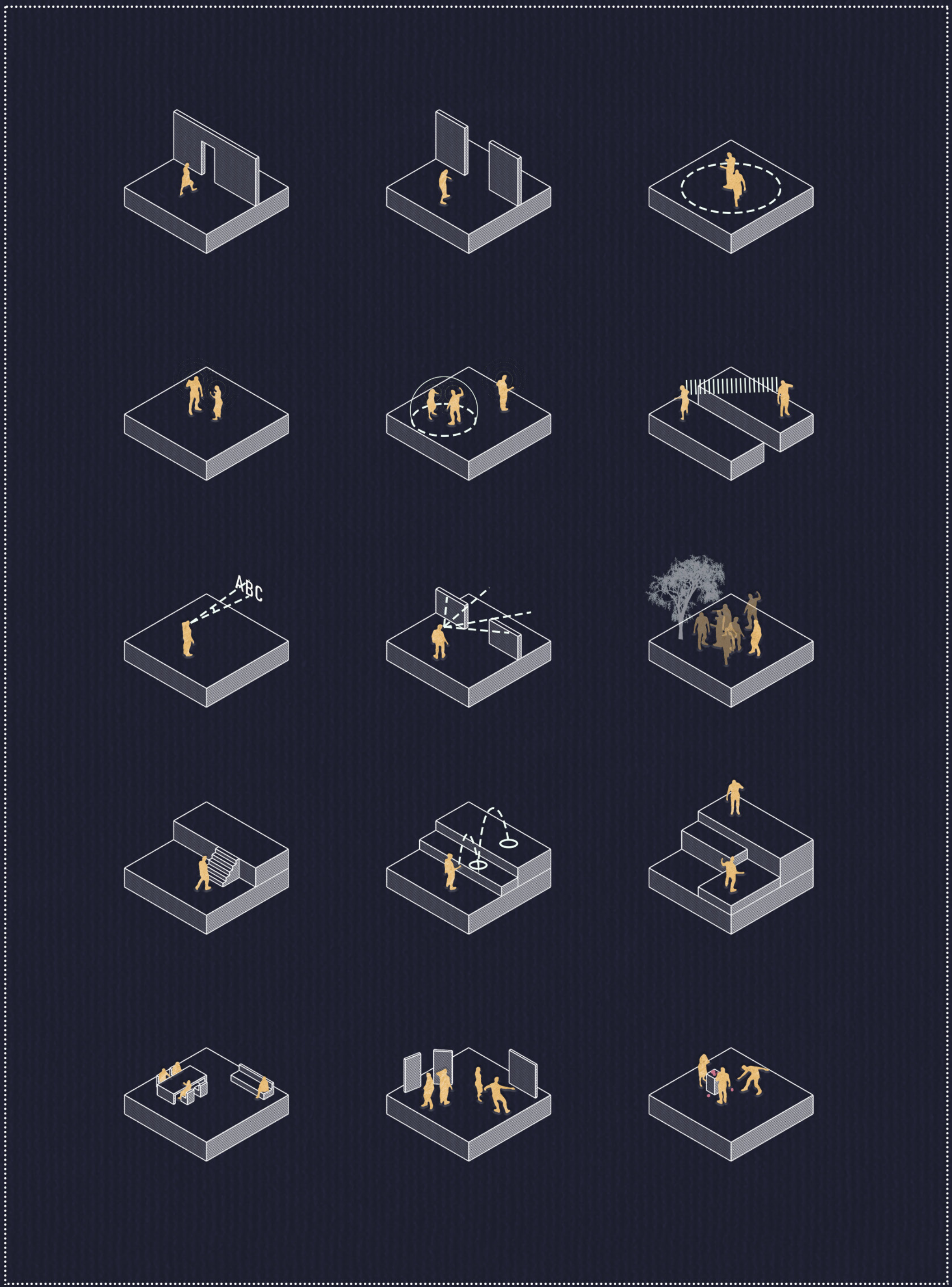


POST.SPACES

VOLUME I: CONSTRUCTING DIGITAL SPACE

CONTENTS

FOREWORD

I have long been interested in the application of architectural design approaches in virtual worlds, which for the most part have been left to concept artists and game designers rather than architects who are trained in the understanding and creation of space. As we spend increasing amounts of time in online worlds, especially with the advent of virtual reality, where virtual space takes on entirely new qualities and meaning, I believe that architects are uniquely suited to design these spaces with a critical eye - not just by improving their utility and appeal but also by pushing the boundaries of what 'space' might look like in the virtual realm.

This first volume is a record of the first part of my Master in Architecture thesis project, with the full project report spanning two volumes and two additional appendices. The thesis explores the potential of architectural design for VR spaces as an end in itself, given the immersive nature of such spaces and their increasing relevance.

In Volume 1, I take a broad-based approach to investigating the various possibilities and design strategies of spatial environments in virtual reality. Precedent texts and case studies are studied to gain an understanding of existing VR spaces, followed by a series of design experiments and user tests covering various aspects of the VR spatial experience. The product is a catalogue of design principles that serve as a reference for future design in VR.

In Volume 2, I attempt the creation of a functional VR environment that exemplifies my design principles and pushes the boundaries of virtual space design. Although the process was a somewhat meandering one involving many iterations and revisions, it has been organised into a cohesive narrative based on the final outcome, that is, a fully-functional VR environment for online forum browsing in Reddit.

The first appendix is a mini-volume containing a series of precedent studies and inspirational projects that might not have warranted detailed explanations in the main report, serving as a reference for readers who might want to explore other related works. The second appendix is a systems documentation of the final app, including a printout of most of the program code as well as some diagrams illustrating the program structure and architecture.

Accompanying these texts is a series of presentation panels and a live demo of the final space in VR, as well as a companion website that should contain most of the information here if you are not viewing this project live.

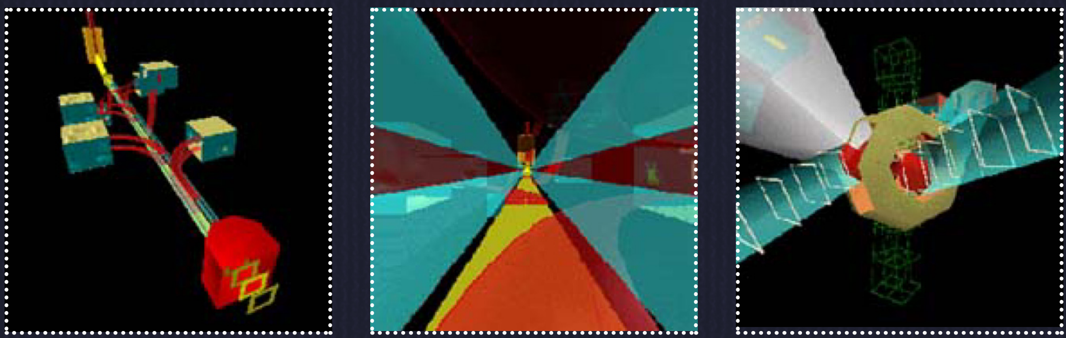
At the conclusion of this year-long endeavour, I can surely say that the project is far from complete - app design and development is an endless process of refinement and adding additional features, and the question of 'what should virtual reality space look like?' can hardly be answered by any one individual.

However, the thesis project has been an incredible learning journey from start to finish, one that I am happy to have had the chance to pursue thanks to Prof. Patrick and the support of the Department. True to the multidisciplinary nature of Architecture, pursuing this project has taught me many new skills such as coding a VR application from scratch, as well as honed existing ones or cast them in a new light, such as doing spatial analyses and technical illustrations for an entirely new paradigm of space.

I hope you enjoy this thesis project as much as I have enjoyed working on it.

Matthew

With special thanks to my thesis tutor, Prof. Patrick Janssen,
for his support, guidance, and helpful resources;
my studio mates, Anna and Derek, for the many zoom meetings and pilot tests;
and all my friends, family, guest critics, and others who have contributed in some way or another towards the completion of this thesis project.



Speculative 'Virtual Environments' by Bourdakis and Charitos in 1999.

1 INTRODUCTION

Despite the fact that virtual environments (VEs) have been around for more than 20 years and there has been continued research into their design and implementation, they have been regarded largely as entertainment and as accessories to physical interaction. More recently, virtual reality through the use of head-mounted displays (henceforth referred to as VR) has introduced yet another way in which such virtual environments might be experienced. While VR remains somewhat of a niche market, improvements in technology and accessibility in recent years has made it increasingly accessible to the average consumer[1].

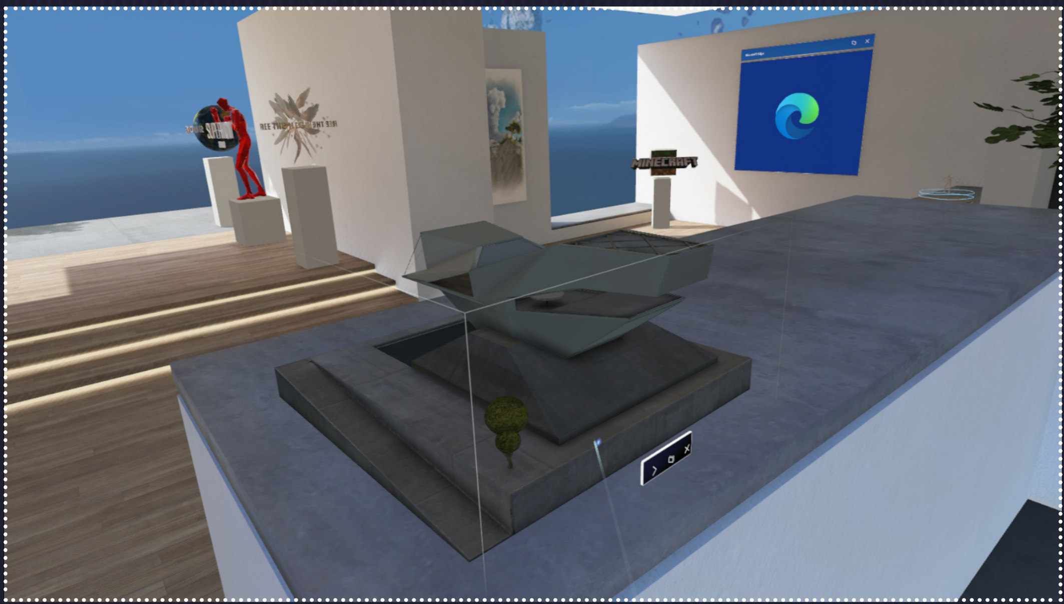
In the midst of the post-digital revolution and the ongoing pandemic, we are increasingly looking at VEs as substitutes for real-life interaction, whether it be for social reasons, education, work, or leisure. Thus far, the design of most VR environments has tended towards imitative environments that mimic physical spaces – in fact, there is often an emphasis on physical cues and architecture to make users feel at ease within the virtual environment, reminiscent of skeuomorphic design during the earlier years of the digital era (Norman, 2013).

However, within virtual environments, traditional architectural conceptions of scale, spatiality, movement, framing and interaction take on vastly different forms. While the architectural conventions of the real world might be comforting, it is clear that the spatial design of spaces in virtual reality warrants a critical re-examination of its foundations.

[1] The VR industry as a whole is growing at a fast pace, with the market size of consumer virtual reality hardware and software projected to increase from 6.2 billion U.S. dollars in 2019 to more than 16 billion U.S. dollars by 2022. (Alsop, 2020).

HYPOTHESIS

In Part 1 of this thesis, I hypothesize that by moving beyond conventional, real-world preconceptions of physics and spatial configuration, the design of virtual environments can be made more efficient and comfortable for users, especially for the purposes of peer-to-peer interaction.



Screenshot of the Windows Mixed Reality home environment, showing both the spatial conditions as well as a representative model of an alternate home environment used for switching between locations.

RESEARCH APPROACH

While many of these efforts were taken in parallel, the core of the research methodology can be traced in a roughly linear fashion. This following order will also serve as the structure for this report.

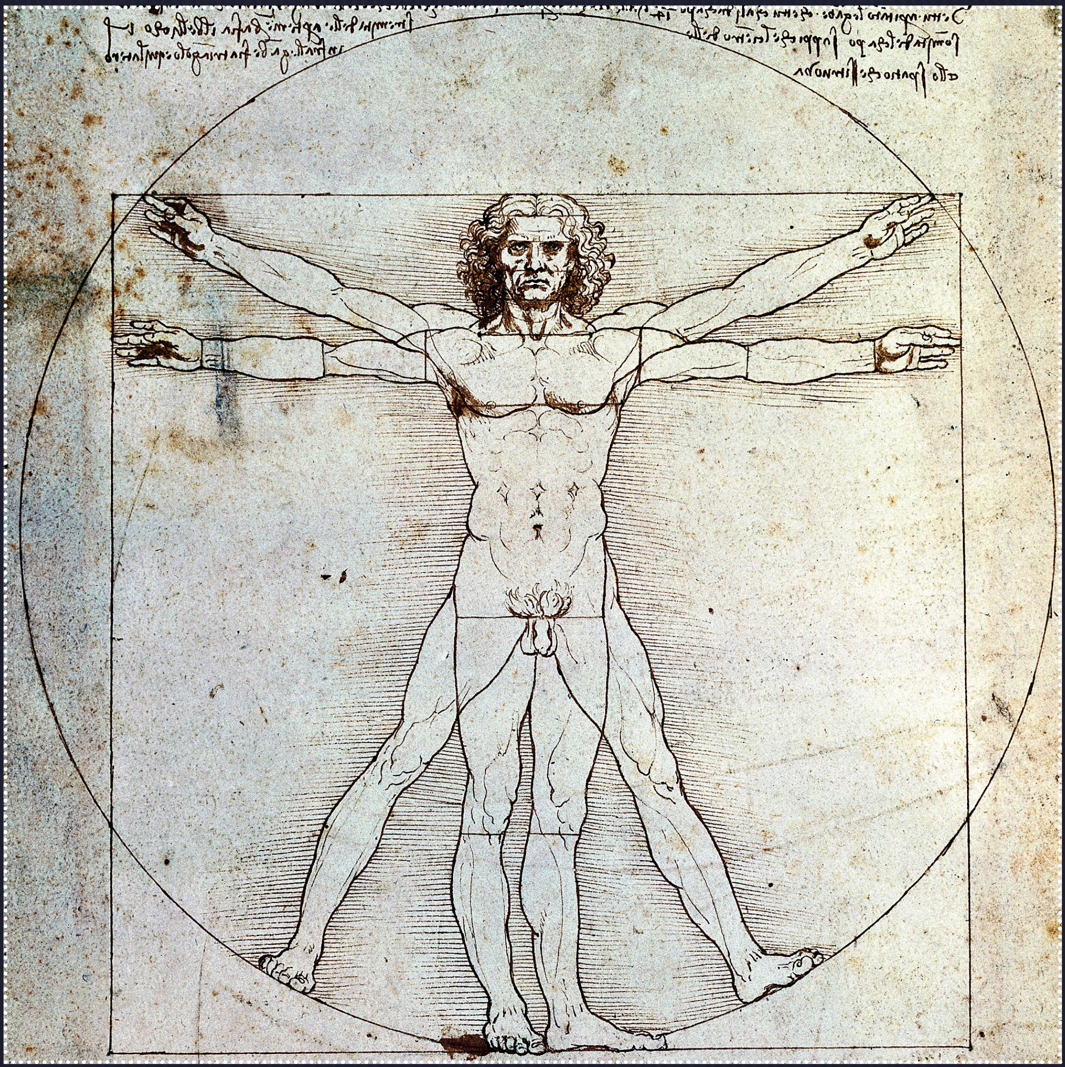
Firstly, I began with a review of the existing literature surrounding virtual environments. At the beginning of the project, I had not definitively settled on the use of VR as a medium, having equally considered developing a 'web app' that would necessarily be presented in screen-space. Hence, this research investigated the design of both VR and non-VR virtual environments, providing the theoretical and contextual underpinnings for my project as well as ultimately influencing my decision to work with VR. After reviewing the existing literature, I undertook precedent studies of several existing virtual spaces to understand and critique the existing state of spatial design in VR.

Subsequently, I distilled several parameters and strategies governing the design of virtual spaces, developing and designing various test cases in VR. Learning the requisite programming skills and developing the virtual environment in Unity also took place in parallel to the design and research work. Several users were then recruited to test and give feedback on the new spatial designs, collecting both qualitative and quantitative data that would inform subsequent design choices.

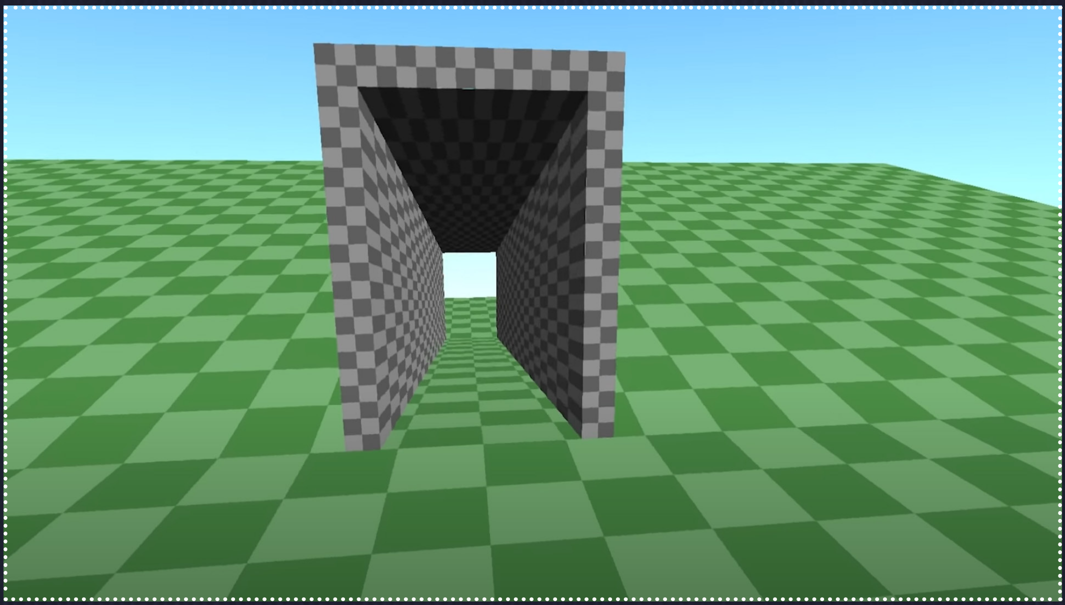
Finally, these inputs and iterations were synthesized to create a set of design parameters and possibilities that would serve as the foundation for the next stage of the thesis project – designing the overarching generation of these virtual spaces and the user experience within them.

2 VIRTUAL ENVIRONMENTS

From Vitruvius to Le Corbusier and Neufert, architects have sought to design spaces with the scale and capabilities of the human body in mind, as well as attempting to express the tectonics of material and function in construction. In the same way, the design of virtual spaces ought to reflect the different rules that govern both user and environment in the virtual world (Hansen, 2012). Since the late 90s, researchers have called for “a new theory and practice” due to the nature of space in VEs being “fundamentally different from the nature of real space” (Bourdakis and Charitos, 1999). While the design of virtual spaces remains largely on the fringe of architectural practice, the ability to experience these spaces in full 3D warrants a re-examination of these fundamental design principles.



Sketch of the Vitruvian Man, an attempt at distilling a natural order of proportion based on the dimensions of the human body.



Non-Euclidean virtual world showcased by user 'CodeParade' on YouTube, showing a tunnel that slopes downward even as its external form is level.

Screenshot from the game 'Calvino Noir', depicting an in-game space represented purely through architectural section.

POSSIBILITIES OF VIRTUAL ENVIRONMENTS

For the most part, VEs are differentiated from physical spaces due to their freedom from physical and structural constraints. While this affords a significant degree of freedom to create almost anything the designer might imagine, the following are the most significant implications of VEs from an architectural perspective.

1. Unless consciously implemented, there is an inherent lack of physical rules such as friction, gravity or sound propagation (Bridges & Charitos, 1997). This affects not just the user experience but also the design of spaces, which are not bound by the usual considerations of load-bearing or material properties.

2. Spaces might be multi-dimensional or non-contiguous (Bridges & Charitos, 1997), being connected by portals or other means of translation, or even completely non-Euclidean in nature (Coulon, Matsumoto, Segerman, & Steve, 2002).

3. Scale of the user, objects and environment is unconstrained, allowing for unconventional experiences even of conventional spaces at different scales.

4. Modes of interaction with the environment are explicitly determined by the designer of the virtual space – this allows for new modes of experiencing space, either by restricting interaction to certain actions such as climbing or modes of movement, or allowing the user to perform actions that go beyond the experience of conventional architecture, such as creation, manipulation, destruction, and so on.

LIMITATIONS OF VIRTUAL ENVIRONMENTS

Despite the seemingly limitless nature of virtual environments, the design of such spaces comes with its own set of constraints that govern design choices. These constraints can be seen as analogous to the physical and resource considerations that limit architectural design in the real world.

1. Resource intensiveness, both from a development and user performance perspective, remains a key concern. Although the gaming and simulation industry seem to have moved towards ever more realistic renderings over the years, such detailed environments require both extensive development time as well as advanced hardware to run. VR is especially taxing, requiring two separate renders to achieve stereoscopic vision – as such, most current VR environments have been designed to minimise graphical complexity (Sundstrom, 2015). With the advent of more untethered headsets such as the Oculus Rift that run on their own mobile processors, the performance constraint on VR is unlikely to go away anytime soon even if PC hardware improves.

2. No matter how abstract or realistic the environment is designed to be, it ought to be designed in a way that allows the user to easily understand the space for (1) navigation and (2) interaction. While navigational concerns are similar to those of real-world architecture, interaction presents a novel challenge as the visual representation of virtual objects might be entirely divorced from their function. Designers need to provide users with the affordances necessary to understand the environment, both at a macro and micro scale (Ellis, 2019).

3. Finally, comfort is a concern that applies to most immersive spaces but is especially a concern in VR. Especially for users new to the technology, movement in VR can cause discomfort and nausea due to the brain's attempt at processing the artificial spatial visualisation (Thompson, 2020). Spaces and interfaces should be designed so that the user feels at ease within the space, both in terms of physical discomfort as well as subjective unfamiliarity with the space.

3 PRECEDENT STUDIES

In order to gain an understanding of the current state of spatial design in VR, I undertook a series of studies of virtual spaces, focusing on archetypal VR spaces that exemplify either (1) player navigation in VR space, or (2) peer-to-peer interaction in VR.

Navigation and Design of VR Spaces

In order to gain an understanding of the current state of spatial design in VR, I undertook a series of studies of virtual spaces, focusing on archetypal VR spaces that exemplify either (1) player navigation in VR space, or (2) peer-to-peer interaction in VR.

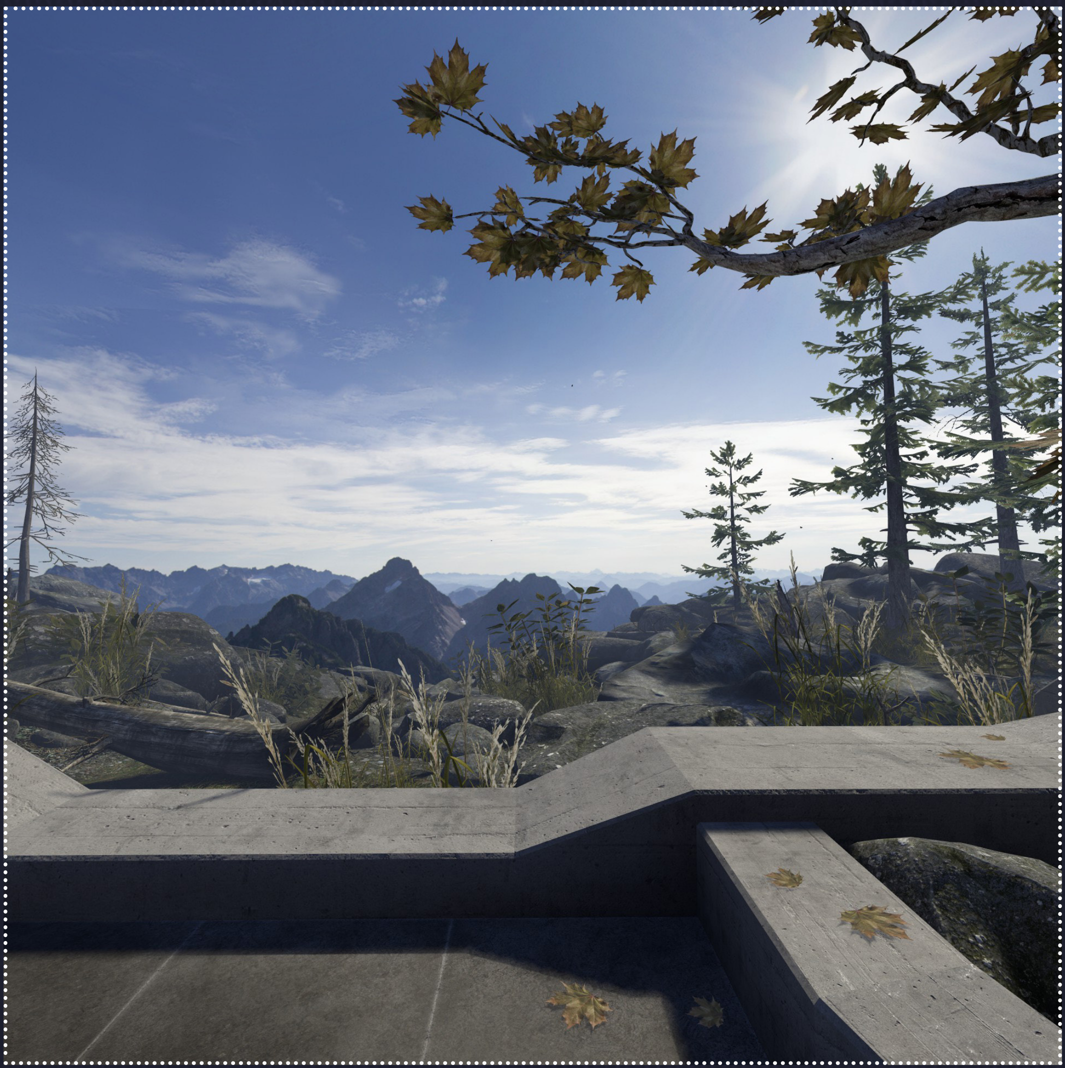
Several 'home base' environments were studied to gain an understanding of the current state of spatial design in VR, especially with regards to navigation and representation. These would be the first environments a user encounters when they put on a headset or launch particular apps, making it likely that they would have been carefully and intentionally designed to suit the VR medium. These spaces are the two default houses for the Windows Mixed Reality (WMR) and SteamVR platforms – 'Cliff House' and 'Summit Pavilion' respectively – as well as the two starting 'house' environments for the social applications AltSpaceVR and VRChat.

Home environment in AltSpaceVR.

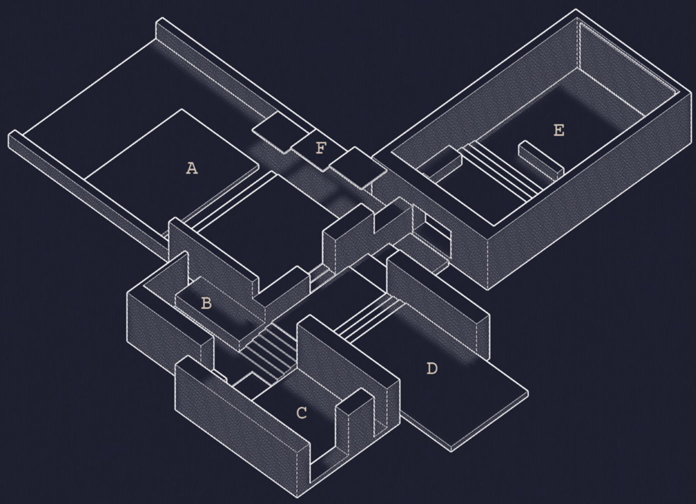
Home environment in VRChat.

IMMERSION

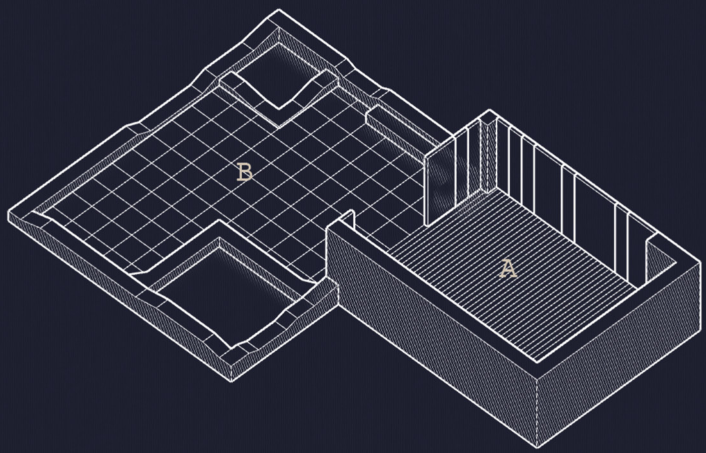
Within all of these environments, there is a clear trend towards realism – skeuomorphic details help the user acclimatise to the virtual world and show off the immersive capabilities of VR technology. In both the WMR and SteamVR houses, photorealistic textures such as concrete and timber flooring are used to imitate real-world surfaces, while the latter features architectural elements such as window frames and thick structural walls that convey a sense of structural realism. Props such as sofas and beds are present in both environments to mimic real-world interiors, despite having no real functionality as the user is unable to physically interact with them. In contrast, the home spaces in VRChat and AltSpaceVR are designed in a much more cartoonish manner with skewed lines and exaggerated proportions in some cases – however, despite the cartoonish aesthetic, the design of both environments features furniture and decorations that mimic a real-life environment.



Photorealistic textures and environment in the 'Summit Pavilion'.



Axonometric drawing of the Windows Mixed Reality 'Cliff House'.



Axonometric drawing of the SteamVR 'Summit Pavilion'.

SPATIAL CONFIGURATION

In terms of spatial configuration and movement, teleportation is the predominant means of locomotion in all cases, controlled via a raycasted arc that allows users to aim up at surfaces that might not necessarily be in direct line of sight. Aside from the WMR house, the three other houses feature relatively flat plans with no changes in elevation, likely for ease of navigation.

In the 'Cliff House', however, the environment is broken up into a number of different spaces with varying degrees of enclosure. While some spaces are open and could be considered 'exterior' spaces (spaces A and D), others are partially (B and C) or fully (E) enclosed, providing the user with a variety of spatial experiences. More significantly, every one of these spaces is separated from the others by some form of level differential, mediated by steps of various heights.

A series of platforms (F) near the starting point leads up to the roof, which is completely bare aside from some apertures serving as skylights. Taken together, there is a clear attempt to encourage movement along the vertical axis by means of teleportation, even in unconventional ways such as climbing onto the roof level. It is notable that the inclusion of 'steps' serves little purpose beyond physical imitation and the marking of continuous space - although they are somewhat wider than a regular stair tread, there is no reason to use them instead of teleporting straight to the intended destination.

In contrast, the ‘Summit Pavilion’ in SteamVR is designed with a very simple layout, comprised of a clear ‘interior’ (A) and ‘exterior’ (B) space. The traversable area is fully planar with no changes in elevation, and is even highlighted with an overlay when the user is aiming the teleport. This makes it clear to the user that movement is restricted to the intended surfaces only.

Finally, the scale of the environments appear to be largely in line with real-world proportions, with the notable exception of some structural features and aperture sizes. Without the need for physical realism, the ‘Cliff House’ features 0.5m thick walls and no supports for the floating roofs, likely for aesthetic effect.

In the ‘Summit Pavilion’, the low concrete walls that surround the external patio are far lower than real-life barriers - again for aesthetic effect - as the user’s movement is already constrained by the active teleportation area. Additionally, in both houses, the ‘doorways’ between spaces take the form of wide open apertures or gaps in the walls, with the minimum width being about 1.5m. This shows a clear attempt at designing for teleportation, as these wider openings minimise the amount of precision turning and aiming required to navigate, allowing the user a clear view of the space beyond and an easier time teleporting between the various spaces.

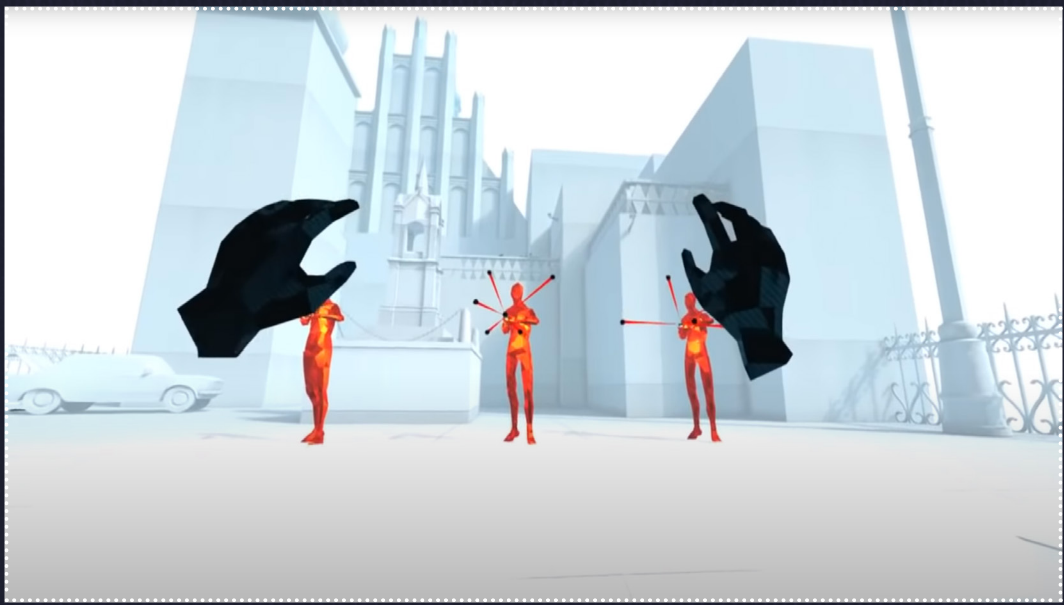
Screenshot of the 'Cliff House' showing floating roof planes and wide steps on the left.

Screenshot of the 'Summit Pavilion' showing the view from the starting interior space.

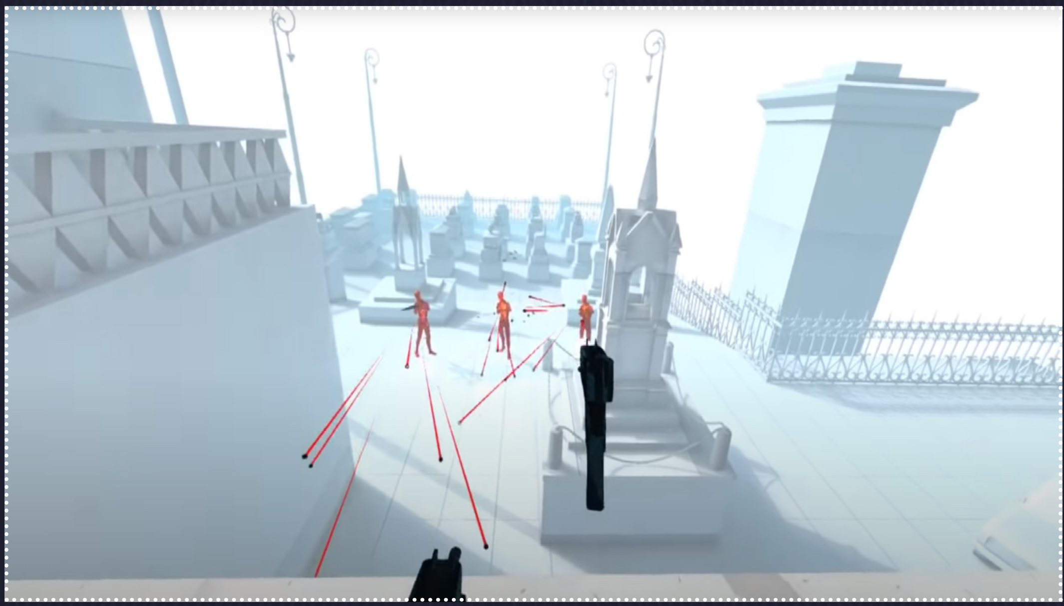
SUPERHOT VR: EMBRACING TELEPORTATION

In VR, teleportation as a means of locomotion completely changes how we navigate spaces. SUPERHOT VR, one of the most acclaimed games for VR, takes place as a series of action vignettes that the player has to complete. Particularly relevant is the fact that locomotion is taken out of the player's hands, as the player is automatically teleported to the next location upon defeating all the enemies at the previous one. Deliberate positioning of these successive points of view allow the player to understand that the scenes are taking place in the same overall environment by recognising common environmental features or figures. Here, teleportation is embraced as a core feature of the VR experience, with spaces, framed views, and action sequences designed around that fact.

In addition, while the 3D modeled spaces appear to simulate real-life environments, they are presented in monochrome white, with enemy figures colored in bright red and interactable objects in black. Despite the lack of realistic texturing, the player is clearly able to understand the nature of the architectural space via depth perception, while their attention is drawn to the key objects of importance. These two design choices demonstrate the potential of designing VR environments that go beyond copying real-life environmental conditions.

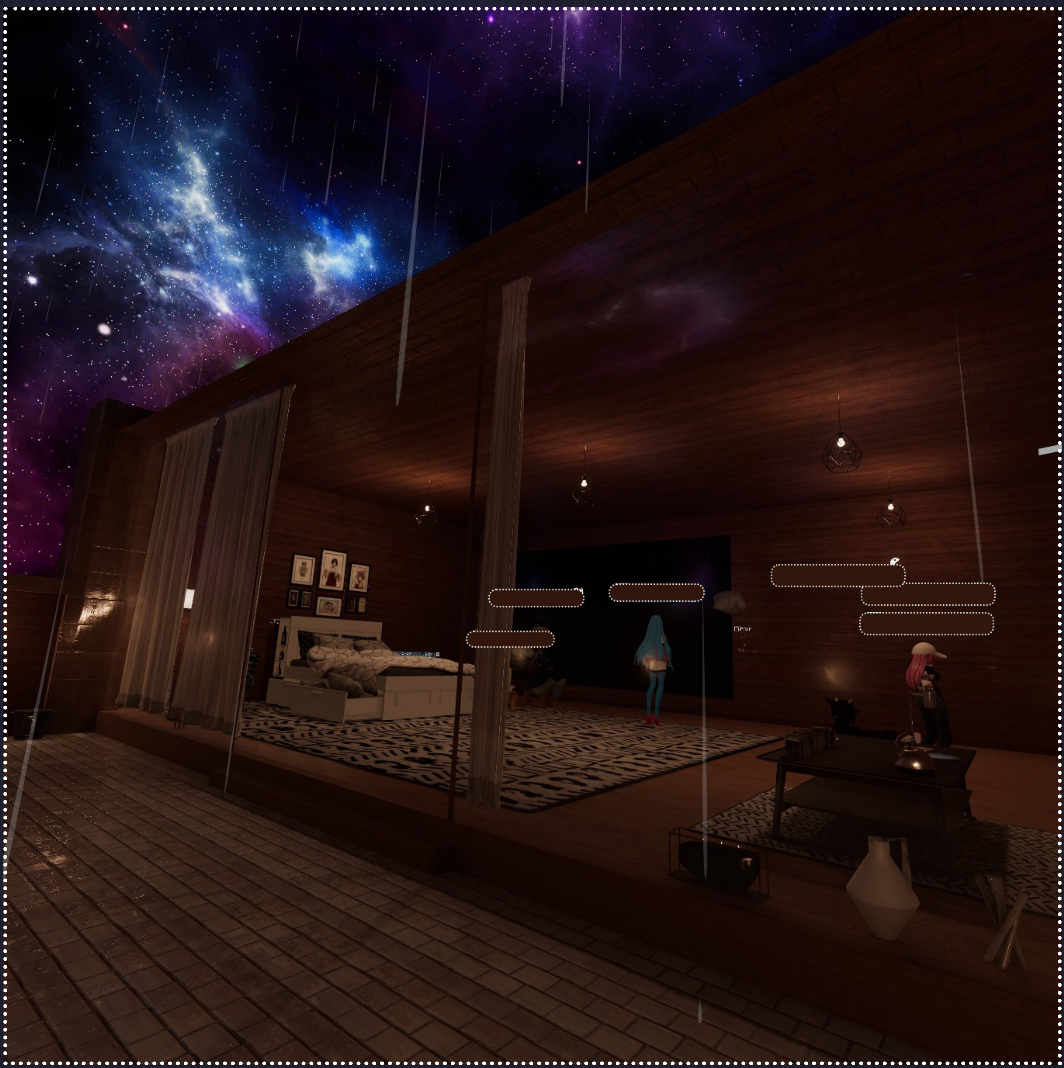


Screenshot of SUPERHOT VR during a typical enemy encounter



After dodging the bullets, the player is teleported behind the enemy figures, recognising the space from a different vantage point

The 'Black Cat' room in VRChat, taking the form of a conventional bar and restaurant with multiple sections



The 'Room of the Rain' in VRChat, a simple space with an 'indoor' room and 'outdoor' balcony

PEER-TO-PEER INTERACTION IN VR

As the focus of this project is on designing spaces for multi-user interaction, I also studied several spaces in social VR platforms, namely, 'The Room of the Rain' and 'The Black Cat' in VRChat, and the 'Campfire' space in AltSpaceVR.

In the first two rooms, the design was once again imitative of real-life spaces, featuring photorealistic textures and elements such as non-interactable furniture and even a toilet. It is possible that users feel more comfortable with analogues of real spaces, even if their use of the space is entirely different. This was especially evident in 'The Black Cat', a virtual bar and restaurant, where users ignored the imitative restaurant seats and bar and instead congregated at the virtual 'mirrors' (allowing the user to observe themselves and others) for social activity.

In all three cases, audio was modulated based on distance from speakers as in real life, meaning that people naturally congregated to hear each other better, and moved away from other groups so as not to be distracted by other conversations. To access other rooms or instances, users have to bring up a 2D interface where they can select another room of their choice, as all the rooms are isolated within their own spaces.

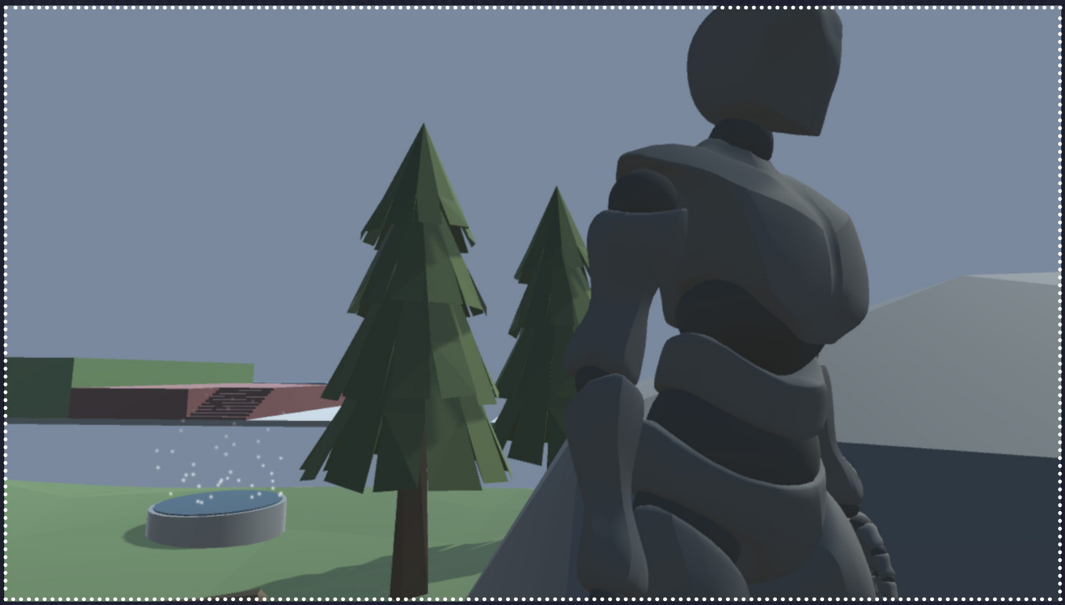
Screenshot of the 'Campfire' gathering space in AltSpaceVR

From the above case studies, we see that the current iterations of VR spaces are largely derived from our conceptions of physical space and navigation. While this might afford a degree of comfort and accessibility to new users, there is a clear opportunity for spatial design to embrace the modes of locomotion and interaction inherent to the VR medium, moving beyond physically-imitative design. In addition, menus and abstracted representations that appear to be remnants of screen-space design have the potential to be conveyed spatially rather than relying on cumbersome menus navigated via controller buttons.

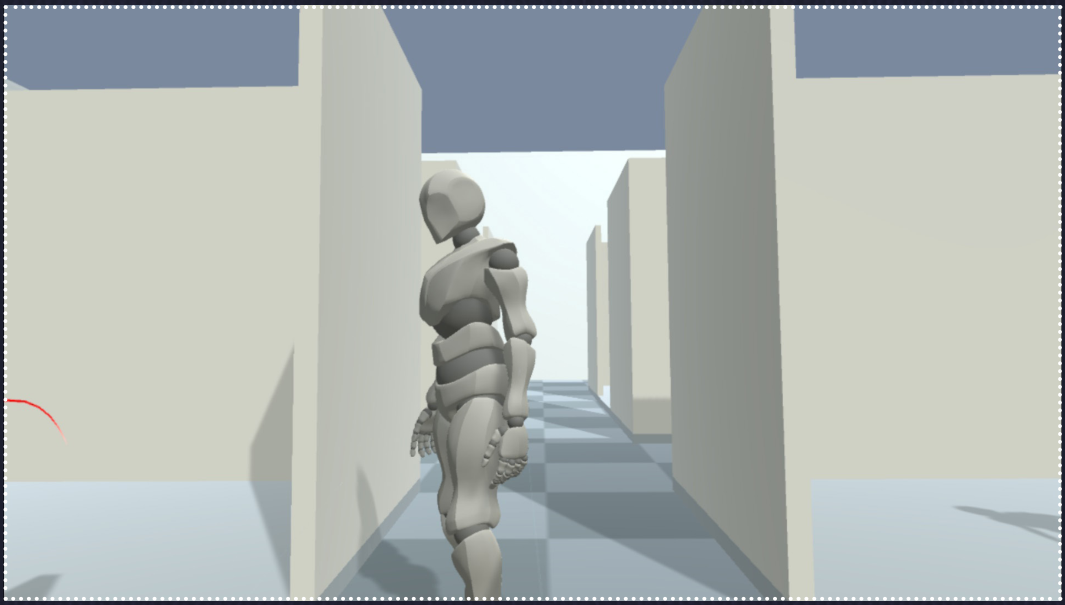
4 VR SPACE TESTING

In order to distil a series of design strategies that might govern the design of VR space, as well as explore any potential limitations or aspects of the VR environment that might not be intuited at first glance, I created a series of environments exploring various parameters - some of them minor tests and experiments, and others more rigorous tests with other users. In the process, I was exploring and familiarising myself with the quirks of VR environments as well as the challenges of designing them with the Unity editor and C#.

The process of distilling and refining the various design strategies and anthropometrics for VR was an ongoing and at times circular one. For the sake of clarity and organisation, the two major user tests will be reported here first, while the comprehensive list of distilled strategies will be laid out once in full in the final section.

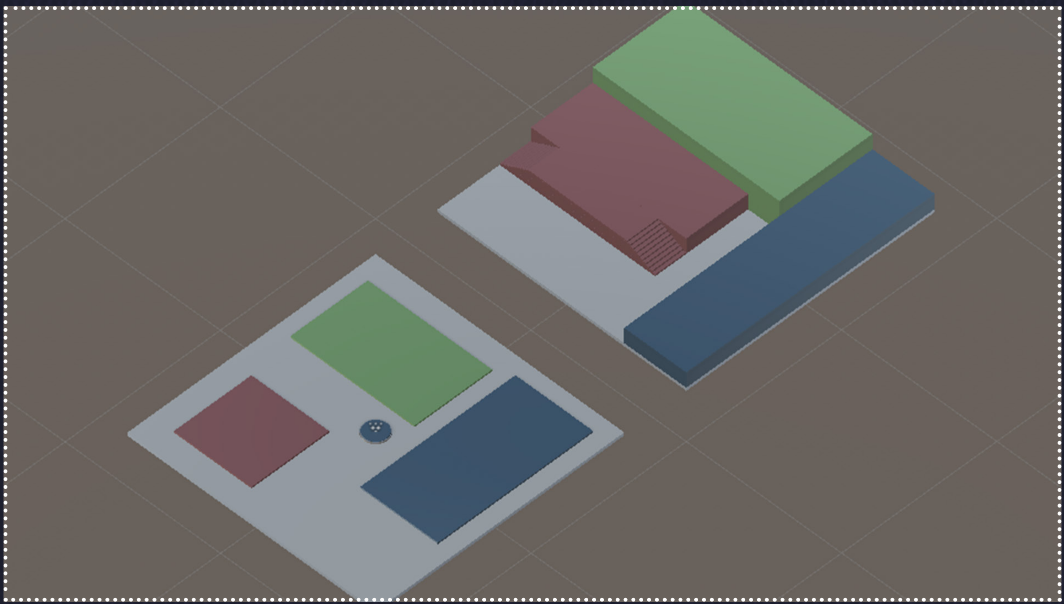


Early multiplayer testing footage in a custom environment, with other members of the studio using their own VR headsets



Early testing footage in the 'corridor' environment used for later tests

The first multiplayer test environment, made using basic objects from the Unity asset store hooked up to scripts for interaction and teleportation.



Other basic 'spaces' and forms used to test out movement in VR and the implications of design choices such as elevation and division

EARLY EXPERIMENTS

Some of the early experiments took place when I had just started playing around with the Unity editor and getting the basic VR scripts set up, and were focused more on trying out the technical aspects of development as well as playing around with being in a VR space and adjusting to the unfamiliar controls and environment.

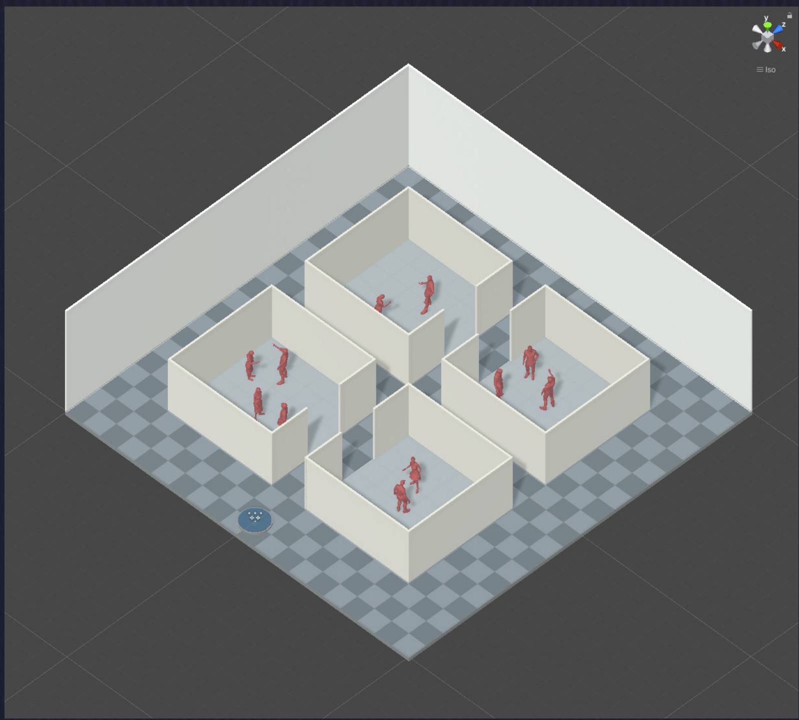
Indeed, simply by trying out some basic environments and spatial relations such as portals, steps, and levels during studio meetings with the other students opened up interesting lines of questioning such as - do these platforms need walls? is gravity necessary? can we just teleport across platforms without portals? Such questions raised during our preliminary testing were important starting points to begin thinking about the possibilities of VR space and how it might differ from design in the physical world.

SPATIAL NAVIGATION TEST

The most promising series of test designs in the first round focused on the spatial configuration of various rooms and how they affected the user experience of navigation and perception of comfort. These formed the basis of a more targeted investigation as well as greatly shaping the intermediate stage of the design proposal.

Due to the vastly different way in which people experience space through teleportation, it was clear from the beginning that traditional architectural features such as doors, stairways and corridors do not serve their original purposes in VR – in many cases, they are redundant or even obstructive. Thus, I sought to find new ways by which spaces could be composed and aggregated that were better suited to this new mode of locomotion. Furthermore, on a larger scale, existing social platforms dealt with different 'rooms' by having them accessed through menus and lists, making for a cumbersome experience in VR. Is there a way to represent and navigate these rooms spatially, removing the need for text interfaces as well as offering the user an intuitive understanding of the overall space?

From the above analysis as well as that of several other VR environments, a series of test environments were developed that showcased various alternative design approaches in VR, mainly pertaining to spatial navigation and way-finding. These test environments were developed in the Unity3D game engine and tested with a combination of Windows Mixed Reality and Oculus VR headsets.



In each scenario, participants were tasked with two information gathering assignments. Firstly, out of the six groups labeled ABCDEF, they were to identify one letter which had been replaced by an 'X'; secondly, they were to identify the letter belonging to a highlighted figure in each scenario. This meant that they had to visit each platform in turn for the first task, while keeping an eye out for the highlighted figure, testing their ability to navigate the space.

Participants were quizzed on their time taken as well as three subjective metrics rated on a scale of 1-10: navigational ease, degree of physical discomfort, and perceived comfort of the rooms in each scenario as a prospective user. Participants were also asked to provide further elaboration on their response to the last question, if any.

Each test scenario contained six equally sized rooms or platforms, representing discrete spaces in the VR environment. Each of these rooms contained a group of static human figures, tagged with a unique letter that appeared when the user got close, representing other users in a multi-user environment. However, the scenarios differed in the form and configuration of the six rooms.

1. Scenario 1: Rooms surrounded by high walls and a doorway of 2m facing towards a central corridor. This scenario replicates a physically-imitative approach to design, albeit with a greater allowance for doorways.

2. Scenario 2: This scenario leveraged the virtual medium with the use of 'virtual rooms', which appeared as translucent volumes from the outside but spawned opaque walls on all sides when the user entered the room. This configuration allowed for a quick overview of each room from the outside as well as multi-directional entry to the room from any position, while affording a sense of enclosure from the inside.

3. Scenario 3: This scenario made use of varying platform elevation to separate each room, building on the varied levels implemented in the case study. The lack of walls and open plan made it easier to navigate while utilising level changes to delineate space and afford privacy.

4. Scenario 4: In this case, the platform heights were uniform and an elevated corridor was introduced in the center that allowed for a quicker overview of the space. Participants could also easily jump down into any space or jump back up to the linear platform by teleporting.

Series of test scenarios for the navigational experiment

Scenario 1	Time	Navigation	Discomfort	Conducive
Participant 1	73	3	8	6
Participant 2	150	4	7	6
Participant 3	54	4	8	8
Participant 4	103	5	9	7
Participant 5	137	5	9	6
Participant 6	110	7	8	6
	104.50	4.67	8.17	6.50

Scenario 2	Time	Navigation	Comfort	Room
Participant 1	41	9	5	10
Participant 2	130	6	6	7
Participant 3	40	8	4	9
Participant 4	90	7	5	8
Participant 5	120	10	4	10
Participant 6	114	8	5	9
	89.17	8.00	4.83	8.83

Scenario 3	Time	Navigation	Comfort	Room
Participant 1	49	7	8	8
Participant 2	138	6	4	7
Participant 3	31	7	3	6
Participant 4	84	6	5	8
Participant 5	129	5	3	7
Participant 6	97	7	5	5
	88.00	6.33	4.67	6.83

Scenario 4	Time	Navigation	Comfort	Room
Participant 1	52	7	8	10
Participant 2	106	9	2	7
Participant 3	36	8	4	7
Participant 4	75	9	5	8
Participant 5	95	7	3	8
Participant 6	94	7	4	7
	76.33	7.83	4.33	7.83

Survey results for navigational tests

NAVIGATION TEST RESULTS

Along with the above scores, participants also provided some written feedback on the comfort level of each scenario, of which the key points will be noted below.

Notably, scenario 1, modeled after conventional architectural spaces, scored the worst in all metrics, especially in terms of navigational ease and physical discomfort. Some reasons given were that there were too many walls, the environment felt claustrophobic, and the navigational experience to get into each room was poor. This was in line with earlier expectations, that too many obstructions and excessive turning requirements would be detrimental to VR navigation.

The 'virtual rooms' scenario scored highest for both navigation and room comfort. Participants highlighted the 'interesting' feature of the appearing/disappearing walls as providing the user with an increased sense of privacy, while the porous nature of each room minimised the amount of turning required, in turn resulting in navigational comfort. The positive reception to this scenario shows that by breaking conventional expectations of structural and space (in this case solidity of walls and responsiveness to user action), ease of navigation and user comfort can be significantly increased.

Scenario 3 had average scores, with users noting the awkwardness of wide-open platforms and the disjointed layout requiring a lot of turning and head movement to navigate. However, scenario 4 scored relatively high in all metrics and best for time taken and physical discomfort. Users noted that the clear hierarchy of space and the higher vantage point from the central platform afforded a much better navigational experience compared to the previous scenario.

First full design iteration making use of the results from the above tests, titled "Hyperspatial"

From the above tests, it was clear that while conventional layouts with walls and doorways prove detrimental to the VR experience, the ease of teleportation allows for the use of vantage points and open-plan configurations as a means to organise space. Taking advantage of virtual features such as ephemeral walls allow for complex spaces that are uniquely suited to the user experience in VR space.

VISUAL COMFORT TESTS

Sometime after the first round of navigational tests, I looked into devising another series of pilot tests that would gauge users' preference for environmental decoration and visuals of the space.

To explore the potential of visual comfort within these virtual spaces, a second set of tests were conducted with five different room conditions in place of the blank walls featured in Scenario 2. As in the earlier scenario, these rooms were viewed from a higher platform, with their internal conditions only made visible when the user stood on the platform itself. These room designs were as follows:

1. Empty space with no walls or detailing
2. Space with blank perimeter walls as in the earlier test scenario
3. Space with perimeter walls as well as an assortment of furniture imitating a real-world discussion room
4. Space surrounded by an empty, open field
5. Space surrounded by a larger real-world discussion room

In spaces 4 and 5, triggers were used to hide the rest of the test environment, creating the illusion that users were transported to an alternate room that was larger than the actual platform.

Participants were tasked with reading sample texts placed near dummy characters in the center of the room but were not quizzed on the contents as in the previous experiment. After they had visited each room, participants were asked to rate their comfort level on a scale of 1-10, as well as provide open-ended feedback on each of the spaces.

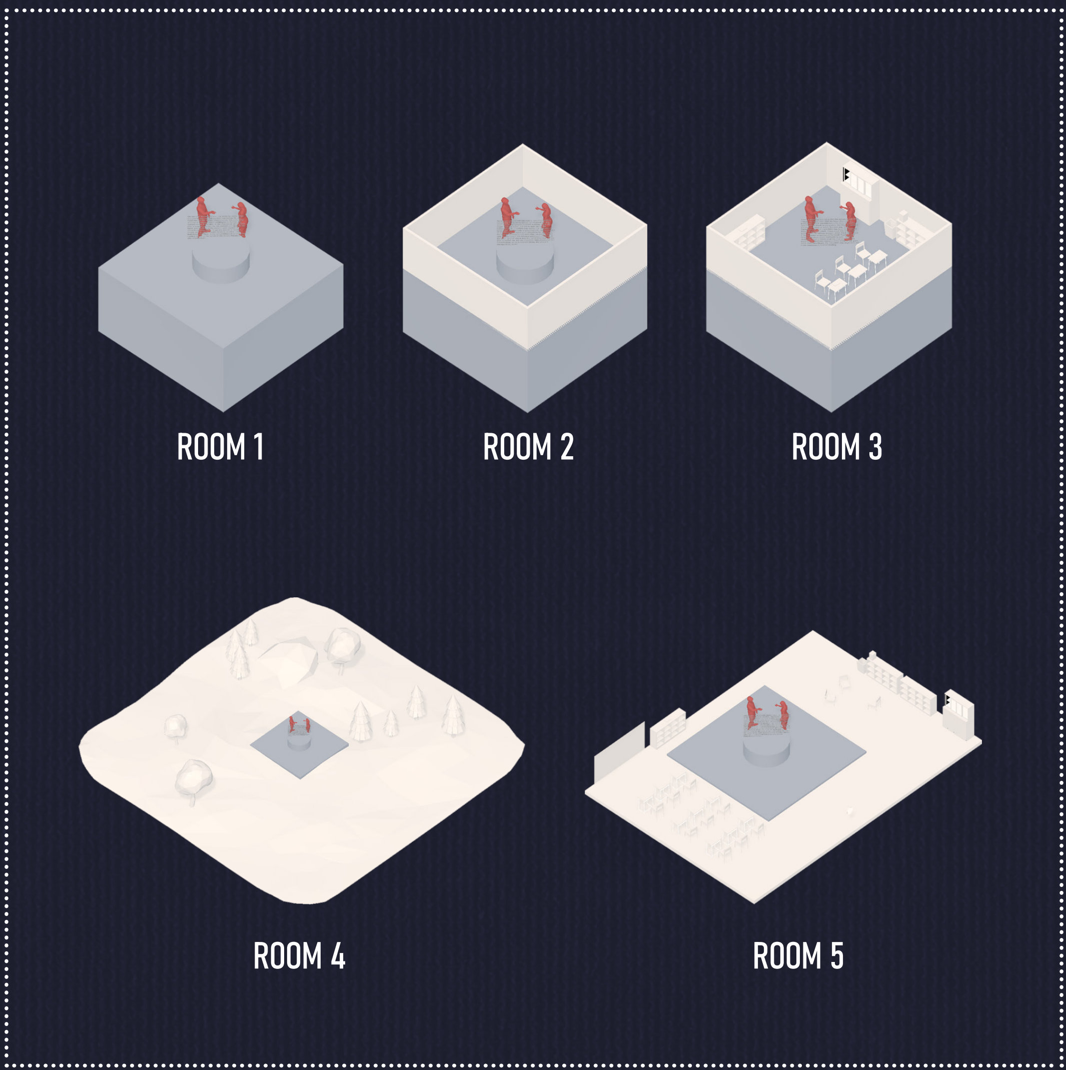


Diagram of spaces used for visual comfort experiments

VISUAL COMFORT RESULTS

5 participants were recruited for the second study. From the results, it is interesting to note that although the room with enclosed walls had been received well in the previous experiment, it scored the lowest here compared to all the other spaces. All participants quoted a sense of claustrophobia as their reason for disliking the space.

In contrast, space 4 with an open field and no distractions was rated the highest by all participants. This space was described variously as ‘peaceful’, ‘zen’, ‘casual’, and ‘outdoorsy’, suggesting that wide open spaces and natural settings might prove conducive to users in VR space.

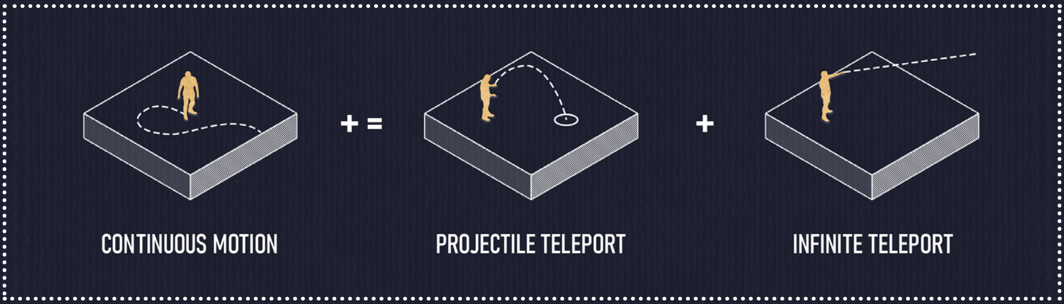
Both discussion room environments (spaces 3 and 5) were received moderately well. While three participants found the realistic props in (3) to be familiar or comforting, the other two felt that they were superfluous and unnecessary. In comparison, space (5) was received slightly better, with participants enjoying the spaciousness as well as the space being merely a backdrop to the text rather than non-interactable props that got in the way.

Overall, the second series of experiments clearly showed a preference for more complex environmental design beyond the closed walls present in the navigational experiments, even though that design had originally been rated the highest. More spacious environments were preferred for user comfort, especially the scenario with the open field and nature setting.

Although the idea of having “alternate dimension” environments ultimately did not make it into the final app, it remains a potentially interesting future implementation option or as a strategy in other VR spaces.

5 VR DESIGN PRINCIPLES

The final section of this booklet deals with the series of distilled principles for VR design, based on a combination of trial and error, personal testing, user experiments, and research findings. Some of these are recommendations as to best practices, while others merely identify possible environmental aspects to consider when designing VR spaces that might not be immediately obvious.



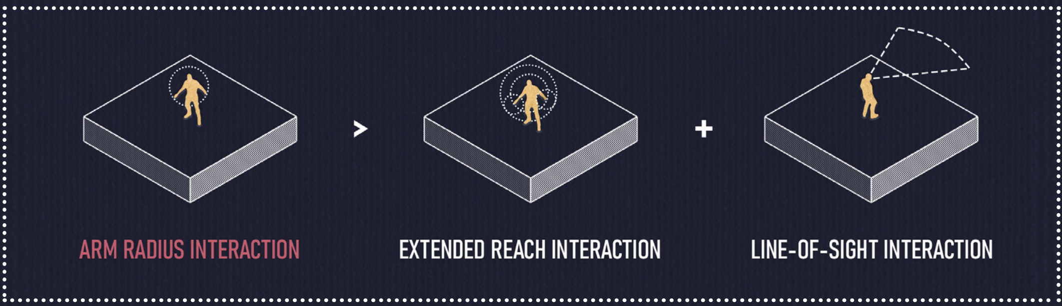
LOCOMOTION

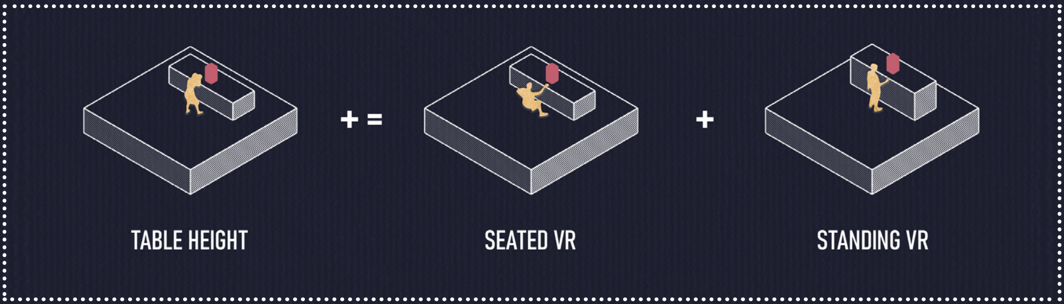
While continuous movement remains an option in some VR apps, teleportation is the generally favoured mode of locomotion due to the minimal nausea and discomfort associated with it. Embracing teleportation is one of the most significant factors influencing VR space, bringing with it a host of other design considerations such as the design of 'circulation' and lines of sight.

Furthermore, different modes of teleportation offer further opportunities for the construction of space. Short range teleportation mimics the distance restrictions and movement patterns of regular movement, while long-range teleport beams completely transform the nature of movement and allows users to ignore most distance restrictions, being only constrained by line of sight.

INTERACTION

Despite adherence to real-life human scale, the mode of interaction and spheres of influence of an avatar in VR differ greatly from real life. Although advanced controllers and suits are available, most commercially available headsets only track the user's head position and their two hands, meaning that perception and interaction are centered around these key nodes of the virtual avatar. The hands are empowered by the ability to grab objects at a short distance, or even interact with objects far away through the use of projected beams, extending the user's reach beyond human proportions.





ACQUISITION

While there is little need for virtual furniture such as chairs and beds to be ergonomic since the user cannot physically interact with them, the sphere of influence around the upper body means that convenient surfaces for placing and observing objects become an integral part of the environment.

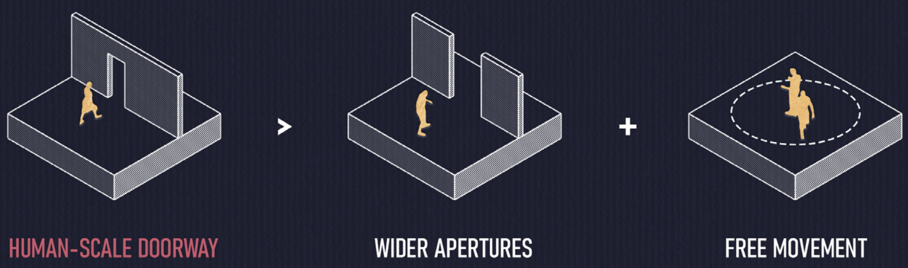
This is further complicated by the fact that VR users can either be seated or standing in real life, although the reach provided by the virtual grip allows for some additional flexibility. Testing with objects and pedestals of various heights revealed that the comfortable height of surfaces was about 700-1100mm for standing users, and 600-800mm for seated ones – giving a recommended height of 700-800mm to accommodate both users.

Large doorway opening in AltSpaceVR home

NAVIGATION

The lack of collision in the virtual space makes spatial allowances a matter of comfort rather than necessity. The key concern regarding the width of entrances, however, arises from the need to navigate via teleportation.

In most of the case studies, having wider doorways or even an entirely open boundary allows users to see and teleport with ease, minimising the number of jumps and amount of head turning. An entrance width of about 1.5m appears to be the minimum size for comfortable navigation in VR.

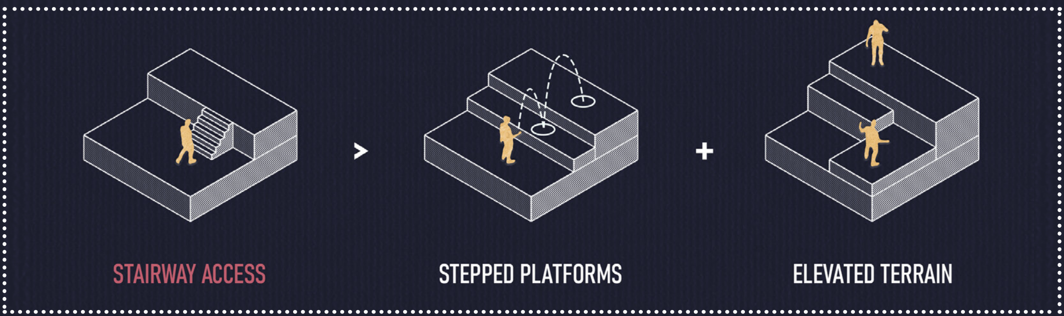


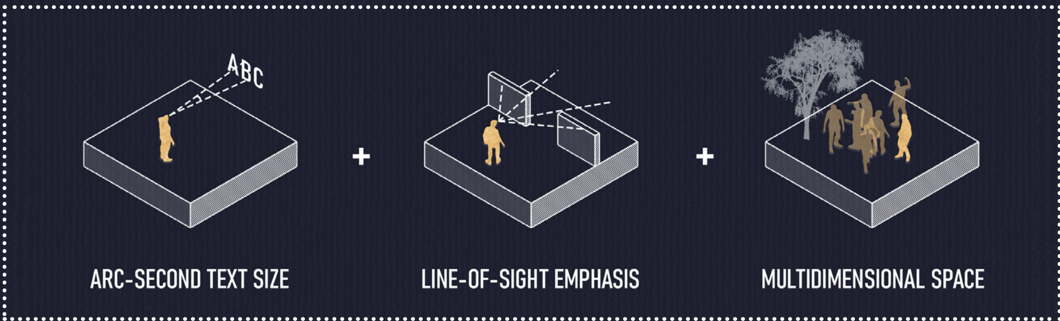
COMMUNICATION

At present, existing VR chat rooms largely have audio modulated by proximity, imitating the real world and creating a natural incentive for groups to cluster or spread out. While this might be ideal for regular conversations, there is an opportunity for audio to be transmitted differently in asymmetric situations such as a lecturer speaking to an audience, or a small discussion group where everyone wishes to hear each other clearly.

ELEVATION

Structural gestures such as stairs designed for the physical world have less relevance when teleportation is the primary means of movement. Wider platforms seem to be more conducive to teleportation and terrain elevation can be used to effectively organise VR space, due to the impact of elevation not just on visual prominence but also line-of-sight teleportation accessibility from higher levels.



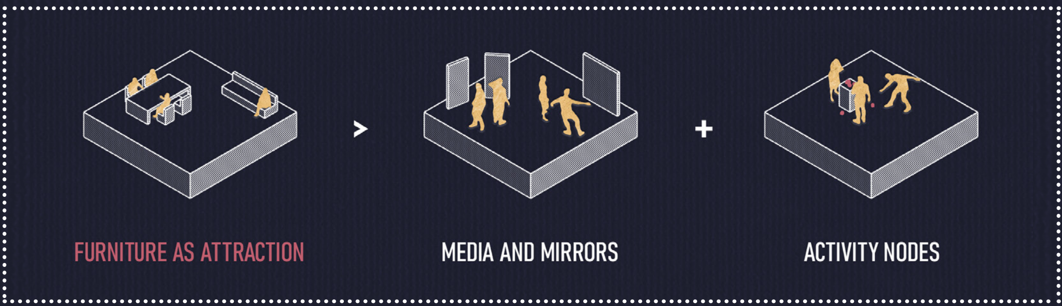


PERCEPTION

Text in virtual reality is generally harder to perceive, due to the constant movement and the relatively lower resolution of most currently available headsets, resulting in pixelation known as the `screen-door eect'.

As such, text needs to be clear and legible if it is to be presented in 3D. Taking reference from existing work, several font sizes were tested at varying distances and it was concluded that a perceived font height of 3.5° was suitable for comfortable viewing at any distance.

Other key aspects of perception include the emphasis on line-of-sight interaction and the possibility for multidimensional spaces, which were explored in more detail with the user tests above.



ATTRACTION

While furniture such as chairs, tables, and other seemingly interactable objects are often present in physically-imitative VR spaces, they are largely ignored and abandoned by users since there is no need to physically sit down or rest. Such objects become visual decorations at best and inconvenient obstacles at worst.

Instead, users are drawn instead to media objects or interactive activity nodes as natural focal points for social interaction. In VRChat, mirrors that allow users to see themselves and others in third person are a popular point of interest; in other social spaces, gimmick toys such as throwable balls or sparklers provide a sense of novelty and enhance interaction between users.

CONCLUSIONS

These investigations and design principles sum up the efforts of the first half of the thesis project. Not all of these strategies or experiments made it into the final design - in fact, there were many turns and dead-end explorations which will be covered in the next volume on design development. However, the breadth of experimentation in the first half laid the groundwork for decisions made during the later design process, creating a toolbox of spatial conditions and implications to draw on.

Furthermore, it is hoped that these experimental efforts might be useful to other designers and researchers who are exploring similar concepts in VR, which is partly the reason why they have been clearly documented and diagrammed in this project report.

It is clear that in many ways, the rules of VR space diverge significantly from the physical world. In some cases, such as virtual activity nodes or ideal entrance dimensions, a clear analogue or replacement property for the physical world can be identified. In others, such as with the entirely new modes of locomotion in VR, or the heightened importance of line-of-sight and elevation, there is no clear answer regarding the design of spaces to suit such realities. The next half of the project detail my efforts to explore the implications of these design rules and ultimately design and realize a novel approach to space in VR.

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