ARCHITECTS IN THE DESIGN OF VIRTUAL REALITY SPACES

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Our lives today are increasingly virtual. Social interactions, communication, entertainment, work—all take place, to a large extent, in the virtual realm. Up until this point, our interfacing with that virtual realm has largely been through flat screens. The recent widespread release of virtual reality devices, e.g. Oculus Rift, presents a new opportunity, and arguably an imperative, to reintroduce spatiality back into our lives. Who will design these virtual spaces? Architects, through their traditions and modes of spatial thinking, are uniquely positioned to contribute to the field of immersive virtual space design. But virtual space presents inherently different opportunities and limitations than physical space. Architects need to start thinking about virtual reality as not just a tool, but as an end medium in itself. This thesis presents an architectural design for a virtual reality social media network and an argument for why architects should be involved in and thinking about the design of immersive virtual spaces.
Virtual Reality

What is virtual reality? Dictionaries define virtual reality as: “an artificial world that consists of images and sounds created by a computer and that is affected by the actions of a person who is experiencing it.” Although the term “virtual reality” technically includes non-immersive artificial worlds, it is currently understood to refer to the immersive artificial environments viewable through specialized headsets which allow a user to turn their head to look around and, to some extent, interact with the environment. The term “virtual reality” is problematic, however, in the sense that it implies that “virtual reality” is not real. It is, in fact, a very real thing, merely non-physical. The artificial world experienced by a user immersed in virtual reality may be artificial in the sense that it is generated by a computer; nevertheless, the experience itself is genuine. This thesis argues that it is therefore as important to design the spatial experience of these virtual environments as it is to design the spatial experience of physical environments. Functionality may differ, i.e. the requirements of the body, but since the experience itself is equally real in both cases, there should be no less consideration given to the design of a virtual spatial experience than to the design of a physical spatial experience.

2 “Due to the introduction of the computer into the architectural environment, this question has arisen: is the object created in the computer only a representation? Certainly not. In fact, a complex model generated by the computer, more than a representation or an idea that we have formed of the external world or of a certain object, is a simulation, that is to say an appearance of something that is not, and it is more near the reality of what can be imagined. To this point, Nicholas Negroponte states ‘the real thing is not an expression of itself, it is itself.’” [Magemans, Audra. “Architecture and Cyberspace.” Intelligent Agent 4.3 (2004). Web.]
Virtual Boy, by Nintendo, released in 1995. It was the first portable console that could display true 3D graphics. (<kotaku.com>)

Dactyl Nightmare, an early virtual reality arcade game from the 1990's. (<vrfocus.com>)

Oculus Rift virtual reality headset, released Spring 2016. It is one of the recent mass released consumer headsets for immersive VR. (<forbes.com>)

Altspace VR, a social VR app recently released for Oculus Rift, HTC Vive, and Samsung Gear VR headsets. (<digitalera.net>)
Spatiality

This thesis is concerned with the particular opportunity of spatiality in virtual reality. The flat screens that are, to a large extent, our exclusive means of interacting with the virtual information that is such a large part of our lives today deprive us of the spatiality that so enriches human existence. Spatiality is vital not only to the quality of human experience, but also to organizing our thoughts and understandings of the world. Furthermore, there is vital information contained in spatial cues that is absent from flat interfaces, such as proximity, privacy, and territoriality.

1 Data drawn from various sources suggest that the average adult spends over 12 hours a day in front of a screen. (‘Screen Fiends | Infographic Reveals Shocking Truths on Technology Usage and Screen Time.’ The Future of Business Collaboration Powered by PGi. 08 Oct. 2013. Web. 10 May 2016.)
2 “In addition to their role as a mental setting for thoughts of action, environmental images function to organize our perceptions, permit us to code, structure and store visual and spatial information and directly mediate and regulate our responses to the things we see. By allowing us to recognize, select, register and conserve particular aspects of our unique personal experience in the world these schematizations constitute the enduring reality which we construct from the phenomena of direct perception” (Stea, David. “Architecture in the Head: Cognitive Mapping.” Designing for Human Behavior: Architecture and the Behavioral Sciences. By Jon T. Lang. Stroudsburg, PA: Dowden, Hutchinson & Ross, 1974. Print.)
3 “It has been shown that the richness and quality of our environmental experience directly influences the character and utility of our comprehensions of the world” (Burnett, Charles. “The Mental Image and Design.” In Designing for Human Behavior: Architecture and the Behavioral Sciences. By Jon T. Lang. Stroudsburg, PA: Dowden, Hutchinson & Ross, 1974. Print.)
4 “Members, working in proximity to each other, are passively aware, through audio and visual cues, of changes in the workspace without explicit communication attempts… They utilize a complex repertoire of task and interpersonal communications skills involving privacy, social distance, topic threading, and body language, skills that are context sensitive.” (Johnson, Brian R. “Between Friends: Support of Workgroup Communications.” Clayton, Mark J., and Vasquez De Velasco Guillermo P. ACADIA 2000: Eternity, Infinity and Virtuality in Architecture. United States: Association for Computer-Aided Design in Architecture, 2002. Print.)
Virtual Space

Virtual space is not a new phenomenon, nor exclusively one limited to the computer. In his Virtual Space Theory, Or Ettlinger defines “virtual space” to include that which is created by any medium capable of describing a space apart from the immediate physical surroundings. Indeed, it may be argued that architects have been designing virtual space since their medium shifted from the physical product itself to drawings that describe the intended physical product. However, relatively recent advancements in technology have made it possible to visually simulate physical space to an unprecedented degree. Where other mediums such as pictures and film require the viewer to imagine and extrapolate to imagine a virtual space apart from their physical surroundings, the immersive computer-generated space of virtual reality that responds to a viewer looking around and interacting with it presents a degree of simulation that approximates the visual effect of physical spatiality. This makes immersive computer-generated virtual reality a new medium apart from that found in pictures and film and deserving of separate consideration.

1 “At the heart of The Virtual Space Theory lies the interpretation of virtual space as the overall space which we see through pictorial images, and of ‘virtual’ as describing any visible object which is located inside of that space. By pictorial images I refer to paintings, drawings, prints, photographs, films, video games, TV, and so on - physical devices that allow us to visually experience through them something that is not physically there.” (Ettlinger, Or. The Architecture of Virtual Space. Ljubljana: U of Ljubljana, Faculty of Architecture, 2008. Print.)

2 “Drawing in architecture is not done after nature, but prior to construction; it is not so much produced by reflection on the reality outside the drawing, as productive of a reality that will end up outside the drawing.” (Evans, Robin. Robin Evans: Translation from Drawing to Building and Other Essays. London: Architectural Association, 1997. Print.)
The Designers of Virtual Reality Spaces

While the architecture profession is following the rapid rise of virtual reality closely, they see it primarily as a tool to design and visualize spaces planned for the physical world. This thesis argues that architects should be thinking about virtual reality as not just a tool to design and visualize physical spaces, but as something to design in and of itself. Designing virtual reality experiences is a complex problem and requires expertise from an array of different fields - user interface and interaction design, information design, character design, game design, etc. What seems to be missing from existing current virtual reality experiences, however, is attention to the spatial experience, and it is in spatial design that I believe architects have an important contribution. Architects are trained and experienced in spatial design - spatial thinking, traditions of spatial theory, a language of spatial communication and representation, and an archive of precedent and typology are some of the skills that uniquely qualify architects to contribute to the spatial design of virtual reality experiences. Virtual reality experiences designed without attention to spatiality misses the most important opportunity of the technology.

1 “Generally we think [ideas about using virtual reality] improve the design process and help both in-house and client teams better visualize our projects.” ["4 Ways Virtual and Augmented Reality Will Revolutionize the Way We Practice Architecture." ArchDaily. 12 Mar. 2016. Web. 10 May 2016.]
The Design of Virtual Reality Space vs Physical Space

There is a tendency, however, for virtual reality experiences that do incorporate spatiality to replicate the physical world too closely. Architects should not fall into the trap of designing for the virtual world exactly as they would for the physical world. Virtual reality space presents different opportunities and limitations than physical space. Physics, navigation, materiality, construction, and environmental issues are different in the virtual world, and the solutions to these problems consequently take different forms. The virtual world, too, presents its own constraints. Cybersickness - the nausea, headaches, and fatigue people can experience when moving about in virtual reality - can restrict certain kinds of navigation and there are various spatial strategies that can help reduce its effects. Optimization is the new budget - polygon counts, complex lighting calculations, high numbers of textures1 - these all impact processing speeds that can affect battery life, hardware requirements, and frame rates.

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Nevertheless, there is value in the familiar. Skeuomorphic design takes advantage of archetypal physical forms to present something recognizable to the user. While virtual space design should not necessarily replicate all the details of physical space, designers of virtual reality spaces can reference familiar forms and organizational structures that will help users understand and navigate virtual space. Certain physics may no longer impose the same limitations on form and movement in virtual reality space as it does in physical space, but designers should not necessarily see this as an imperative to throw away all conventions. Forms and materials may no longer have the same functionality in virtual reality space, but they may still express certain behaviors and qualities through reference to their physical analogs. Where physical constraints no longer dictate form and space, designers may look to psychological factors in usability—affordances, signifiers, and conceptual models—for guiding forces in virtual space design.

“An affordance is a relationship between the properties of an object and the capabilities of the agent that determine just how the object could possibly be used.” (Norman, Donald A. The Design of Everyday Things. New York: Basic, 2002. Print.)

“The term signifier refers to any mark or sound, any perceivable indicator that communicates appropriate behavior to a person…signifiers provide valuable clues as to the nature of the world and of social activities. For us to function in this social, technological world, we need to develop internal models of what things mean, of how they operate.” (Norman, Donald A. The Design of Everyday Things. New York: Basic, 2002. Print.)

“A conceptual model is an explanation, usually highly simplified, of how something works…Conceptual models are valuable in providing understanding, in predicting how things will behave, and in figuring out what to do when things do not go as planned. Without a good model, we operate by rote, blindly; we do operations as we were told to do them; we can’t fully appreciate why, what effects to expect, or what to do if things go wrong.” (Norman, Donald A. The Design of Everyday Things. New York: Basic, 2002. Print.)
Spacebook is a reimagination of a virtual interface as a spatial experience. It demonstrates the spatial approach to designing a virtual reality experience proposed in this thesis. The ubiquity of social media and particularly, the lack of spatiality in its 2D interfaces inspired Spacebook's choice of program. Spacebook is a response to the hypothetical question: “What would Facebook look like in virtual reality, and particularly, if an architect designed it?”
Spacebook is a literal spatialization and inhabitation of the abstract informational structure of a social network. The network is comprised of nodes and connections. Nodes are the objects of the network - in Spacebook, a node is a profile, or archive, of a person. Connections link nodes to one another - in Spacebook, they are the relationships between people, their communications and the things and moments they share. The network visibly surrounds all the spaces of Spacebook as a presence of social connectivity.
Layers of Privacy

Information about a person is filtered through layers of privacy. In Facebook, this is controlled through user interface elements such as buttons and toggles. In Spacebook, layers of privacy are controlled spatially. This has architectural precedent, such as is formally exhibited in the Chinese courtyard house. In Spacebook, the surface of the outer sphere is the most public. One layer down on the surface of the inner sphere is more private, but information is still censored. Inside the inner sphere is most private, accessible only to friends.
The outer surface of the inner sphere is accessible to visitors and utilizes the wandering gallery archetype. The wandering gallery is characterized by a multitude of walls arranged in a non-linear fashion. This non-linear arrangement of walls frees the visitor to choose their own path, encouraging exploration, discovery, and experiences unique to the path chosen. In Spacebook, the orientation of the walls follow the projected geometry of an inscribed icosahedron. This geometry takes advantage of a sphere’s non-biased directionality.
The inner surface of the inner sphere in Spacebook functions as a hub - a central point that provides access to many other spaces. In virtual space, spaces do not have to be static - in 2D computer-generated space, the rectangle of the screen does not change, though the content does. While in the physical world, a hub needs to be physically connected to the spaces it connects to, in Spacebook, the hub only needs to provide the ability to select new spaces - the space of the hub itself can then change to host the new space that was selected.
In the physical world, a person’s bookshelves reveals a great deal about who they are and what they are interested in - in a way, a library can be as much a museum of a person or society as a pictorial one. The library in Spacebook takes inspiration from the round, multi-tiered libraries from architectural precedent. Virtual space should not necessarily replicate its physical analogs, but there is value in the familiar. Spacebook’s library is a literal ‘twist’ on stacked bookshelves, changing the recognizable form to take advantage of the non-physicality of virtual space.
The content of relationships between friends are displayed in linear galleries. These linear galleries comprise the spatial connections within the social network. Linear galleries are typified by directionality - the path is usually singular and defined. In Spacebook, the relationship between friends is presented narratively, and the chronological nature of the narrative is supported by the linear gallery archetype. The linear gallery is relieved by a social space where friends can communicate, surrounded by their social network and the narrative of their relationship.
Relationships are visible as lines connecting profile spheres with one another. A person moves around the surface of the profile sphere as on a planet with gravity. Depending on the profile’s privacy setting and the person’s relationship with the profile owner, they can sink through the surface of the profile sphere to access the visitor gallery below.
In the visitor gallery, a person can wander among walls displaying a curated selection of content from the profile. Overhead, the connecting lines that represent the profile owner’s relationships pierce the surface of the outer sphere, forming an overhead canopy and enclosing the space. A friend can access the hub by rotating through the floor of the visitor’s gallery to walk on the inner surface of the inner sphere.
The hub provides access to other spaces in the profile. To access these other spaces, a person walks along the inner surface of the inner sphere to a pad with the appropriate icon and stands on it. For example, the music icon activates a space where they can view and experience the profile owner’s music collection. The books icon will activate a space where they can browse the profile owner’s collection of books.
When a space is activated, it rotates into the sphere, replacing the hub with the selected space. In the books space, a ramp spirals around the inner surface of the sphere, guiding a person along the spiraling shelves that display the profile owner’s collection of books. Pulling a book from the shelf magnifies it to display more information. In the center, a smaller sphere contains a map of the social network.
A person with access can grab a connection line on the surface of the profile sphere. A selected connection line will expand in diameter until it becomes a tube that houses a gallery that displays content describing the relationship between the owners of the connected profiles. A person floats up through the tube, passing 360 degree panoramas wrapped around the inner surface of the tube.
In the middle of the connection gallery is a social space where friends can talk with one another. A person ‘sits’ in this social sphere, where they can see a representation of their friend in a corresponding ‘chair’ across from them. While functionally unnecessary, virtual ‘furniture’ that is familiar, though not necessarily replicas of their physical analogs, are spatial elements that create atmosphere and suggest behavior.
Trainspace is a complement project to this thesis. The goal of Trainspace is to present an actual, working virtual reality space that demonstrates two primary points of the thesis: 1) spatial design is an important consideration in the design of immersive virtual reality interfaces and experiences and 2) virtual space presents fundamentally different opportunities and limitations than physical space.
Trainspace was designed and built with the Unity game engine, a 3D modeling program that offers scriptable control over its components. Trainspace has been built to run on the Gear VR, an immersive virtual reality headset powered by smartphone. Software and hardware limitations encouraged the use of simpler geometries and rendering setups than those depicted in the proposed Spacebook project presented in this thesis.

The spatial experience of Trainspace is based on the manipulation of a cube, animated to audio taken on the BART train as it traveled between stops. The cube undergoes a number of transformations in size, proportion, geometry, position, orientation, and light to illustrate how even simple changes in spatial properties can dramatically affect the character of an experience.

Trainspace also shows that the virtual world operates under different rules than the physical world. Changing gravitational conditions, fluidity between materiality and immateriality, and animated spatial transformations in Trainspace demonstrate spatial experiences that are rare or impossible in the physical world.

A screen capture video of Trainspace can be found at: https://dl.dropboxusercontent.com/u/1025694/Trainspace.mp4
Appendix

*Early Work | Sequences*

These image sequences describe some of my early thinking regarding the transformation of physical space to virtual space.
Early Work | Archetypal Differences

These two images illustrate that virtual space operates with different “physics” than physical space. The archetypal form of transportation in physical space - stairs - has no functional meaning in virtual space, where a person can “transport” anywhere. What might the form of transportation look like in virtual reality?
PARAMETERS

Users will have human-scale avatars.

Users’ avatars are generally the same size so that space is bodily experienced in a similar way. A general upright orientation is maintained.

Users are generally oriented with the same direction as ‘up’. To break this rule, a space must be entered through a ‘gate’ that passes the user into another virtual world with different spatial characteristics.

Spatial movement is limited to walking or running speeds.

Users cannot ‘zoom’ around. Users move at relatively the same speed as one another. Long distances can be traversed more quickly through teleportation.

Teleportation has an associated visual metaphor.

Users cannot ‘blink’ in or out. If a user enters or exits a space through teleportation or disconnect, an appropriate visual metaphor will indicate that is happening.

The virtual world experiences the passage of time.

Time passes in the virtual world and is based on a 24-hour day (12 hours of dark, 12 hours of light). The virtual world does not have timezones and is independent of the timezone the user is in.

Solids experience solid collisions.

If an object is rendered as solid, it cannot intersect other solid objects. Objects can alternatively be specified as non-solid objects, in which case they can overlap other objects (see guidelines).

Websites have spatial location and size in a consistent virtual world.

Websites cannot overlap in virtual space and are not rearrangeable. Space that appears to one user appears as the same space to another.

Visible space is spatial within a consistent spatial world.

If one can see another space or object and it appears to exist in their virtual world, then that space or object has the spatial properties that it appears to have. To break the spatial consistency of a virtual world, one has to separate that space into separate virtual world accessible through a gate. For example, if a website occupies a certain volume in browser space, then it can only have more space inside if users cross a ‘gate’ when entering that transports them to another world.

GUIDELINES

A visual distinction should be made between solid and non-solid objects.

Users should be able to tell whether they can pass through an object to avoid unnecessary ‘bumping’.

There should be a visual indication if an object is actionable.

Objects that a user can interact with beyond creating space or functioning as a solid should indicate so, or users will be overwhelmed by the number of possible actionable objects.

BROWSER FUNCTIONALITY

Browse websites
Search websites
Enter websites
Exit websites
Bookmark websites and locations
View simultaneous websites
Set preferences

WEBSITE FUNCTIONALITY

Find content
Display 2D content:
  text
  images
  videos
  interactives
Display 3D content:
  virtual images
  virtual videos
  virtual interactives
Separate content
Hyperlink to external sites
Hyperlink internally
Save, clip, copy content

ELEMENTS

Plot

Plots are areas in the virtual browser where sites are located or can be built. They have defineable area and location.

Site

Sites are equivalent to websites in the traditional 2D internet. They can be private or public.

Path

Paths connect sites and plots in the virtual browser. Users can move along them using their avatars.

Portal

A portal hyperlinks two locations in the virtual world, allowing a user to travel from one location to another without traversing the space in between.

Gate

A gate is an access point between one virtual world and another. Since space is consistent within a virtual world, to break that one must create a separate virtual world whose space is separate from the other’s and can only be accessed via a gate.

Apparition

An apparition is a 3D window into another part of the virtual world. It is not part of the space and cannot be accessed, but rather acts as a reference.

Interactive Object

Objects constitute the geometries of the virtual world. An object can be solid, in which case it cannot intersect other solid objects, or it can be non-solid (a ‘ghost’). Users can interact with interactive objects beyond their geometries and solidities.

Static Object

Non-interactive objects are static. Users can only interact with them insofar as their geometries and solidities.

Pane

A pane is a 2D surface for accessing 2D content. It has no thickness, and therefore does not constitute an object. A pane can be solid or non-solid.
Early Work | Diagrams

These diagrams illustrate some of my early thinking about the position and interaction of the viewer with various types of space - screen space, virtual space, and physical space.

**SCREEN SPACE**

PRESENCE OF VIEWER RELATIVE TO SPACE

VIEW OF SPACE, SECTION

VIEW OF SPACE, PLAN

CIRCULATION IN SPACE

**VIRTUAL SPACE**

**PHYSICAL SPACE**

FIGURE GROUND - SCREEN SPACE (AMAZON.COM)

FIGURE GROUND - VIRTUAL SPACE [PORTAL]

FIGURE GROUND - PHYSICAL SPACE [APARTMENT]
Early Work | Diptych

The following are screenshots from a diptych comparing screen spaces (left) with their physical analogs (right). The video can be found at: https://dl.dropboxusercontent.com/u/1025694/Diptych.mp4
**APERTURE**
provides a connection and understanding of how one is situated in a context.

**THRESHOLD**
through which one transitions from one space to another.

**HORIZONTAL CIRCULATION**
connects spaces in the horizontal plane.

**VERTICAL CIRCULATION**
connects spaces between horizontal planes.

**HORIZONTAL BOUNDARY**
defines spaces and separates them from one another on a horizontal plane.

**VERTICAL BOUNDARY**
defines spaces and separates them from spaces on adjacent horizontal planes.

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**Early Work | Matrix of Architectural Components**

Video elements can be found at: [https://dl.dropboxusercontent.com/u/1025694/Typology%20Matrix.mp4](https://dl.dropboxusercontent.com/u/1025694/Typology%20Matrix.mp4)

**COMPONENT | DESCRIPTION | FORM | DIAGRAM | PHYSICAL SPACE**

**VERNALCULAR | HIGH ARCHITECTURE | INSTALLATION ART | SCREEN SPACE**

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Early Work | Spacebook - Alternative Organization Diagram
This diagram describes an early alternative strategy for the spatial organization of Spacebook and its circulation strategy.

![Diagram of Alternative Organization Strategy]

Early Work | Spacebook - Iteration 1 Program Diagram
This program diagram describes the categorization of Facebook activities used to organize the spaces in early iterations of Spacebook.

- **[SETTINGS]**
  - **HUD**
  - **MESSAGES**
  - **PROFILE (SELF)**
  - **PROFILES (FRIENDS)**

- **PAGES**
  - The Face of Things

- **EVENTS**
  - The Club

- **GAMES**
  - Entertainment and Fun Here!

- **NEWSFEED**
  - The Hub
Early Work | Spacebook - Iteration 1 - Hub

This is an early iteration of Spacebook that uses more conventional spaces. The central platform is a “hub” where a wall displays the newsfeed. Adjacent platforms serve as a social space and gateway to groups and events.

Early Work | Spacebook - Iteration 1 - Profile

This is an early iteration of a Spacebook profile, which includes an “endless ramp” to display the profile timeline. On one wall is a collection of “friend spheres” and on the other is a space to display interests.
Early Work | Spacebook - Iteration 2
The second iteration of Spacebook is a literal spatialization of the network diagram. Photos float around the sphere and in the center is a “timeline ramp”. Visitors can walk across bridges to access other profile spheres.

Early Work | Spacebook - Iteration 3
This iteration of Spacebook challenges the constraints of gravity and scale. Information is presented as “nested networks”. A visitor shrinks or grows in scale when entering or leaving a space.
Early Work | Metanet

Before Spacebook, I explored virtual reality space at an urban scale. This was inspired by Neal Stephenson’s novel Snow Crash, which describes the “Metaverse” in which all virtual spaces are spatially connected.

- **SITE**
  - unit size available to host a webspaces
  - multiple adjacent sites can be combined to form a larger site

- **BLOCK**
  - adjacent sites bounded by streets and cross streets

- **STREET**
  - streets run along the length of the blocks
  - cross streets can be used to cross between streets, both horizontally and vertically
  - a user must enter the Metanet at one of the cross streets or designated spots in the interdistrict
  - streets are transparent, though indicated by other cues of solidity, and function as though solid
  - to get to a street above or below, a user floats up or down in a cross street

- **DISTRICT**
  - a unit 16 blocks wide, long, and tall, including streets and cross streets
  - districts have local character, defined by the aesthetic design of the streets, ambient lighting, sound, nature of the interdistricts, and webspaces hosted there

- **INTERDISTRICT**
  - districts are bounded on all sides by interdistricts
  - interdistricts are spaces reserved for civic use and may contain a variety of functions
  - the interdistricts are bounded on the outside by opaque surfaces that contain the district visibly and functionally (districts are independent, although adjacent)
  - a user can cross a district boundary into an adjacent district, which instigates the leaving of the old district and a loading of the new district
Early Work | Weatherspace

Before settling on spatializing a social network, I considered spatializing weather information. The following are vignettes exploring how weather information might be translated to and conveyed spatially.

Above, images on a dome convey weather conditions. The wall color displays temperature, and the length and direction of sticks on the ground indicate wind speed and direction. Spheres around the periphery contain the weather forecast.

- CLEAR
- CLOUDY
- RAINY
- STORMY
- SNOWY
Cybersickness

- high fps ✅
- low fps ❌
- steady movement ✅
- acceleration ❌
- level movement ✅
- head bobbing ❌
- viewing angle too close to feet ❌

Early Work | Tip Cubes for Designing Virtual Reality Spaces

An early ambition was to create “tip cubes” that would describe the considerations a designer would need to keep in mind when designing virtual reality spaces.