content in Music Theory for mobile applications. With a growing desire to take part in the cultural arena that pushed creative technology through academic discourse, I returned once more to school to earn my master's degree in design.

Despite my degree and diploma in animation, I did not pursue a career in this field. My reasons for not doing so are the same that motivated my research about creating in VR. Up until this project, I had felt somewhat alone in these reactions, despite having heard similar sentiments echoed by my peers who continue to work in digital animation and design. This thesis gave me the opportunity to encounter other creators who have shared my views about 3D graphics as CAD software has evolved. When I had, as a student, transitioned from hand-drawn to 3D animation, I had felt that modelling and animating in 3D software had felt lifeless by comparison to the intuitive expression I had found in drawing.

Appendix 2: Some notes on the title

Davies argues that divisions like that of our minds and bodies, and ourselves and nature, have cultivated a worldview of the 'self' and 'other' that she traces back to Plato's analogy of The Cave. Where Plato aimed to show that the projections of light in the cave (what we think we know) were no more than illusionary manifestations (cast by 'others'), and that truth could only be sought in the pursuit of intellectual reason (the mind, or 'self') that lies beyond the walls of the cave, Davies suggested the opposite. Her aim, at least how I interpreted it, was to point to the subconscious knowledge of the body as it exists within the cave (nature), physically and spiritually connected as an osmosis of organic form and atmospheric space.

I had initially dismissed Davies' writing about the deeper philosophical themes in VR as being beyond the scope of a graduate thesis in Design. It was only after I had encountered a major impasse in my design research that I returned to these texts and found a solidarity in thought and artistic practice so impactful in its timing that it altered the course of my research. I had initially intended to create techniques for drawing in VR, only to find myself caught in the conundrum of not being able to draw in perspective while immersed inside a virtual simulation of perspective. Davies was the first, but not the last, to point out to me that the method of perspective itself was at the heart of my design problem, but she went far further than that. Davies argued that the origins of the method, which involved a screen between the artist and the subject, or the viewer and the viewed, were the source of fractures in the Western worldview. The paintings of the Renaissance, which either mimicked reality or conjured imagined worlds that enabled an escape from it, were based on a mathematically generated, screen separation of the viewer and the viewed. The practice of using the two-dimensional image plane as a screen continued on in the advent of photography, then film, then TV, news coverage, video games, and finally, the digital screens we now carry with us everywhere we go. For Davies, who had a background as a landscape painter in the style of realism, the immersive quality of VR was a way to step beyond this boundary of the screen that has been separating us from our connection to ourselves, the natural world and one another, and perpetuating these fractures, for half a millennium. In short, Davies wanted VR to be a way to find ourselves again in the cave.

Davies' work in VR took place in the 1990s, at a time when violence in video games and western conquest of the 'developing' world through military force were presiding themes in popular culture. Her VR installations contributed to the induction of themes about connection that have since made their way into the mainstream, like finding one's centre through the focused breathing of meditation. And yet, the intervention Davies had hoped to make in using VR as an artistic medium in its reemergence in pop culture has, in large part, gone ignored. Though the cultural merits of VR are indeed making waves in many institutions, the commercial influence of VR has exacerbated many of the fractures that Davies and other theorists had expressed great concern about regarding entertainment industries. As a regular user of an Oculus headset, new games about killing zombies, aliens, human soldiers or other forms of "other" are marketed to me on a daily basis. First-person shooter games are an example of what Davies considered an extension of the conquering and the to-be-conquered, (that CAVE systems were initially introduced as a training tool in the US military is not lost on the title), enacted in virtual realms through the all-powerful hand-held controller in the form of a weapon.

As the technological design of her works is widely considered well before its time, as tech innovation, these works existed in somewhat of a vacuum. Aided in no small part by significant advancements in digital technology, the VR of today presents ample opportunity to explore, enhance, and continue with the work that artists like Davies had started. Where Davies had, through her installations and writing, invited people to return to the interconnectedness of the metaphorical cave, my own approach takes a slightly different spin on the analogy. Taking all that I had learned from Davies into consideration in my research, this was, and remains, a design project. I wanted to find pragmatic solutions to the design problems I was encountering both inside the headset and in my reflections about it. I am in full agreement, for instance, that linear perspective is flawed as a method, but for better or for worse it seems to be at least partially and perhaps permanently ingrained in how we perceive and interpret visual space. I could not therefore, reject it outright, but rather suggest ways to amend it with other aspects of Western art, design, and science. Nor could I very easily dismiss the hand-controller, and so I chose to shift the implication of omnipotent power of using it to kill, to the empowerment of subjective expression in using it to create. That being said, my plight was not to convert gamers into creators (or at least, not entirely) but to enhance it as a tool for creators. In this sense, the enemy is not commercial entertainment but rather what I saw as fractures embedded in graphics industries. From a paper I read by Design Professor Gurt Hasenhutl, I was able to track many of the challenges I have encountered in own career as a digital designer to the same origin as Davies: The Renaissance, when artists became the tools of industrial development and commercial trade. On a surface level, my approach to the hand-controller as a creative tool is to suggest ways of using it that feel more natural, more intuitive, and more human. Underlying this intention, is both a call to arms to fellow creators, as both artists and engineers alike, in healing the fractures in graphics industries. Digital artists working in commercial fields encounter insurmountable pressure daily, to produce creative work through a pipeline of software that is as riddled with obstacles as it is difficult to learn, never mind work with. The direction of creative VR may well be at risk of following the same course as the current zombie apocalypse games Davies and her counterparts had foreseen in the 1990s and done their best to circumvent. As an example, I wrote in this work about an artist who had spent 70 hours in a headset in a single week, expressing my concern about the risks to her vision. In my ensuing work as a VR artist in the video game industry, I now regularly spend *at least* that amount of time working in the headset in any given week, often even more. Before the current conventions in graphics industries turn the VR artists and designers of the near future turn into zombies themselves, I would like to suggest ways that we, the designers and creators at the dawn of creative VR, decide how we want to use this tool before it gets decided for us. The hand controller we create with, and the simulation of 3D space where we work, is only the start. We need to design and new ways of using these tools, then document our findings for engineers to improve them.

In a broader view, I could not refute all that logical reasoning that lies beyond the walls of the cave. Instead, I focused on the path that connects the depths of the shadow-riddled interior to the light of pure intellect outside. It was in imagining a human bridge being formed along this pathway, where those closest to the mouth of the cave could pass along their findings to those who found themselves trying to create something from deep within. Maybe in Plato's day, all these creatives had the means to tell stories with were shadow puppets formed by their own hands. With each generation of this human bridge, the findings passed down have extended those hands into tools of projection that far surpass the range of shapes made by shadow puppets, and the shadows cast by spectrums of light not possible through flames of fire alone. Our truth then, is maybe always evolving like this, in the enlightenment of how our tools are engineered, and what forms of light we create with them. I like to think that Davies and I share this perspective. Unlike Davies, I have no intention of co-founding a computer graphics company as she did with SoftImage, so that I can use for the development of my ideas (respect). But I am right there with Davies in the cave, looking up at the bridge of artists, designers, student researchers, educators, engineers and scientists, to the greatest of mathematicians standing near the surface, asking each of them to have a hand in helping to draw the light in.

Appendix 3: The historical context of VR

When divulging in a bit of commonly known history about virtual reality, the name you will likely come across first is Charles Wheatstone. In the early 1800s there was already some experimentation going on with visual experiences, as Brenden Kelley adds, “to deceive the mind.”(K). Wheatstone’s prankster reputation precedes him in the context of virtual reality. The stereoscope he built in 1838 was in Brendan Kelley’s writing, created to “trick the viewer’s eyes”. Wheatstone was in fact making very significant contributions to the science of human vision. The stereoscope was, at least to my knowledge, the first instrument in western science that studied stereoscopic vision.

- Your left eye is further to the left, so you see more of the left face, and your right eye is further to the right, so you see more of the right face.
- Your brain can use that information, these minute differences in the retinal image, to provide you with a compelling and immediate impression of depth.

- Stereoscopic vision: what gives you this amazing, compelling impression of things jutting out and sticking out from surfaces.

In summary: We can understand these minute differences in the positions of the images of parts of individual objects simply resulting from slightly different viewing points of the two eyes.

Experiments performed with the stereoscope led Wheatstone to notice that there was a difference in the information being processed by each of the eyes. The eyes are separated, which means that the views projected on the retinal plane could not be received by every nerve cell all at once. This is because the images being projected by each eye are not in the same corresponding positions at the same exact moment. This could only mean that there was an additional process happening where the mind interprets the image itself to be a representation of the third dimension(B).

Appendix 4: Big Tech and the negative ramifications for VR

My thesis project took place through the first and part of the second year of the world-wide pandemic. Everyone was stuck at home indefinitely, and Facebook, who had recently acquired Oculus, one of the leading VR companies, had released a portable and affordable version of a VR kit called the Quest. I was meanwhile reading about the rush that was taking place in the tech industry pertaining to VR technology. It seemed that the conditions were perfect for accelerating the momentum of these devices into a wide range of industries, education systems and, doubling as a means of escaping reality but also connecting with friends and loved ones in a virtual setting, right into peoples' homes. I was concerned about the Facebook ownership, but as an interaction designer, I was even more concerned about what user experience paths would be forged into these systems before there was any chance for experimentation.

I was still excited about the potential of VR in how it could enable people to use this technology to create art. The difference was, I was now becoming exposed to the darker side of virtual reality. Situated as I was as a researcher studying what was being hyped as the precipice of a paradigm shift in how we may soon be using this technology to live, work and communicate, I could not ignore these implications. On the other hand, the current state of affairs only served to elevate the significance of figuring out VR as a medium for art making. I needed to know more about the medium itself, and how to make the best use of my own capabilities as a designer, an artist, an educator and a researcher, in figuring out how to make use of it.

Char Davies, whose work in the 1990s was motivated by a desire to suggest a healing approach to our relationship with technology, echoes this concern. “Can artists overcome the inherent biases of the technology, and the profit-driven imperative of the gigantic corporations gathering behind it, to creative meaningful, relevant work?” she asks. “Time will tell.”

Appendix 5: Agency in VR in context

Kelley and Cyanne Tornatzky’s paper from 2019, “The Artistic Approach to Virtual Reality”, attempts to bridge the works of VR artists from the 1990s with recent artistic works through the themes prevalent in both periods. Through an analysis of these works past and present Kelley distills the many topics surrounding VR into two terms that remain prevalent in defining the potential of VR as a creative medium: agency and presence.

Char Davies called attention to the perceived sense of agency implicit in video game culture.[122] Participants of Osmose were invited to float instead of walk, moving up and down

[122] (Brendan Kelley, 2019)

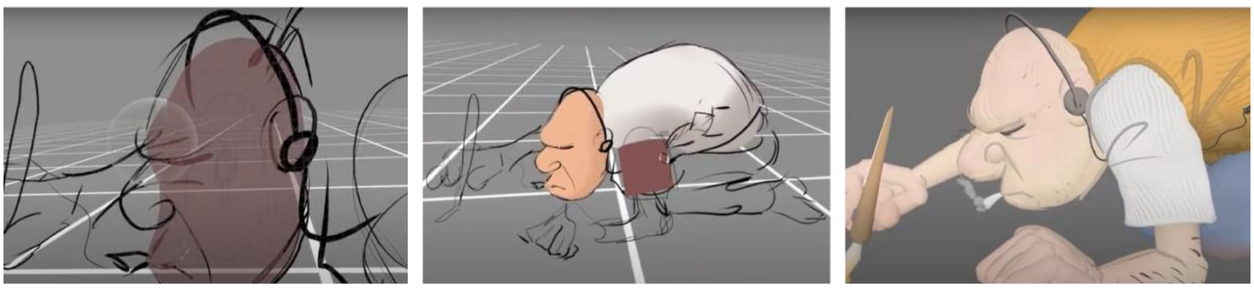
through space rather than upright movement along the horizontal plane.[123] The intention was to break from navigational conventions not just from video games, but everyday life.[124]
Agency in VR is also discussed as a means of empowering the user to leave their unique mark, in a way that can be shared with others. This view of agency evolved through a cultural discussion about the role of the user in virtual experiences. In the 1990s, artists and theorists expressed the need to update the passive role of the "user" or "viewer"[125] into a role that emphasized the quality of user involvement. Char Davies gave the term 'immersants' to the participants of her immersive work Osmose (1994) and Ephémere (1998). The term emphasized how embodied movement can promote a deeply personal sense of agency within virtual space
Davies showed how agency could be realized through interaction by forming an embodied relationship with the virtual environment that enabled the user to become a creator of their own unique and subjective experience.

Brenda Laurel and Rachel Strickland used the term "participant" rather than "user" when they created Placeholder, an immersive VR experience in 1992. Laurel and Strickland showed how participants could share their unique autograph by leaving recorded messages of their voices, or "voice marks."[126] The recordings remained in the experience, enabling the unique signature of each individual to be shared with future participants. These recordings also permanently altered the landscape, thus empowering each user to leave their mark on the world.

[123] (Davies & Harrison, 1996, p. 26)
[124] (Davies & Harrison, 1996, p. 27)
[125] (Brendan Kelley, 2019)
[126] (Brendan Kelley, 2019)

Appendix 6: The "pre-fab" approach to sculpting the mesh in VR

VR artist Daniel Piexe has established a method for drawing the form with gesture strokes with custom fills made up of 3D brush strokes. Because of the unified, vertical orientation of the strokes, the fill shapes adhered well to the paint tool. By setting up a library of geometric shapes beforehand, Piexe had made a conceptual alteration to the workspace. By using the "shape" tool to manually push, pull, and twist the geometry to fill in the form of the hand-gesture drawn contours lines, the entire process seemed fluid and organic.



VR artist Daniel Martin Piexe begins with a gesture drawing of the model, then uses geometric shapes built with the 3D brush in Quill to sculpt the shape. This technique results in a cleaner, simplified mesh.

Appendix 7: The "post-production" approach to sculpting the mesh in VR

The 3D volume brushes form the surface of objects, and if they are to be imported into a gaming engine, clean mesh surfaces are critical in adding shaders and materials. The hand-drawn, organic shapes are fun to create, but limiting in terms of rendering for virtual environments. A practical solution is to redo a cleaner mesh using conventional 3D modelling tools, which is possible in the VR application Gravity Sketch.

Appendix 8: The hiearchy of visual perception

Blakemore shows comparative studies that demonstrated how participants had more difficulty in perceiving a set of points, both in terms of their position in space, as well as the relative distances between them.[127] This finding may support my observations about 3D modelling leading eyestrain, as the process of modelling a 3D shape begins with points, or vertices.

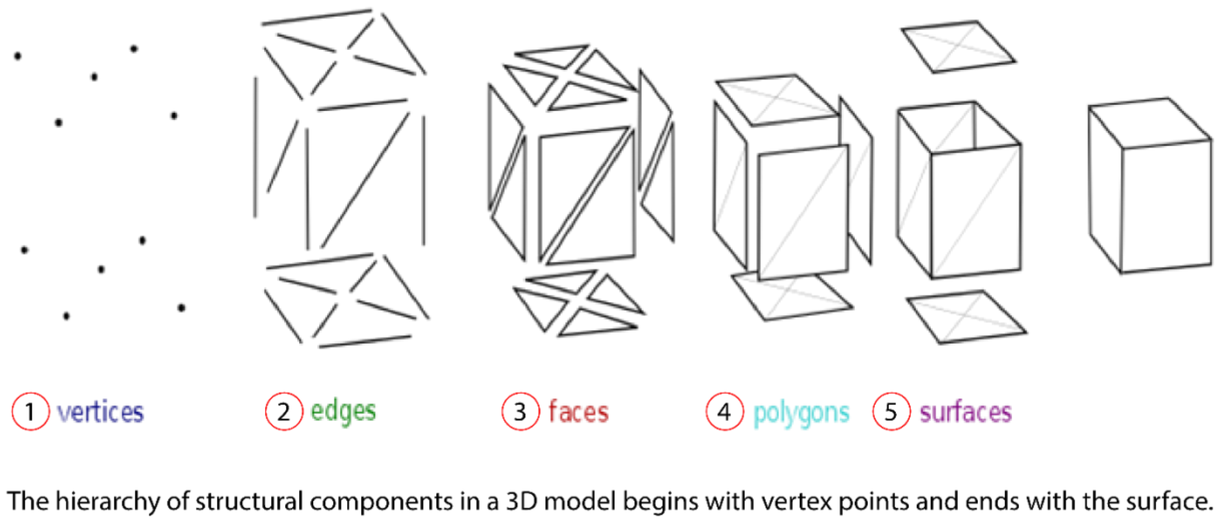


Figure 55 3D geometry is assembled by connecting vertex points, ultimately resulting in a completed shape.

3D models are defined by the vertex points, which is how the system design of 3D graphics can locate and position the objects in virtual space.[128] Traditional 3D modelling techniques in desktop applications use combination of the mouse and numeric inputs on the keyboard. While this practice may make sense with such linear approaches, using physical actions of the body in VR with similar techniques may be causing too great a disconnect. A 3D brush in VR does not interact directly with the edges of the shape, but rather manipulates the surface of the shape in hopes that the edges will result in the desired form.

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[127] (Blakemore, 2019)
[128] (Blakemore, 2019)