# VIRTUAL REALITY

ZACHARY
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ARCHITECTURE

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# Contents


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# Abstract





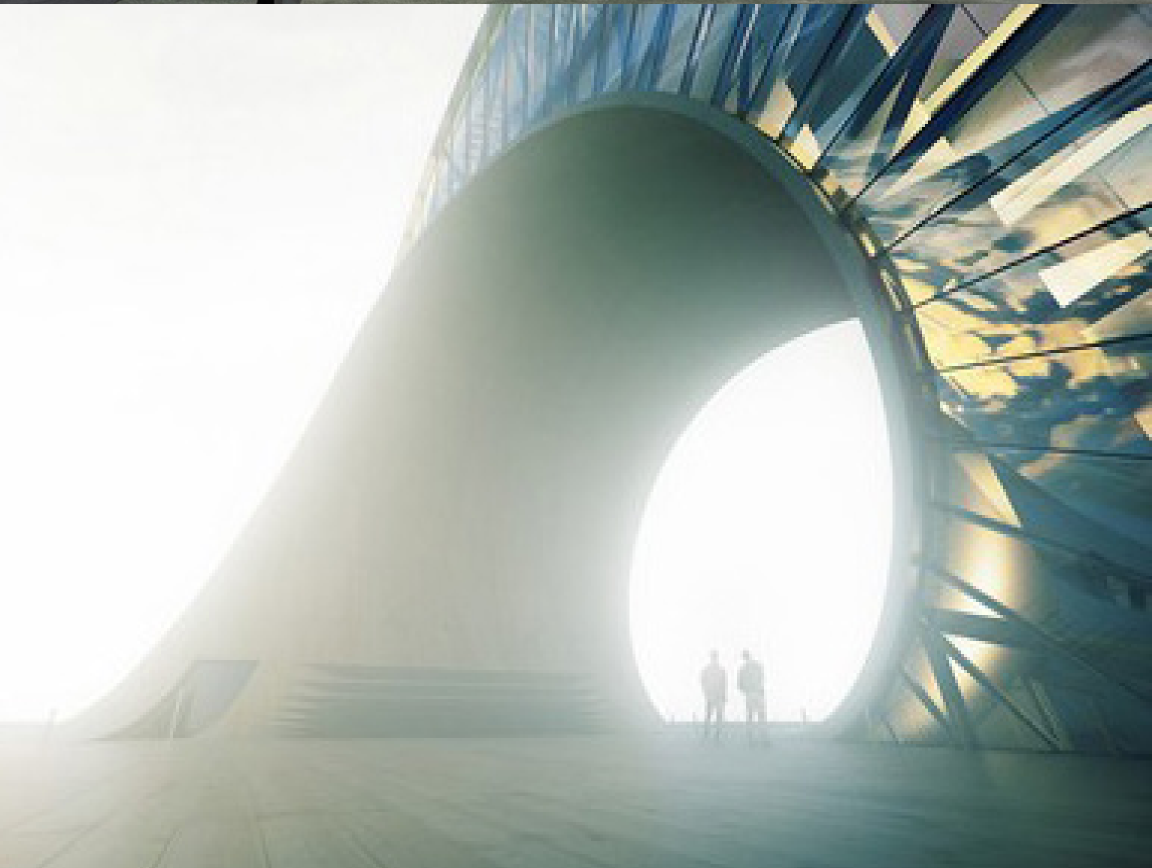
Visualization techniques in architecture have been utilized as communication and design tools since antiquity. Traditional artist force interaction by creating familiarity within the art for an observer, by understanding and utilizing methods such as; line, shape, form, texture, and pattern and color to create a composition. Enhancing such techniques creates a more realistic and familiar understanding of images and space depicted within art. Art/Design in collaboration with modern technology advances, have resulted in Virtual Reality (VR) Augmented Reality (AR) and Mixed Reality. All of which are cutting edge approaches to immersion and interaction. Being a computer generated a form of visualization Virtual Reality, Augmented Reality and Mixed Reality are developing new methods to enhance one's understanding of design and spatial communication. Virtual Reality specifically offers a first-hand experience by placing its audience in an interactive virtual environment which familiarity is promoted to aid design exploration and visualization, the simulation that virtual reality creates can be abstract or very similar to the real world. Virtual Reality may be a tool that can promote and aid design and architectural exploration while also deepen our understanding of other practices. This thesis aims to explore how virtual reality can improve and build upon architectural visualization as a communication medium and design tool.

Figure 1.1 A computer rendering of Cross # Towers
Source: BIG - Bjarke Ingels Group

Individuals rely on all senses to fully understand and communicate. Listening, touching, smelling, tasting and seeing improves the ability to locate oneself in a space. While all of these are important to spatial design, architecture is primarily a visual experience. One's ability to showcase spatial relations, design, and depth through visual methods is considered architectural visualization.

Today's main method of architectural visualization allows for a multitude of concepts to be produced rapidly, allowing for the testing of multiple design options. Architectural visualization in this sense often is used to represent the final design of a product before it is constructed.  Allowing for more insight into what one can expect as a result of design and construction. Individuals lacking in architectural experience find such images helpful for communicating a spaces design, form, layout, and overall aesthetic quality. (Figure 1.1) These images (renderings) are sought after as a simplification for those who lack the knowledge to read professional construction documents, such as floor plans, details, elevations, and sections, all of which serve as guidelines to aid in the construction and understanding of the building. As a result, Architects often rely on visualization renderings and other simplified diagrams to showcase design while retaining clients or users understanding of the design.

Architectural visualization had gradually grown throughout history to improve understanding; from hand-drawn perspectives to the images such as Figure 1.1.  The purpose of such renderings has been to communicate spatial relations while maintaining a clear understanding of design. Until now architectural visualization has been experienced passively and always leads to show architectural projects in their best light. Miscommunications of form, scale and design development may have been brought into question and subject to the fidelity of the image compared to the b¬¬uilt result. Buildings such as "Elbe Philharmonic" by architects Jaque Herzog and Pierre De'Mueron become an example of this. Karen Cilento states "Perhaps some completed projects feel like they are almost missing something because the renderings have ingrained a flawless vision in our minds. Whereas, perhaps, if we weren't exposed to such a sublime picture in the first place, the completed result would be more fulfilling" (Cilento, ArchDaily). Subjecting clients to unrealistic results is a trait that should be minimized, to do so the next step of creating a high fidelity architectural visualization may be utilizing Virtual Reality as an exploratory



medium. To avoid the passive nature of stand-still images, virtual reality utilizes immersion and interaction to give a more hands-on and immediate experience. Spatial relationships scale, design layout, and aesthetic qualities become apparent right before one's eyes and a true sense of space is created that an image cannot produce without the proper use of illusions such as trompe-l'oeil, an image border than enhances the perspective quality. Interaction within a virtual world becomes exceedingly important in virtual reality, interaction immediately alters one's ability to change the virtual world or change the user's viewpoint of their surroundings. Aside from this, the ability to interact with the virtual world in real-time allows for a more familiar and cognizant understanding of virtual space, allowing the user to create familiar relationships with objects much like how they would in the real world.

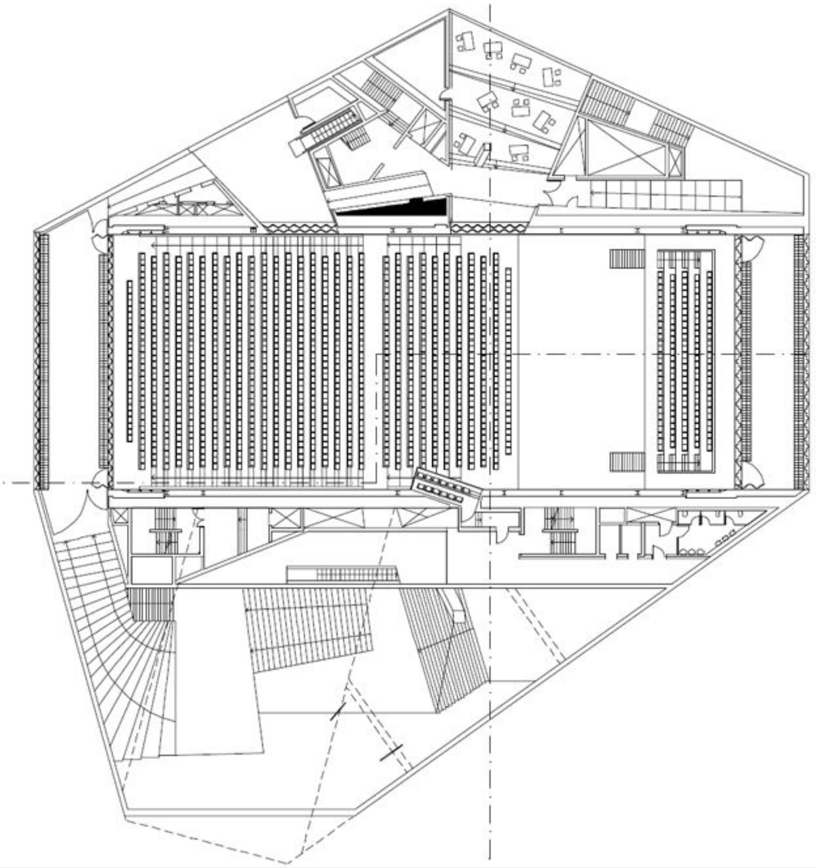
Immersion becomes critical as it creates a sense of presence (telepresence) for the virtual world. Immersion can be defined as:

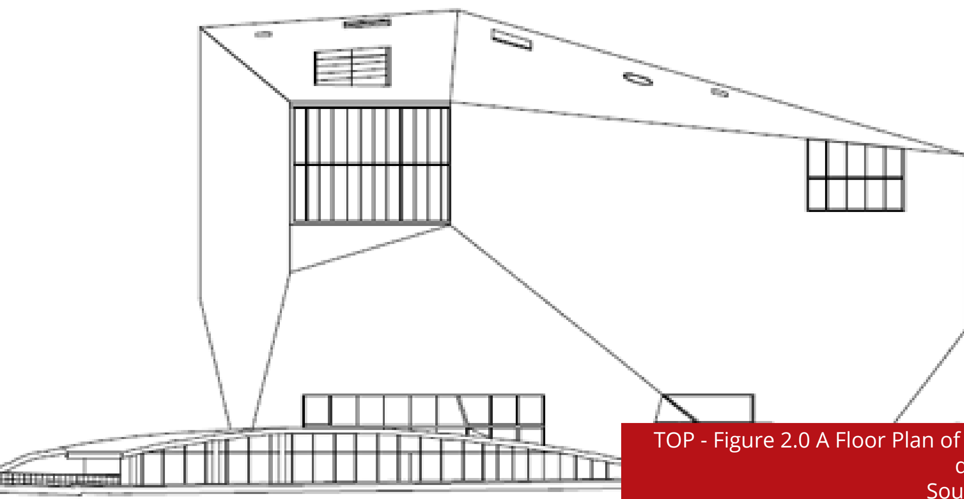
- Immersion - "Sensation of being in an environment that can be a purely mental state or can be accomplished through physical means." (Sherman, 7).
- Mental immersion - "The state of being deeply engaged, suspension of disbelief and involvement." (Sherman, 11).
- Physical immersion "Bodily entering into a medium, synthetic stimulus of the body's senses via the use of technology, this does not imply all senses or that the entire body is immersed/engulfed" (Sherman, 9)

To assume a Sense of Presence in the digital world one must be immersed both mentally and physically. In short, sense of presence means that one perceives the images in front of them as physical and utterly real, this results in changing physical behavior to avoid phantom objects as if the objects were real. Virtual reality begins to offer insight to how immersion, interaction, and overall visualization can improve one's understanding of architectural design communication techniques.

TOP - Figure 1.2 A computer rendering of The Exhibition Hall
Source: OMA

BOTTOM - Figure 1.3 A computer rendering of an unbuilt design for BIG
Source: MIR





TOP - Figure 2.0 A Floor Plan of The Casa de Musica
Source: OMA

BOTTOM - Figure 2.1 A Elevation of The Casa de Musica
Source: OMA

In 27 bc. Vitruvius defined the necessary properties of an Architect stating, "Let him (an architect) be educated, skillful with a pencil, instructed in geometry... he must have knowledge of drawing so that he can readily make sketches to show the appearance of the work which he proposes". (Vitruvius, 6) Architects are trained with an attention to detail and the matter to express three-dimensional space in two-dimensions, traditional drawings such as plans, sections, and elevations aid in this matter to fully understand a building design from a multitude of angles.  Each type of drawing serves a different function that cohesively allows for a design realization.

**Plans:**

Site plans, floor plans, landscape plans and roof plans are often the cornerstone of any set of architectural drawings. "Plans delineate important building components as seen from the top view, often between the floor and ceiling. The primary responsibility of a floor plan is to show precisely where the walls windows and doors are located". (CGSchool, 16) Architectural plans aim to locate a multitude of design components. Scaled to be relevant to the design context all plans aim to showcase the design in a diagrammatic manner that is often easy to identify. Dimension strings (spatial measurements) may be depicted on a plan to aid in locating design components. Viewing a plan informs designers and architects of holistic relationships throughout the design layout, and can be used to outline design conflicts such as means of egress or proper column locations.

> "Using a floor plan as a template the engineer can design the structural components of the building. If the structural engineer decides that walls have to be mover or columns have to be changed, architects will then adjust the floor plan within the construction drawings to accommodate the change. This same process is then repeated with each engineering practice (mechanical, electrical)." (CGSchool, 16).

Plans overall serve as a collaborative representation from which all other drawings are created. Lastly, plans showcase a series of other references that are traditional to architectural construction drawings, elevation locations, and sections cuts are located on plans to coordinate communication between the drawings.

**Elevations:**
Elevations reference the design, complexity, and style of a building's design. Architects often utilize a design's elevation as a guide to façade designs and to emphasize vertical relationships.

> "The elevation shows the actual distances between the building's parts without the "distortions" of vision, thus elevations are visual ideas of thought; they translate the experience of a building into a form the mind can comprehend." (Sheer, 3).

Elevations allow observers to detail and visualize the space in a planar manner. Aspects like scale, distance and depth are explored to diagrammatically represent a building's façade. Architects such as Richard Meier use building elevations to correlate emphasize façade organization and joint design. The ARP Museum designed by Richard Meier creates a series of horizontal relationships that align with the facades joint pattern. Shown in elevation the ARP Museum's joint pattern frames, aligns, and extends horizontal components such as window edges, louvers, balconies, railings, and doors, the detail placed into the elevation showcases an organizational representation that aesthetically complements the vertical elements of Richard Meier's design. Diagrammatically elevations are the easiest architectural drawing to understand. By showcasing a wall or building façade in elevation individuals can easily understand and simplify the constraints of design that are not shown in plan views.

**Section Cuts:**
Building sections, wall sections, and roof sections architecturally demonstrate a planar cut through the building design, emphasizing relationships complex relationships and details in a single moment. Viewed like elevations sections cuts usually are depicted without distortion and drawn to represent higher detail. Section cuts may confuse observers as there must be a collaboration between the location of the cut, the floor plan and the elements highlighted by the drawing.

> "The section reveals simultaneously its interior and exterior profiles, the interior space, and the material, membrane, or wall that separates interior from exterior, providing a view of the object that is not usually seen... Because the section begins with the visualization of that which will not be seen directly, it remains abstracted from the dominant way of understanding architecture through photographs and renderings." (Lewis, 8)

Sections tell the story of design, as they form a shift from linear representation to design performance. Detailing section drawings provide a reference to scale, proportion, and the view of an interior space. Building form is shown clearly through a textured poché or hatch patterns where the cut occurs. Floors and walls defining programmatic spaces can be seen and aligned to create vertical relationships comparable to how plans create horizontal cut relationships and spatiality.

Vitruvius claims such architectural drawings to be The Fundamental Principles of Architecture which in collaboration express architectures Arrangement. “Arrangement includes the putting of things in their proper places and the elegance of effect which is due to adjustments appropriate to the character of the work.” (Vitruvius, 13). Plan, Elevation, and Section harmonize in response to the labor and attention directed in a design plan and aim to solve crisis within the design creating principles of versatility.





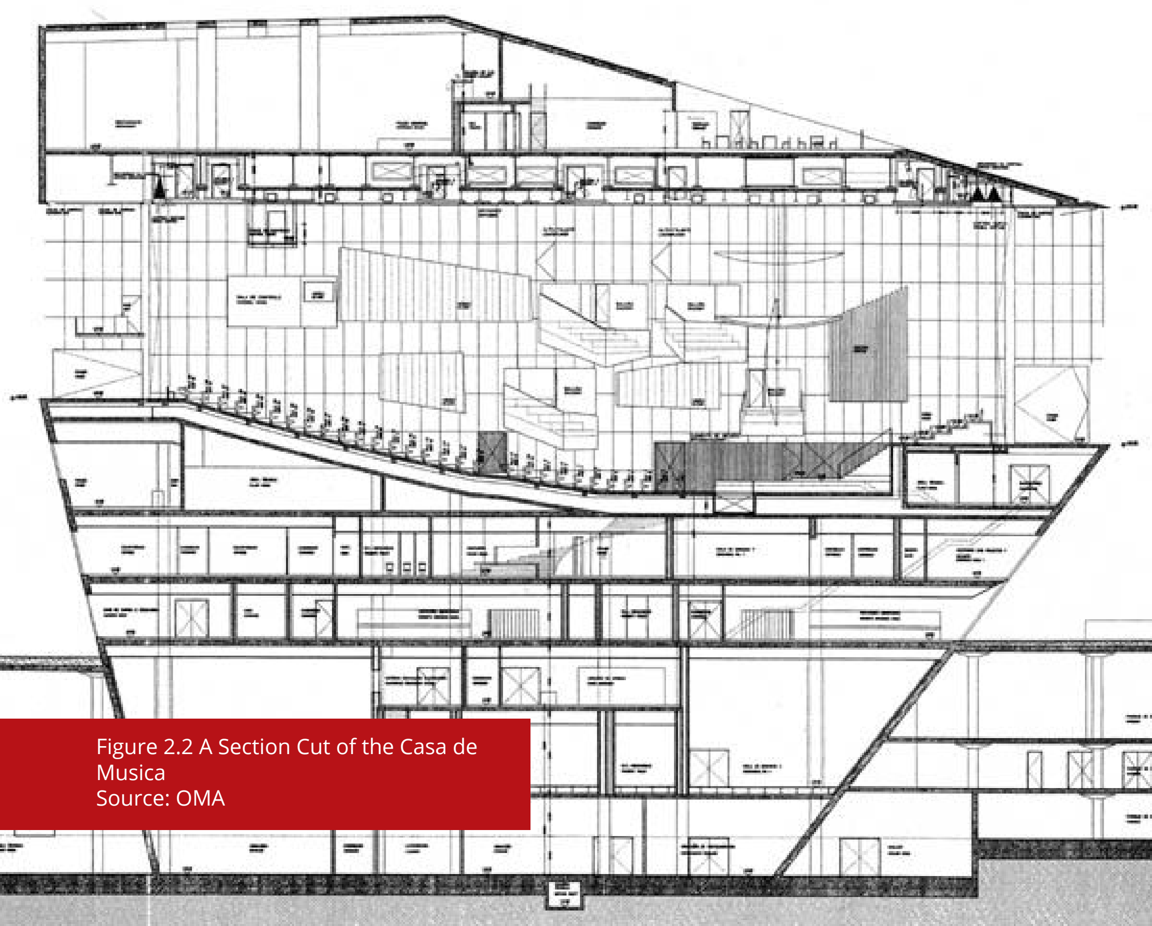


Figure 2.2 A Section Cut of the Casa de Musica
Source: OMA

# Traditional Drawing Methods

Vitruvius' Fundamental Principles largely influenced representation and communication within the visual arts. Defining perspectives as "The method of sketching a front with the sides withdrawn into the background, the lines all meeting in the centre of the circle." (Vitruvius, 14). In 1435 AD, artists, architects, scientists, and mathematicians sought to achieve an expression of the three-dimensional world in two-dimensional images (Bertol, 3) Images were produced not only to inform expression but to define the understanding of the lived three-dimensional world. Advancements in perspective and image perception progressed design understanding and communication. Evolving techniques regarding visualization would inevitably end up creating virtual reality as simulated space, forming the next step of involvement into the design process.

"The first theoreticians and practitioners of perspective reduced our visual perceptions to geometric entities such as points and lines, making them coincident with images of real scenes. The development of perspective brought about an identity relation between vision, nature, and geometry. "(Bertol, 3). Beginning this process offered the two-dimensional medium access to correct proportions, scale, and perspective, and ultimately the ability to recreate the likeness of the three-dimensional world. Discovering how to properly utilize perspective allows artists to control imagery as if it were in our optical lens. Objects that were closer to the artist were accurately drawn larger and had much more vibrant/strong colors, whereas background objects were more opaque and smaller in scale to accurately represent distance. These methods in correspondence with vanishing point techniques opened opportunities to pull an audience into the space through three-dimensionality. Daniela Bertol continues to mention that perspective techniques would primarily control the role in architectural representation; however, indications of virtual reality would begin to exist. Such an example was Brunelleschi's panels, an experiment with wooden panels that aimed to prove the accuracy of representation and proper depiction of space. Brunelleschi painted a perspective of the Baptistery that lies adjacent to the Cathedral of Florence. Brunelleschi's initial viewpoint was within the cathedral's main doors which were represented in the perspective. The Baptistery was then painted on the backside of the wooden panel, later a hole was made on the location of the Baptistery's vanishing point. Considered to be the first experimentation with virtual reality, Brunelleschi would instruct users to:

- Holding the panel, the user was to stand at the same point used to draw the perspective and look from the back of the panel through the hole toward where the baptistery would be located.
- The viewer's other hand would raise a mirror to cover the real world and reflect the perspective matching the real baptistery.
- The viewer's optical focus through the panel's hole would frame the baptistry recreating the experience of peering through the cathedral doors.
- The mirror's reflection of the baptistry would "virtually" represent the experience of viewing the perspective from Brunelleschi's point of view.

To add a level of immersion and interaction, Brunelleschi used brushed silver for the sky of the baptistery perspective. Capturing the movement of the actual sky and blending it with the painting; this improved realism of the illusion by adding familiar characteristics to its composition. Daniela Bertol labeled this as "renaissance virtual reality" (Bertol 15) (Figure 2.3).

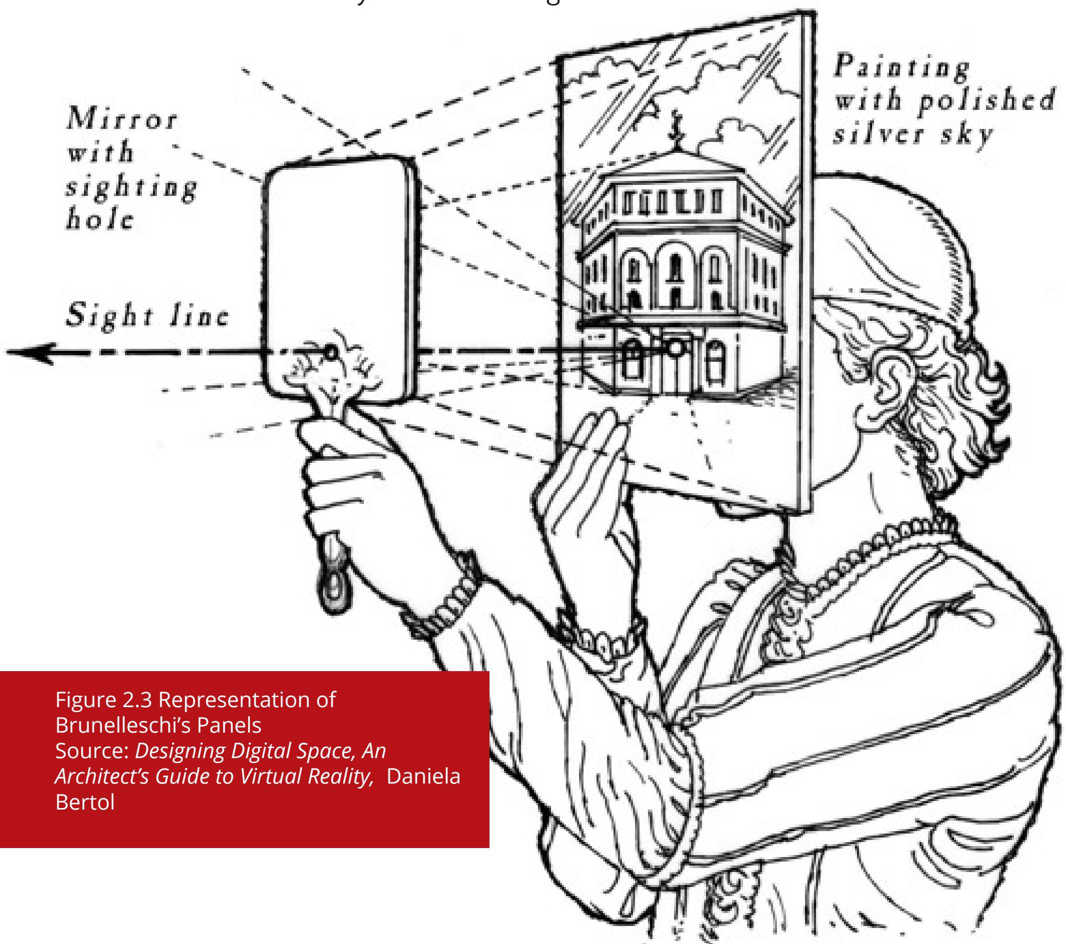



Figure 2.3 Representation of Brunelleschi's Panels
Source: *Designing Digital Space, An Architect's Guide to Virtual Reality,* Daniela Bertol

# Use of Illusions

“The simplest concept of an illusion is a visual experience or ‘percept’ that fails to agree with real world measurements.” (Purves, 2008). Perception is not an absolute representation of reality. Visual stimuli are broken down and processed optically to determine the ‘what’ and ‘where’ of a given scene. Our vision creates a cohesive interpretation of environmental stimuli to react to. Illusions result from assumptions made by the optical system and the stimuli, forcing information to be laid atop one another making illusions difficult to organize. “In architecture, the eye cannot be wholly satisfied by such tools as the level, the square, and the plumb-line. The eye is satisfied only when the appearance is satisfactory.” (Luckiesh, 196). Satisfying the eye to believe the spatial relationships represented are accomplished through small almost unnoticeable changes and proper use of contrast and light. For Example, The Parthenon in Athens, corrects observer’s perspective by curving and tapering columns, resulting in the appearance of straight and symmetric columns. If the columns were not altered the result would be as if the temple was sagging. Greek colonnades much like The Parthenon were often subjected to alteration to avoid visual satisfactory, columns standing straight may appear shrunken in the middle, often artisans intentionally made the columns swollen so they appear straight. Visual satisfactory often relies on symmetry and balance in architecture. “A composition must appear to be stable; that is, a large component such as a tower must not be situated too far from what we take as a center of gravity.” (Luckiesh, 201). Balance often defines designs that are aesthetically pleasing but altering this balance and creating the illusion of weightlessness also intrigues architects. Cantilevers seem to float effortlessly overhead and invoke anxiety and uncertainty due to this perceptual loss of balance.

Illusions became more dynamic as artists and architects develop spatial representation and perspective. Utilizing optical illusions in accordance with accurate representations of light, shadow, and proportion create depth within paintings and three-dimensional representations. Anamorphosis illusions greatly distort an image only to have it revealed from a single vantage point or from a reflection. Observers must actively engage in the process of an Anamorphosis illusion to identify the viewed subject. Once the viewpoint point is reached the subject is reinforced and reaffirmed by optical vision, observers essentially become part of the art. Trompe-l’oeil illusions are closely related to

Anamorphosis illusions, both illusions trick the observer into questioning and interacting with the art. Trompe-l'oeil illusions combine false illustrations with painted compositions. Observers are lead to view a painted composition that is framed by the false illustration, adding a level of depth the observer is tricked to perceive the false illustration as reality. (Figure 2.4)

Virtual Reality relies on the use of illusions to create an immersive sense of presence, lacking the physical components of reality, virtual reality is just an illusion of such. Achieving the illusion of physical reality makes Virtual Reality successful.  Simulations of an environment are rendered to trick the eye, like an illusion, to believing the simulation is real.





Figure 2.4  An example of trompe-l'oeil
Source:*School of Athens*, Raphael

# What is Virtual Reality?

Virtual reality has a multitude of interpretations, most of which are based around the definition of "a computer-generated world involving one or more human senses and generated in real time by the participant's actions." (Bertol, 67). Others consider virtual reality to be a direct simulation "A medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation." (Sherman, 13) It is important to understand that virtual reality allows users to interact with a virtual environment through simulation. Simulating environments requires three components that make up an immersive experience,

- Interactive – users can interact with the model;
- Spatial – models are represented in three spatial dimensions;
- Real-time – feedback from action is given without a noticeable pause. (Whyte, 3)

Interaction aids the user in creating familiar spatial relationships within virtual reality simulating real-time feedback that tricks the user's perception to adapt to the virtual environment. Simulating the virtual world should be considered a tool to explore anomalies that are not possible within the physical world, virtual reality has the potential to change a multitude of industries and practices as it evolves out of infancy. Virtual reality devices introduce the need to re-evaluate our current understanding of reality.

**Immersion:**

Immersion allows users to have multi-sensory experiences, leading the user to perceive the virtual world as physically real. "Immersion is achieved by removing as many real-world sensations as possible, and substituting these with the sensations corresponding to a virtual environment." (Mestre, 1). Relating to the interactive experiences, immersion personifies virtual reality devices to replicate the physical world. Replicating optical visual fields, sound, and other stereoscopic characteristics within a virtual environment creates an extensive, vivid, and inclusive display of space creates a high-fidelity experience that is sensually mimicking the real world. Presence, in virtual reality, refers the realistic, but remote nature of the virtual environment. Instilling belief that the user is now “present” in the virtual environment. Being “present” in virtual reality psychologically convinces the user's perception and cognition to “exist” within an immersion virtual environment. Immersive presence in virtual reality may enhance interactive design and creative performance; however, Virtual Reality would have to be socially adept and allow for exterior critique with ease to aid in design.



**Types of Immersion**

Foundational categories of immersion:

1. Tactical immersion - immersion that aids tactile operations that require deep concentration and skill.
2. Strategic immersion - immersion that focuses on undertaking a mental challenge.
3. Narrative immersion - immersion within a story or description (often found in the video game genre).
4. Spatial immersion - immersion where a simulated world becomes perceptually convincing.



Immersion begins to split into these categories when it is applied contextually to a situation. Virtual Reality experiences are often made up of one or more of these categories. Complex simulations may require a hybrid of immersive situations developing elaborate dynamic experience further challenging the illusion of physical vs. virtual reality. Architectural experiences rely on spatial immersion as it offers a perceptive experience that can be accessed by C.A.V.E. virtual reality, or head mounted displays (HMD). Spatial immersion reduces the cognitive thought process of putting on a head mounted display and mentally fades the perception that you are no longer staring at the physical world but a screen.





TOP - Figure 4.0 - The Original Stereoscope
Source: Stereoscope.com

MIDDLE - Figure 4.1 - A Classic View-Master
Source: Viewmaster.com

BOTTOM - Figure 4.2 A flier for the Senseorama
Source: Telepresenceoptions.com

Brunelleschi's panels demonstrated that virtual reality is a blend of illusion and reality and that there have been traces of virtual reality since the 1400s; however, virtual reality was rigorously being developed in the 1900s. The first device, however, was beginning development in the late 1800s, the stereoscope.

**Stereoscope** (Figure 4.0)

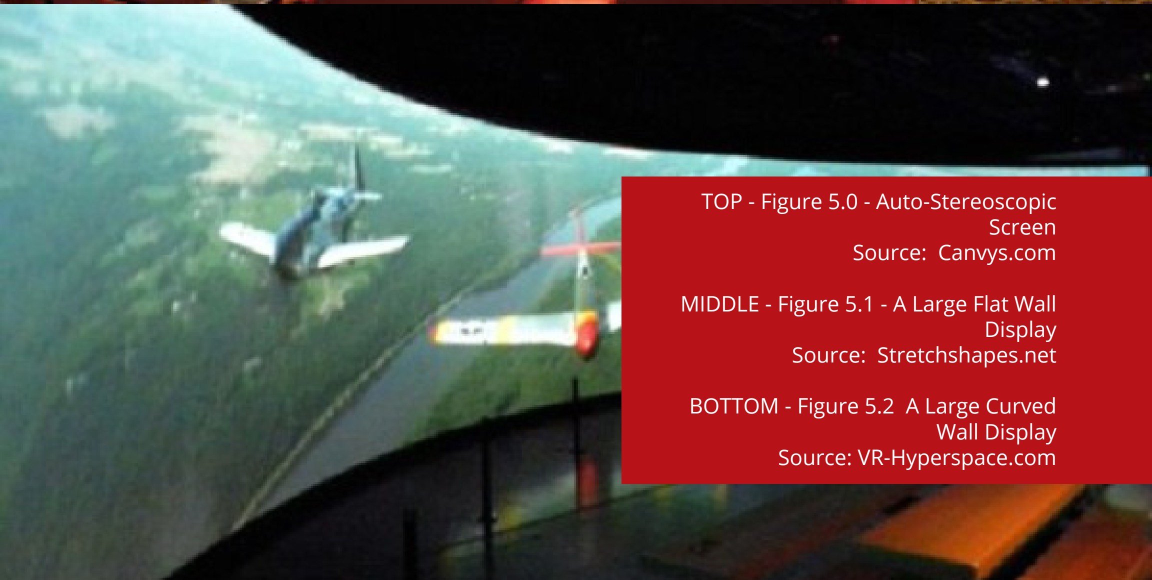
Utilizing the importance of our binocular depth perception, slightly different images of the same object are projected individually to the left and right eye. Resulting in the brain splicing the images together, and view the image as if it were three-dimensional.

**View-Master** (Figure 4.1)

Child of the stereoscope, the view-master offered reels of cardboard disks containing a multitude of stereoscopic images. These were mass produced after 1939 offering three-dimensional views that expanded visualization options to a multitude of users. The view-master also saw a small hint of popularity as it prioritized a few stereoscopic reels to personal training and fitness exercises.

**Senseorama** (Figure 4.2)

Senseorama was a 1956 invention that created the first multisensory and immersive experience and truly began to define the term virtual reality. The device utilized wide vision screens, motion, color, stereo sound, aromas, the wind, and vibrations. Simulating a virtual motorcycle ride the user could experience the wind on their face, rapid vibrations, and isolation from exterior light to create a feeling of immersion. These relate to utilizing exterior properties to develop illusions of immersion, much like the silver sky in Brunelleschi's panels and foreground in Trompe-l'oeil.



TOP - Figure 5.0 - Auto-Stereoscopic Screen
Source: Canvys.com

MIDDLE - Figure 5.1 - A Large Flat Wall Display
Source: Stretchshapes.net

BOTTOM - Figure 5.2 A Large Curved Wall Display
Source: VR-Hyperspace.com

Today there is a multitude of virtual reality systems; each differs on graphic quality and level of immersion. Different systems are used for different applications or research professions. One can expect to use either a multitude of projectors or specialized head mounted display to experience virtual reality. Listed are the most common devices that can be found today.

**Auto-Stereoscopic Display Screens**

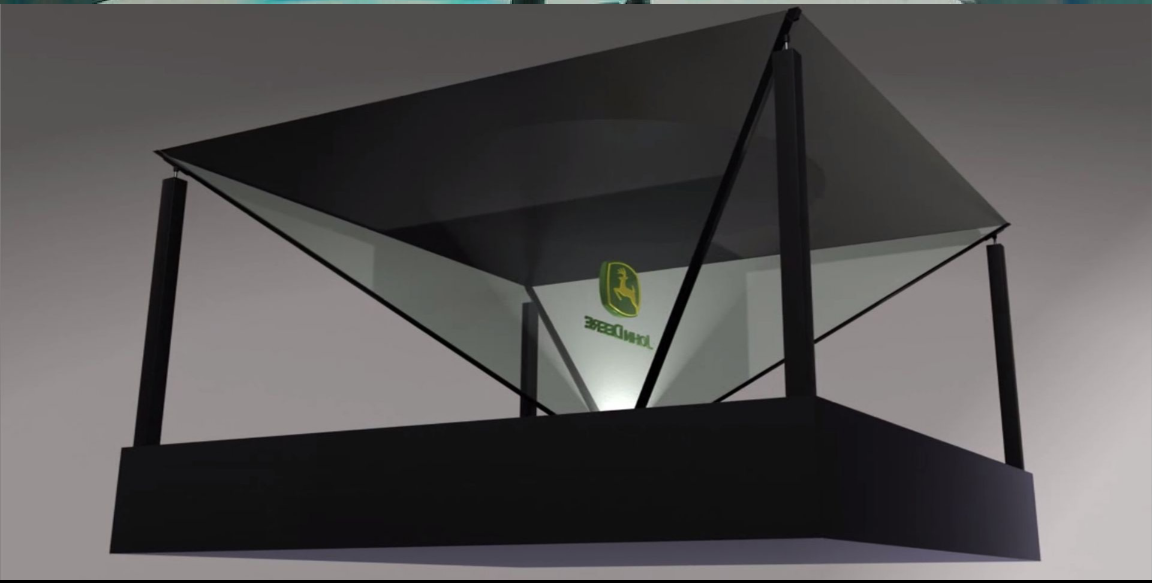
A holographic stereo screen that does not require stereoscopic glasses to be worn by the user. More advanced screens enable touch activated capabilities on screen and do not confine a user to a certain distance and position to be able to view the 3D stereoscopic depth effects. Commonly found as household televisions. Dimension quality is based on distance and content viewed on the screen; however, Auto-Stereoscopic Screens lack true immersion as they are viewed from a distance.

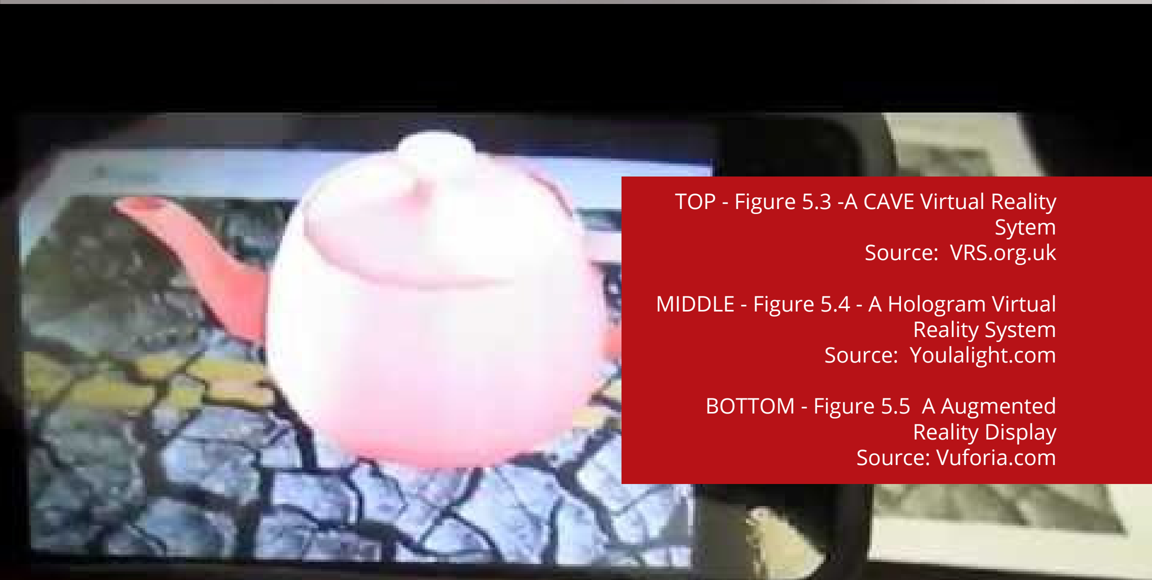
**Large Flat Wall**

One or two computers generate a VR scene. They are then connected to projects behind screens. The projectors separate images projected on the screen. Users are required to use stereoscopic glasses to receive the full effects. The advantage of this system is that it accommodated multiple users at a time and has higher definition displays. Three-dimensional models are shown as if located on a large two dimensions' television screen, showcasing low levels of immersion that require minimal interaction.

**Large Curved Wall**

Consists of three computers or more, these projections are produced from the back of the curved screen and surround the user to create an immersive environment. Large audiences utilizing stereoscopic glasses are required. Immersion is subject to 180° of panoramic views, individuals can walk throughout the space, but lack motion sensors for environmental reaction.





TOP - Figure 5.3 -A CAVE Virtual Reality Sytem
Source:  VRS.org.uk

MIDDLE - Figure 5.4 - A Hologram Virtual Reality System
Source:  Youlalight.com

BOTTOM - Figure 5.5  A Augmented Reality Display
Source: Vuforia.com

## C.A.V.E. (Cave Automatic Virtual Environment)

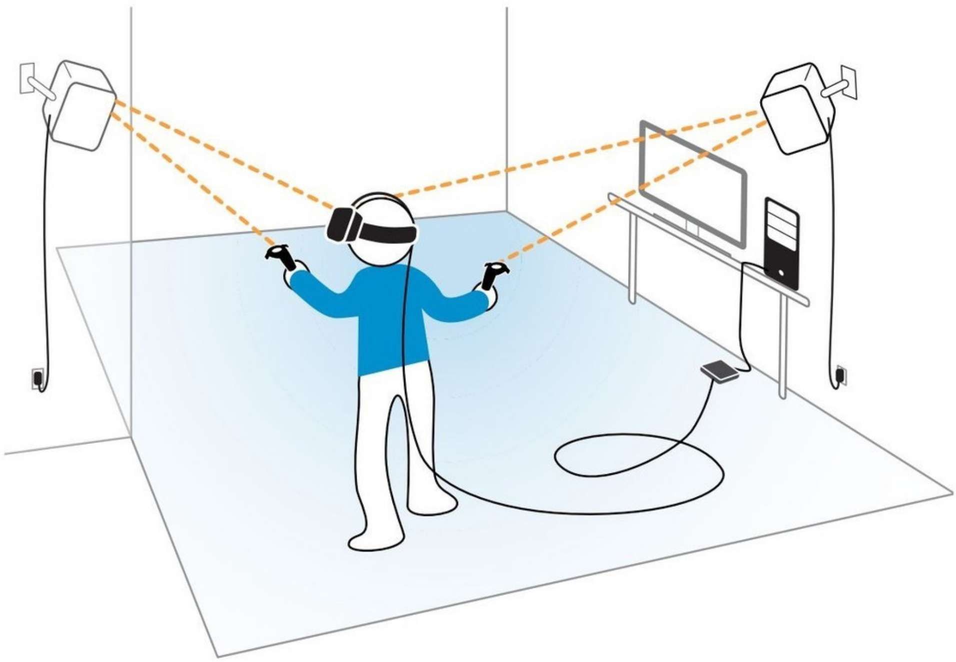
A significant amount of area is required for a C.A.V.E., five projections forming engulf the user in a "cave" environment, completely immersing an individual. Images are mirrored and projected onto the back of each cave screen. Users have a more immersed experience in the C.A.V.E. than most other devices, but it requires a significant amount of computer power and energy to maintain high-resolution images.

## Hologram

50" wide High Definition TV and PC screens are projected from below so that users can sit around it and visualize 3D images in midair. Individual objects are more likely to be shown through Holograms as spaces would require users to only view the exterior walls of the space.

## Augmented Reality

Augmented reality relies on computer generated information that directly presents itself to the physical environment. Augmented Reality is currently widespread via mobile devices and bridges the gap between the virtual world and the real world. Users observe digital information as it appears to become part of the physical environment. Through visual media such as Microsoft Holo-lens, Google Glass, and majority of all mobile cell phones augmented reality is the most readily accessible real-time feedback device. Limitations are based solely on user input, and spatial registration. Augmented Reality encourages interaction with the real world to receive real-time data about one's surroundings. Markerless Augmented Reality accesses a visualization device and projects three-dimensional models and information onto a defined ground surface. Image-based Augmented Reality requires an activation image, the image then displays the information or three-dimensional model onto it, if the tracking image is obstructed the information disappears and must be reconfigured. Creating an augmented reality experience requires three components, a tracking component (GPS or phone gyro), a registration component (software interface) and a visualization component (camera or glasses). Experiences are defined as a feedback loop between users and computer systems, users observe augmented reality display and control the viewport; the computer system then tracks the user's viewpoint within the real world and simulates virtual content.



## Head Mounted Displays (HMD)

Head Mounted Displays (HMD) allow individuals to fully immerse themselves in a virtual environment through 3D imagery involving sight and motion control. Motion tracking via infrared lights map out a walkable area and track the HMD and device controllers allowing for haptic feedback. Movement is limited to a 15x15m walkable area and a 'blink' mechanism, 'blinking' is the act of teleporting to a distance via device controllers. Head Mounted Displays are the most advanced form of spatial immersion available today, presence within a virtual environment is common due to the interaction mechanics involved with the device. Fronting the virtual reality movement, head mounted displays have access to online interactions with other users creating a social presence amongst people in the virtual world. Current leading manufacturers are Google Daydream, HTC Vive, Oculus Rift, and Samsung Gear VR. HTC Vive currently has the most development properties as it comes encourages room scale virtual reality.





Figure 5.6 A HTC Vive and all its components
Source: Vive.com

Figure 5.7 A typical HTC Vive Setup
Source: Vive.com

TOP - Figure 5.8 Unreal Engine 4’s Logo
Source: Unreal Engine.com

BOTTOM - Figure 5.9Unity Game Engine’s Logo
Source: Unity.com

Real-time visual feedback is essential to virtual reality immersion. Establishing themselves as the solution to smooth virtual integration video-game engines are leading virtual design. Game engines are software frameworks designed for the creation and development and require the following for the creation of video games and virtual environments.

- Main Game Program
  - Algorithmic logic that developers alter per game. Split into a series of game categories the Main Game Program offers blank templates to alter to develop games. Essentially, the Main Game Program is the foundation of all video games controlling basic controls and interactions
- Rendering Engine
  - Generates three-dimensional animated graphics through rasterization, ray tracing, or other rendering techniques. Rendering engines are often built within application programming interfaces, methods of communication between software, such as Direct3D or OpenGL, providing a software abstraction of the graphics processing unit (GPU) for visualization.
- Audio Engine
  - Component algorithms related to sound, aids in creating realistic sound effects and surround sound experiences within video games.
- Physics Engine
  - Software that emulates simulated physics. Collision detection, fluid dynamics, gravity. Can implement realistic laws of physics or create alternate reactions based on user commands.
- Artificial Intelligence
  - Intelligence system within the game engine, commonly known as a programmed device that perceives its environment and takes actions to maximize its chance of success at a specific goal. Limitations are defined by the amount of programming sourced to the artificial intelligence machine.

### Unreal Engine

“Complete suite of creation tools designed to meet ambitious artistic visions while being flexible enough to ensure success for teams of all sizes, Unreal Engine delivers powerful, proven performance.” (Unreal Engine, Docs). Known for being a premier game engine Unreal Engine integrates dynamic interfaces for all development needs. Lighting customization and area controls allow the user to focus on aesthetic and immersive qualities to create integrative virtual worlds and video games. Material mapping showcases high-quality real-time solutions with visual relief and minimal distortion and bitmap distraction. Designing interactions such as opening doors and teleporting in Unreal Engine is accomplished through blueprints. Blueprint Visual Scripting is a programmatic coding solution utilizing node-based interfaces to create object-oriented interaction. Unreal Engine provides high-quality materiality, lighting, shading, and scripting to ensure seamless integration of virtual simulations in a quick and intuitive fashion.

### Unity

“You can create any 3D or 3D game with Unity. You can make it with ease, you can make it highly-optimized and beautiful, and you can deploy it with a click to more platforms than you have fingers and toes.” (Unity3D, Docs) With a large user community, Unity Game Engine provides a series of ready-made assets to optimize one’s design. Graphically Unity is sub-par in comparison to Unreal Engine but makes up for it in resourcefulness. Integrating a strong developers’ library and importation of design models, Unity offers more customization than Unreal Engine. Prefabricated scripts and coding methods showcase complex interactions such as video fly-throughs and realistic physics. Virtual Environments created in a grid-based area that allows for quick snapping and location of objects. Providing customization and ease of use aids in creating unique virtual experiences that are only limited by the users coding experience. Augmented Reality optimization is also a standard toolkit found in Unity as it creates a blank slate to place information data or three-dimensional models on.

**Workflow**

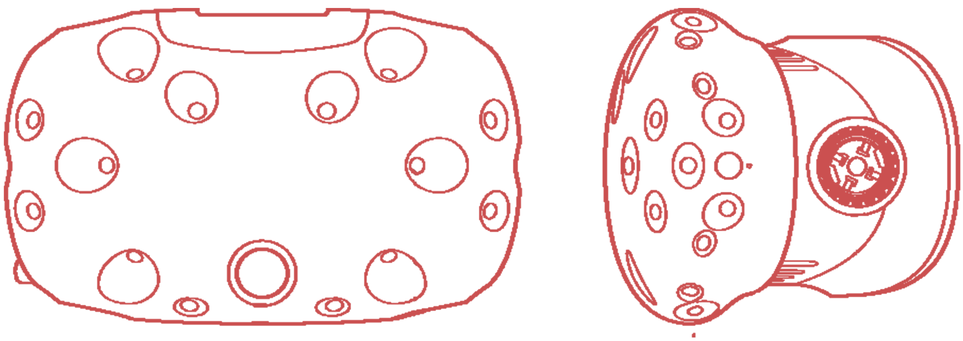
Cross platform manipulation is required for modeling and integrating one's virtual reality scene into a video game engine. Proficiency in Autodesk Revit, 3DS Max, and the video game engine of choice is recommended. Initial massing is created within Autodesk Revit or Autodesk 3DS Max including all essential geometries and design details.

Exporting a design model from Autodesk Revit

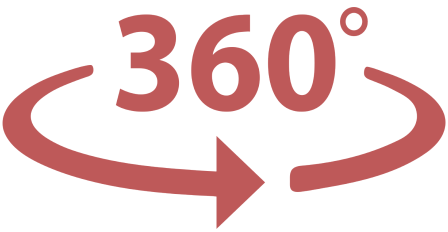
- Create a three-dimensional fully modeled design.
- Export Autodesk Revit three-dimensional view as a .fbx
- Open .fbx model in Autodesk 3DS Max with a centimeter scale parameter.
- Create new UV Maps for design on Channel 2 with .01-.07 spacing.
  - o Creating new UV maps defines baked lighting and collision detection.
  - o Optimize polygon count to maintain the quality of the model, if necessary.
- Export .fbx model into either Unreal Engine or Unity Game engine.
- Create virtual reality experience.

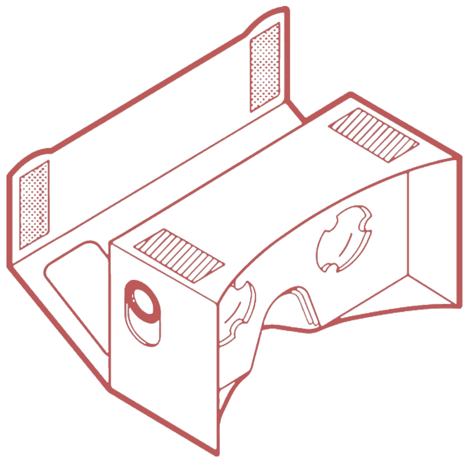
Exporting a design model from Autodesk 3DS Max.

- Set unit scaling to centimeters.
- Create a three-dimensional fully modeled design.
- Create new UV Maps for design on Channel 2 with .01-.07 spacing.
  - o Creating new UV maps defines baked lighting and collision detection.
  - o Optimize polygon count to maintain the quality of the model, if necessary.
- Export .fbx model into either Unreal Engine or Unity Game engine.
- Create virtual reality experience.



INTERACTIVE VIRTUAL REALITY



360°- VIRTUAL REALITY

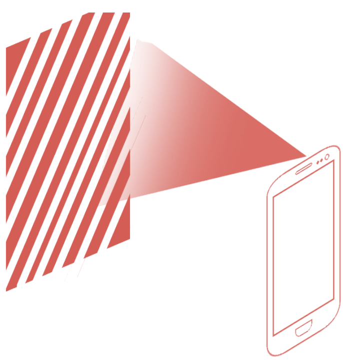
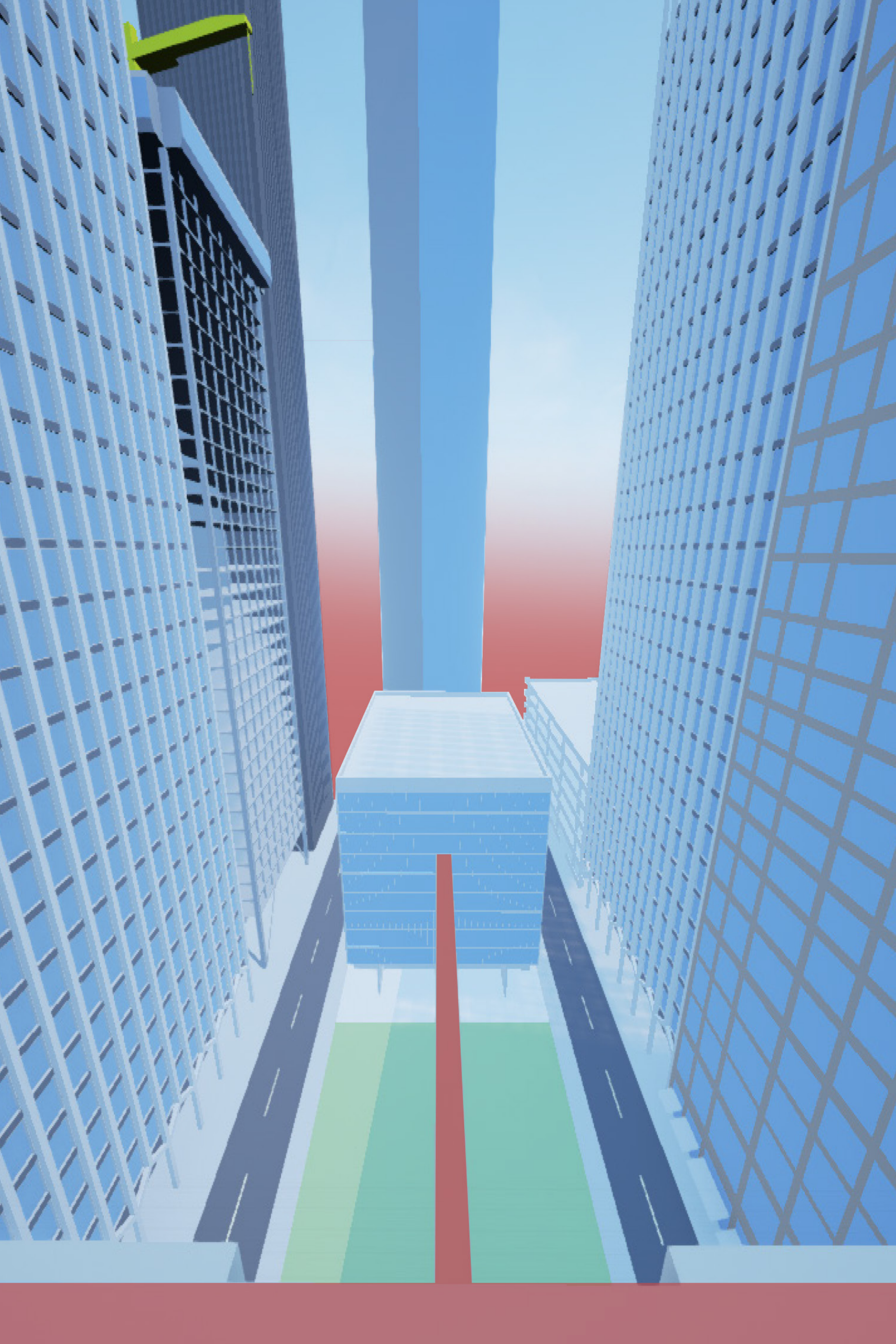


IMAGE-BASED AUGMENTED REALITY

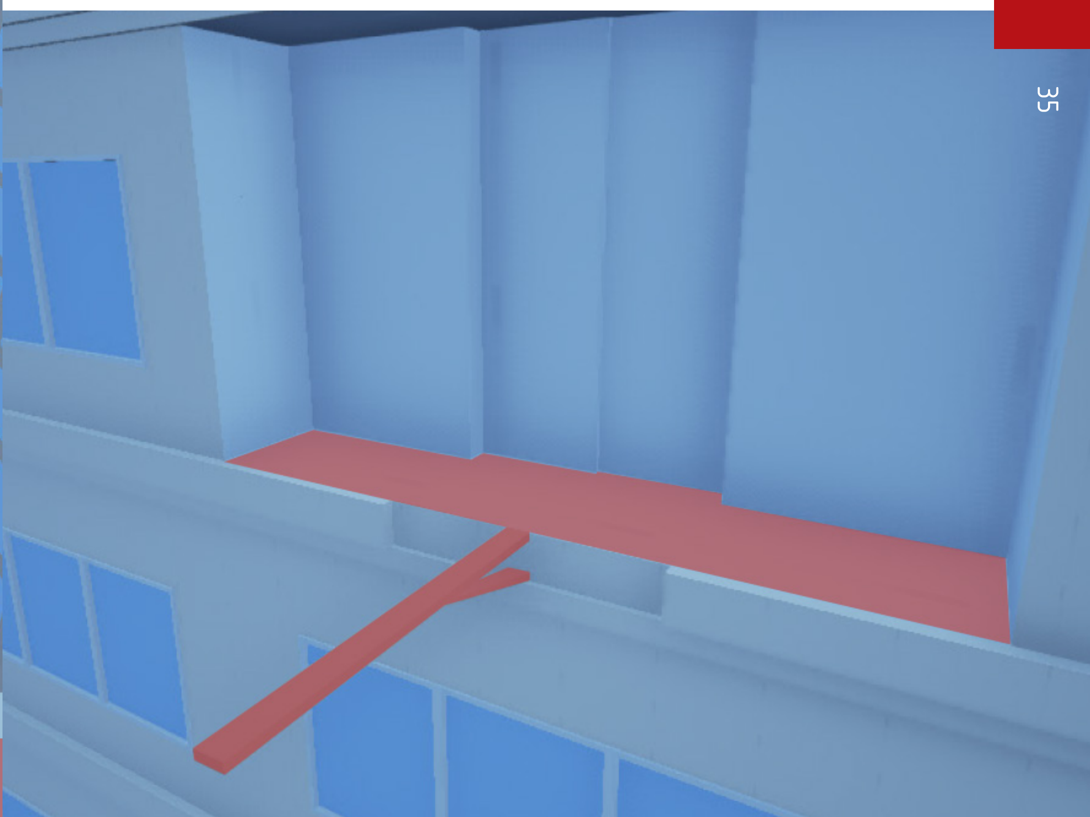
## Human Interaction and Perception in Virtual Reality

Human interactions in virtual reality are exceedingly important to understand, initial reactions in virtual reality aim to create a more cognitive simulation for an audience to experience. Without such knowledge, one may fall short in receiving the desired perceptive virtual world or design showcase. How humans perceive color, scale, materiality, lighting, shadow, depth perception, proportion, to wayfinding and spatial relationships explore how humans will react to virtual environments. Sensational responses of presence create engaging virtual experiences that feel realistic. Adapting virtual models, and utilizing elements of computer gaming and visual media are speculated to create a more fulfilling user experience. Enhance the audience's cognition of response to design and spatial immersion. Embodying virtual reality experiences through multiple sensory inputs drastically adds to user's perception of being in a virtual environment. Interactivity and sensual input are essential for an immersive virtual reality experience. One's visual perception of the space often feeds the mind to believing that an experience is exceedingly real. Immersion offers opportunities for exploration that can help aid the design process and overall ontological response toward the utilizing virtual reality as a tool and ultimate visualization medium for architectural space.



## Walk the Plank

Testing the sense of presence created in virtual reality, the Walk the Plank experience tests the user reaction to a virtual environment. Presence, the feeling of 'existing in' space was challenged through anxiety and fear of heights. Utilizing mixed reality, a blend of physical objects and computer simulations, users are to traverse a 10' – 0" long plank at 120' – 0" in the air. Simple opaque materials were created to develop an unrefined visual typology and explore the spatial immersion that the HTC Vive creates. Complete 360-degree stereoscopic real-time rendering feedback aimed to create a smooth experience that's interactive. Additional tactile feedback was used to emphasize the realism of the virtual environment, user's heard birds chirping, wind howling, and a 2" x 10' wooden plank in coordination with the virtual representation of the plank. Additional sensory devices aided the creation of a realistic virtual environment with physical properties. Walking the Plank as a virtual experience tested the human sensory response to immersive feedback, and how a user's perception reacts to drastic situations in a virtual environment.



## User Response

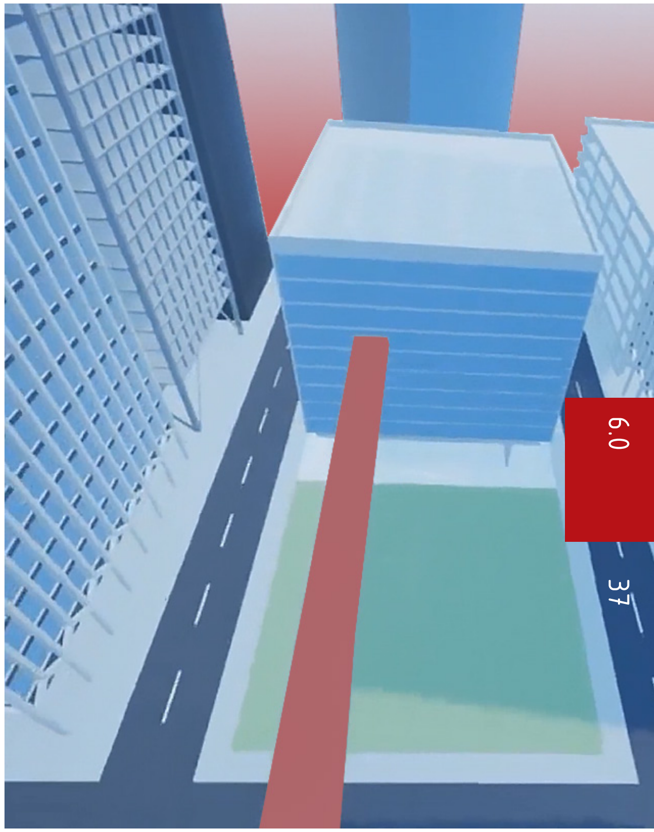
Participants were immediately enveloped in the virtual environment, the illusion of virtual reality would overwhelm one's senses and disassociated participants from physical reality. Psychologically participants found difficult convincing themselves the experience was only a simulation. Feeling fear and anxiety were recorded as participants crippled when walking to the edge of the building. Upon stepping on the plank many participants sank their center of balance and flailed their arms outward to maintain balance. Inching along the board with small steps became routine through all participants as they crossed the plank. Some participants could completely disassociate the illusion of virtual reality from the experience in the virtual, world when questioned a participant stated,

> "I had mentally prepared myself beforehand, watching other people do this was frightening. While in virtual reality I was constantly telling myself that I was safe and not in harm's way."
>
> – Jacob Theut, Master Thesis Student UDM-SOA

Walking the Plank was initially pushed beyond the limit of spatial immersion with tactile haptic feedback through mixed reality, testing user responses to see how strong virtual reality immersion could be. Participants responded predictably as physical feedback from the real plank and audio cues of wind and birds activated users sense of touch, hearing, and with the HMD vision.

A second user test was completed without the use additional tactile feedback; the real plank and audio cues were removed to make a pure virtual reality experience without and additional distractions. Testing the response of strictly visual perception, participants were once again asked to walk to the edge of a 10' – 0" plank at 120' – 0" in the air. Subjected only to real-time visual feedback users struggled to Walk the Plank. Claiming that even though they hear the physical world around them and feel the floor visually they cannot separate the two experiences and felt tricked to believing the virtual world that they saw. Emphasizing that immersion and sense of presence is possible without physical feedback. One's optical perception in virtual reality reinforces the cliché of "seeing is believing".

Walk the Plank supported the claims that virtual reality has a strong sense of presence, and can induce psychological emotion and response in a virtual environment. Haptic feedback through mixed reality increases illusion that virtual reality is real by reinforcing familiar physical experiences in collaboration with virtual ones. Lastly, purely optical experiences in virtual reality can create spatial immersion that conflicts with the belief that virtual reality is not real and just a simulation.



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**Virtual Apartment**

Creating an architectural space in virtual reality required a different approach because the sense of presence had been tested and confirmed in the Walk the Plank experience it was essential to figure out what participants perceived within virtual environments. Apartments are intimate spaces reflecting the personality of the individual(s) that live there. Attempting to keep the design relatively simple required reducing the amount physical interaction within the virtual space. Participants utilized only the HMD and walked around a 6 x 6m space that was equivalent to the apartment size. Lighting, proportion, and scale were taken into consideration to ensure the virtual apartment reflected the real world as much as possible. Fully furnished, illuminated and textured, participants visualized hardwood floors, leather furniture, and modern appliances. The Virtual Apartment was sought to test the relationships that participants create with the objects in the virtual environment, as well as how aesthetic materiality alters the experience.

**User Response**

The virtual apartment was stated to create a more personable experience within the virtual world, rather than feeling fear or anxiety like the Walk the Plank experience, the apartment offered a more 'homey' and 'warm' feeling. Participants attempted to interact with the digital models by reaching out and attempting to pick them up, only to clasp their hands into a fist in the real world.

> "I feel like something should be there, looking toward the couch and reaching for it I expected to touch the leather that it's made of. It was frustrating to not be able to pick up objects, but amazing how realistic everything felt."
> – Cori Hinterser, Master Thesis Student UDM-SOA

Participants explained that the experience was realistic and believable, everything was scaled correctly and seemed like it could be a physical space; however, they criticized the lack of being able to interact with objects in the apartment. Haptic feedback would have created a more realistic spatial immersion that embodied what it truly was like to be inside of an apartment. Suggestions eluded to improving the experience by integrating interaction to rearrange furniture, move lights around, and being able to add design intervention in the space. Moving the walls or ceiling would allow individuals to customize the space and create a more personal experience based on participant input. Maintaining the spatial immersion within the space allowed for a sense of presence to be created but allowed for participants to criticize aspects of the apartment that they personal disagree with. Emphasizing the realistic quality of the space created, but not creating a controlled virtual experience. Unforeseen to the assumptions made before the user experience was the lack of interaction within the space that participants wanted, had there been more interaction within the virtual environment or the ability to change any superficial aspect of the experience a more holistic sense of immersion would have been achieved.


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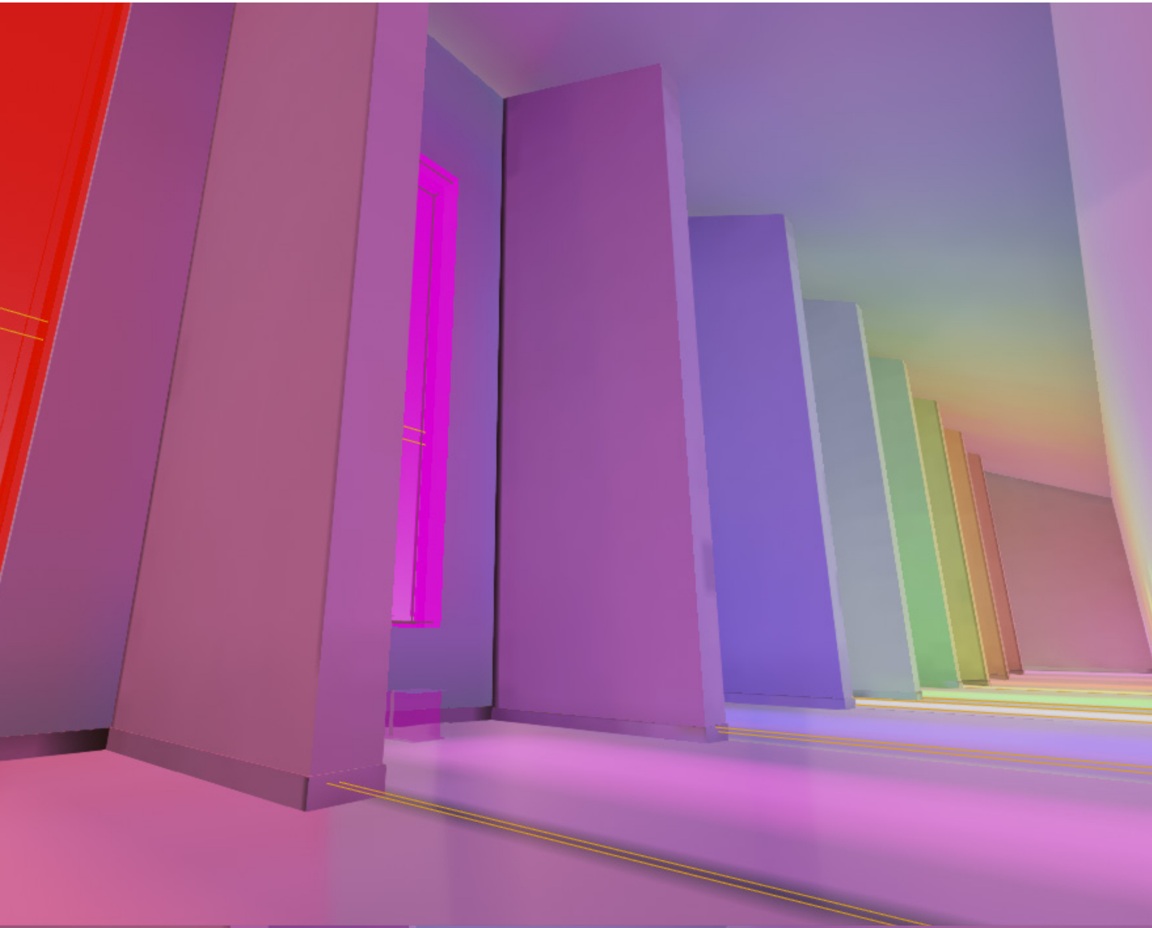


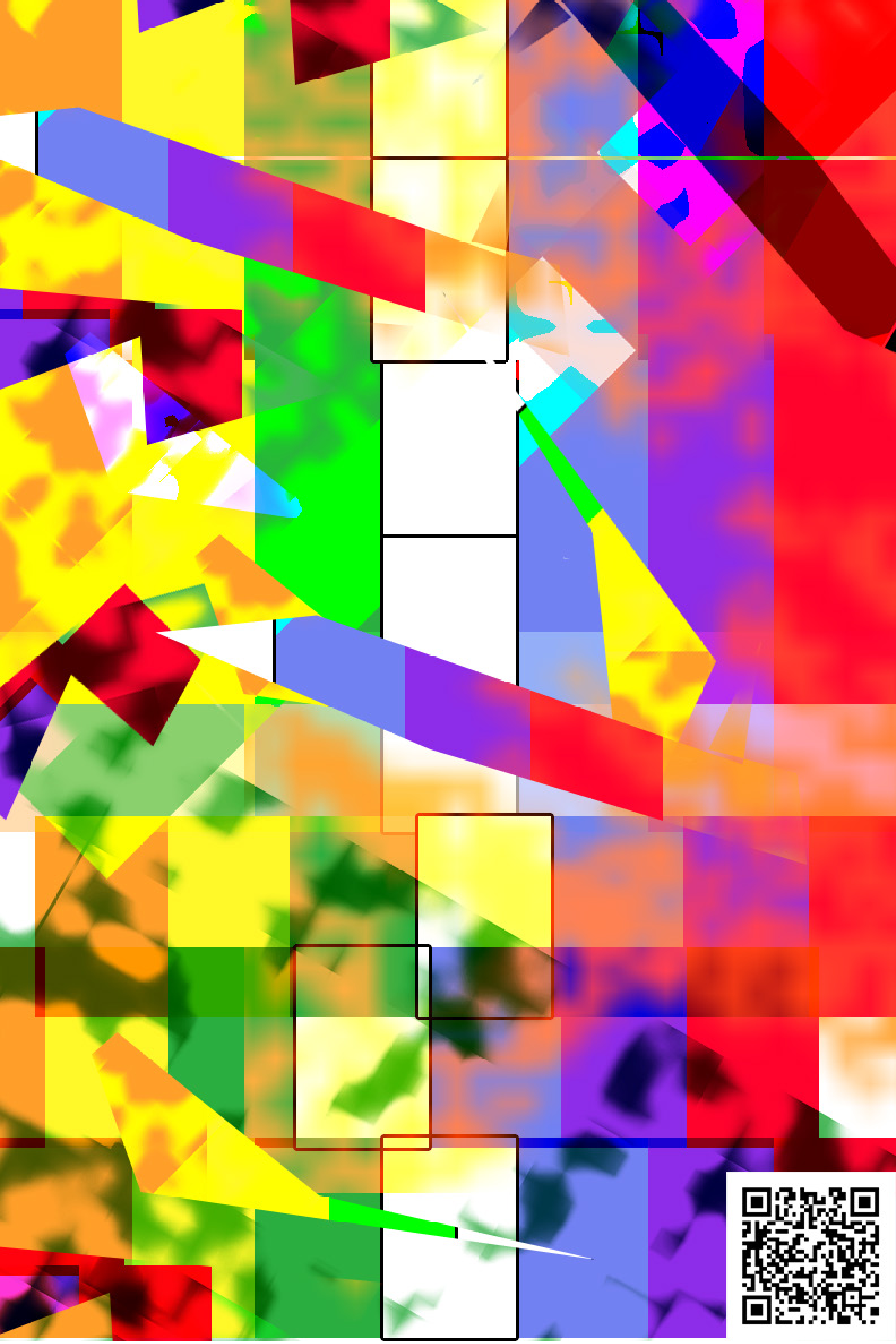
## Color Study

Architectural and spatial visualization rely on designed elements such as contrast, light, shadow, depth, and even color. Our optical senses are attracted to vibrant aspects of design that contrast with familiar expectations of design. Providing aesthetic qualities 'color' is used to transform space, both visually and psychologically. The Educational Centre in El Chaparral, Spain uses color as a signifier for transitional spaces. Natural light diffuses the color of tinted glass throughout the school's hallways and open spaces, bringing an array of color into an otherwise stark white space. Located in transitional spaces, color envelops students and emphasizes the relationship that color and light have. The Color Study virtual environment emulates the transitional experience in the Education Centre, participants are encouraged to explore and critique the diffusion of light throughout the space.

Addressing the lack of interaction from the Virtual Apartment, colored glass cubes were introduced in within this virtual environment. Located beneath the design's windows each cube was tinted to match the colored glass it is located below. Participants are encouraged to pick up, throw, mix, and view the cubes in each colored area. Simplifying the interaction to just basic motor skills aims to test the fidelity of interaction within spatial immersion.







### User Response

Participants experiencing the Color Study were treated with a less detailed version of a hallway; however, the lighting quality within the space was stated to be superb. Less detail within the experience allowed the participants to experience the space without the familiar preconceptions of space, unlike the other experiences. Providing less detail also removed the participant's notion of formulating personal opinions and focusing on the virtual illusion presented to them. Interaction with the glass cubes enabled users to experiment with color and light simultaneously, the ability to reach out and grab a virtual object provided a level of haptic feedback that activated the participant's sense of touch. Further immersing the participants into the virtual environment through vision and touch allowed users to become blind to the illusion quality of the virtual experience. Participants claimed that by interacting with the cubes focusing that experience around color made a more intriguing approach to the virtual integrity of the experience; however, some participants noted that once interacting with the glass cubes became routine, the experience focused more on interaction rather than color. Creating familiar interactive experiences made the designed space fade as if it were a background, the glass cubes offered far more insight to spatial immersion than expected and controlled the participant's focus. Reflecting on the experience a participant had stated that the space became more about the interaction with objects, and he only considered the hallway of diffused light and color in his peripheral vision. Analyzing the responses from the participants showed that the users initially had an attraction to the light and color within the space; however, once the glass cubes had become a routine aspect of the experience, interaction became the focus of the virtual environment and promoted visualization in one's peripheral field.





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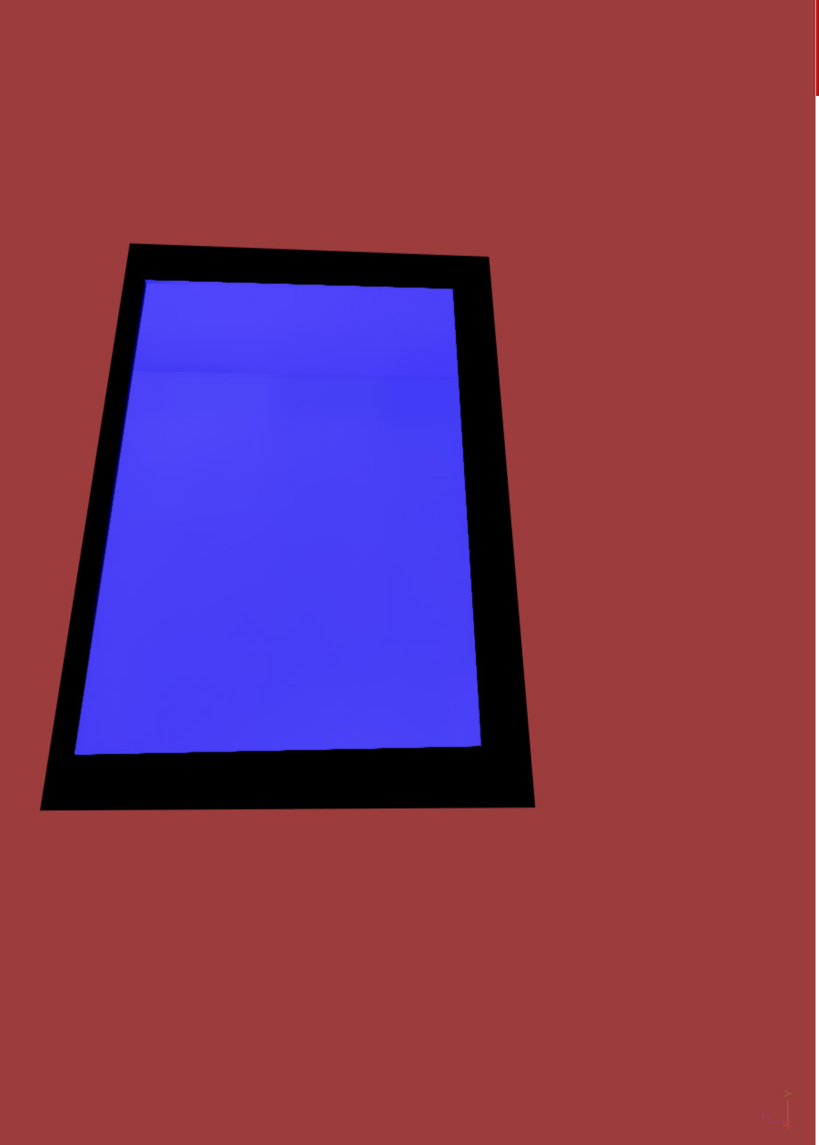
## Light Room

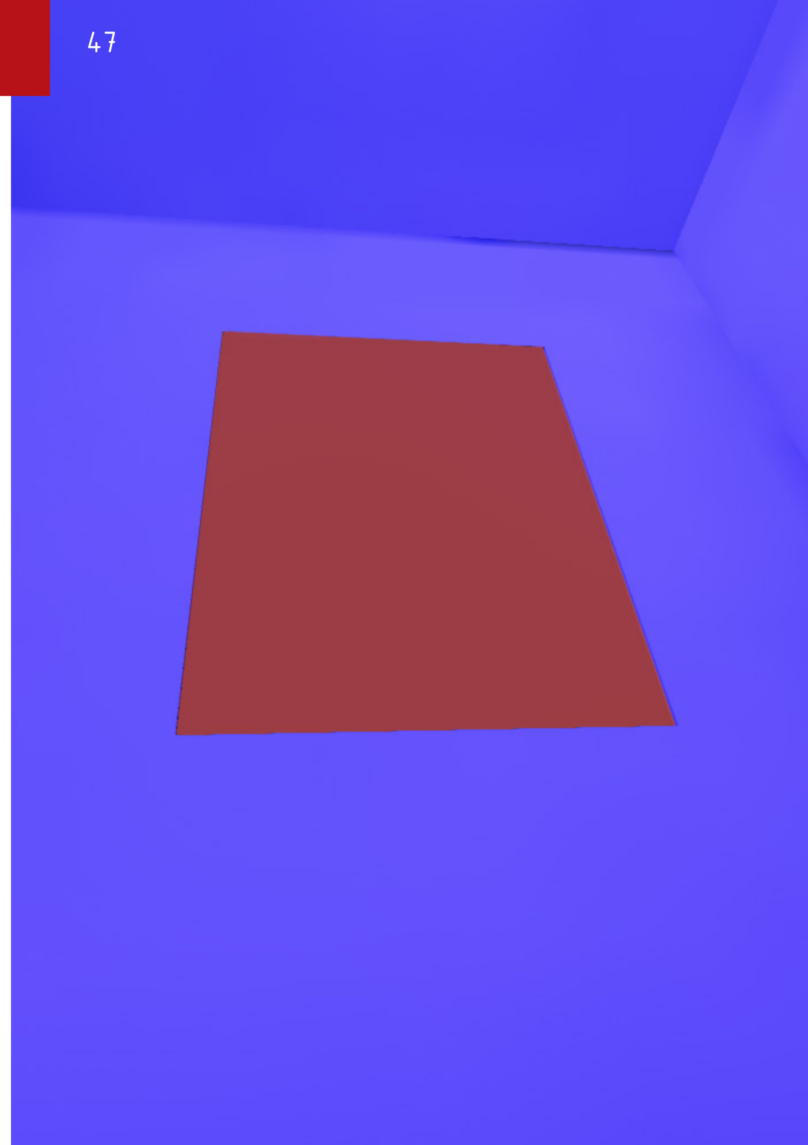
Considering Light is also an essential element of design, much like color, understand light within a virtual environment was explored. Inspired by James Turrell's studies of light and color, a sensory experience of just light was created. Creating a Ganzfeld (complete field) experience of light aims to disorient participants and immerse them in a singular aspect of the experience. Participants will enter a black room void of all light except for a colored rectangle on the wall. Approaching the vibrant plane participants begin to see an additional well lit room rather than a rectangular plain. Emulating the trompe-l'oeil illusion, the experience creates misconceptions with what participants perceive in the virtual environment and explores a controlled interaction within the virtual environment. Keeping the virtual environment simple and not interactive may test the value of the experiment as it is not as elaborate as experiences listed beforehand.

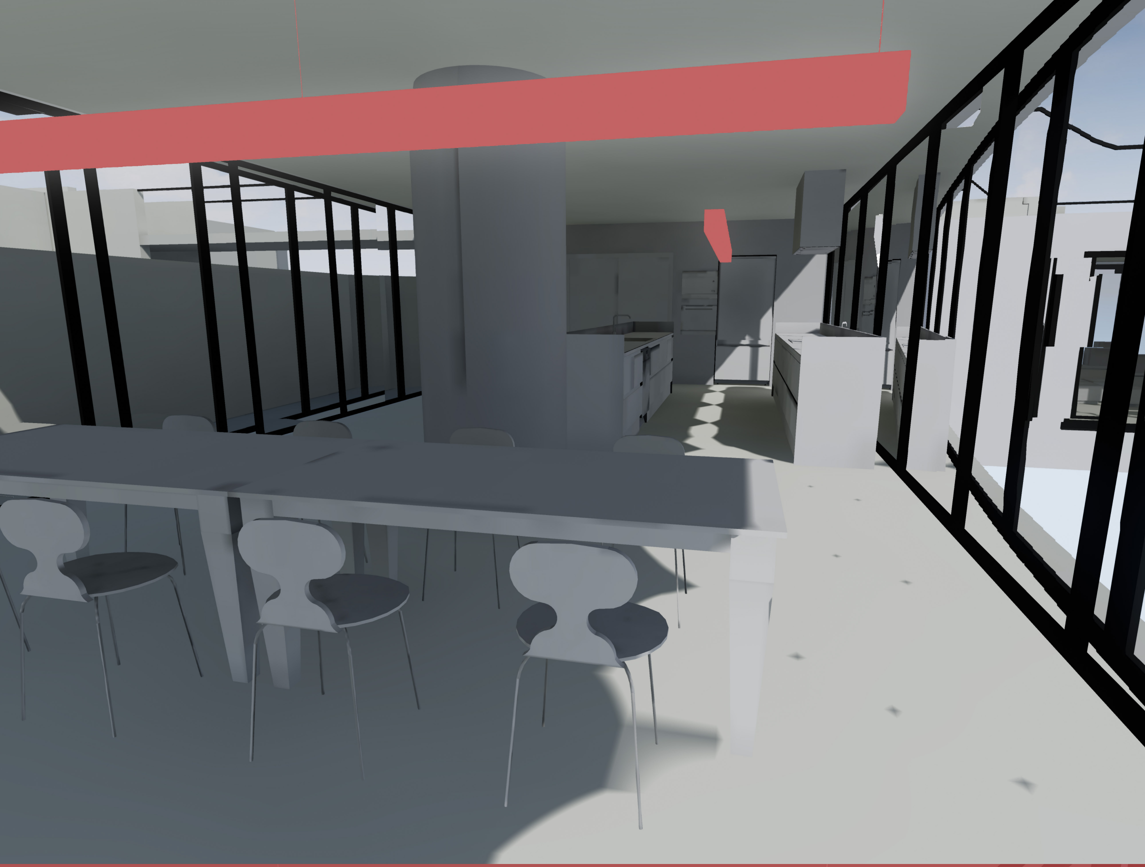
## User Response

Perceiving nothing but the rectangle at the edge of the black room drew participants to that space, controlling their experience to focus on a singular aspect. Successfully drawing curiosity to the rectangle allowed participants to approach the illuminated room and understand the illusion they were subjected to. Quotes such as "it's like a door in a dark room leading out into the world", and "it's just light, but the more I stared at it and once I entered that room it was oddly calming." were noted as psychological effects on participants. Participants did not spend very long in the experience as it was claimed to be 'overly simple', also there was no real sense of presence established within this experience. Mimicking a dark room with an open illuminated door was unknowingly familiar occurrence in each participant's daily life. Participants did not have the opportunity to feel as if they had entered a virtual environment and suggested that creating a multi-sensory experience with objects to interact with may make the experience more virtually oriented.









## Peripheral/Focused Vision

One's vision is subject to only eight to ten degrees of focus at a time. Peripheral vision makes up for the rest of one's visual field through blurred perception. Virtual reality cannot account for one's complete visual field as it is made up of two stereoscopic screens in a HMD, there option to view one's peripheral vision in virtual reality; however, it can be simulated. By obstructing one's center of vision and blurring the remaining one can experience virtual environments through nothing but their peripheral vision testing the necessity of one's focused vision.

Focused perception is possible within virtual reality. One would view the area on the HMD screen and naturally, their optical response will focus on that eight to ten degrees of space while blurring a significant portion of the remaining virtual reality screen. To explore the necessity of peripheral vision, this experiment removes one's peripheral vision by obstructing everything but the center of the visual field, forcing participants to explore space with only with their focused vision.





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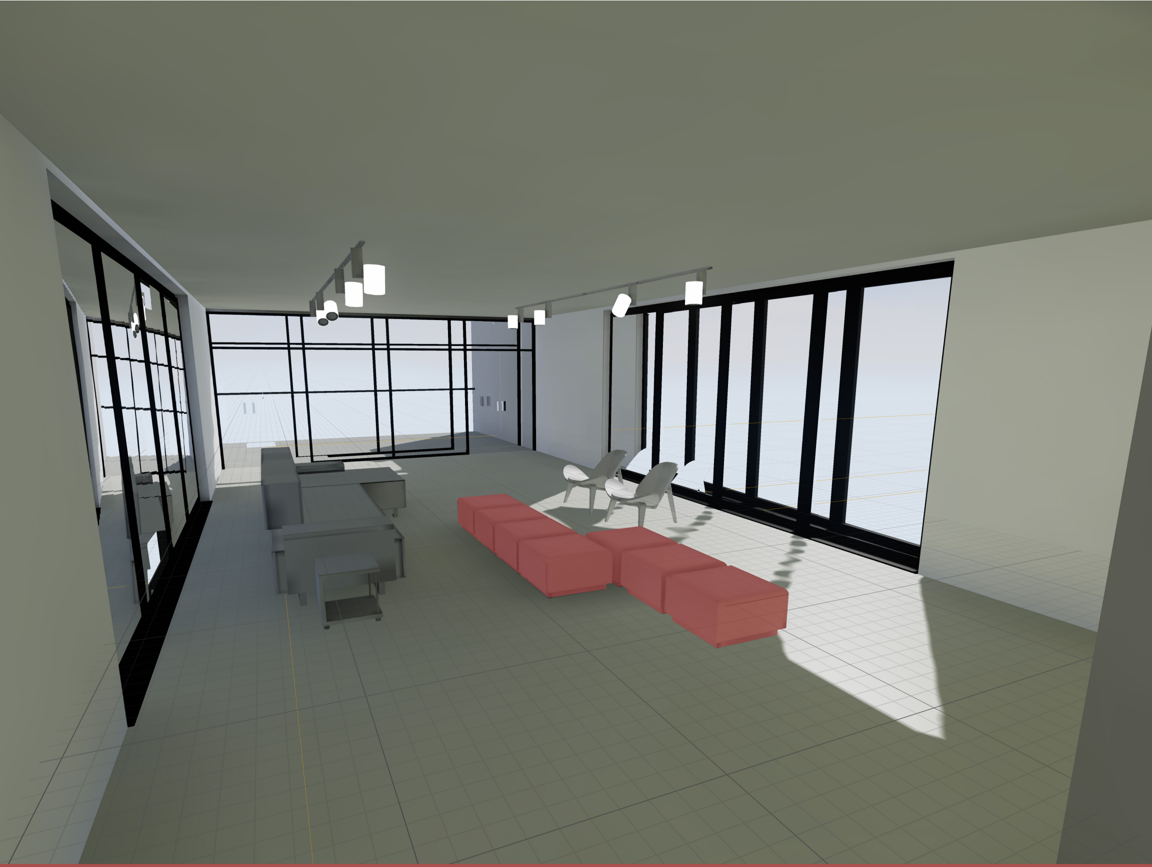

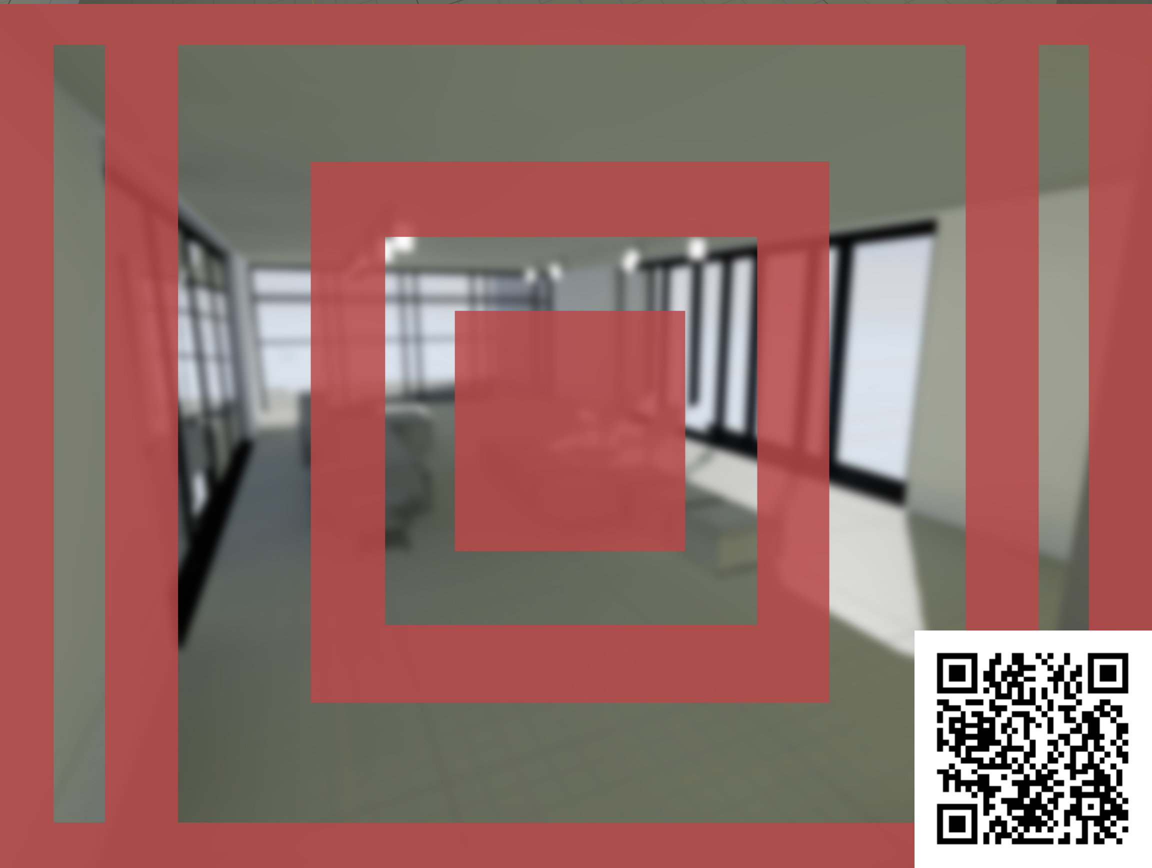

## User Response

Participants explored a virtual environment initially without any visual obstructions, once the participant developed a sense of spatial orientation their view was obstructed. Blurring out majority of the HMD screens to simulate a peripheral vision made participants experience the space at a much slower pace than before. Majority of participants utilized different shades of color and object forms to orient themselves within the peripheral experiment and navigate through the virtual environment. Unfortunately, participants explained the experience and inability to focus on details within the space began to give them a headache or motion sickness, testing then concluded due to health risk issues.

Experiencing the same virtual environment with only focused vision created a more sporadic experience for participants. Participants were observed to be frantically spinning shaking their heads to find details to orient themselves. Navigating the virtual environment became exceedingly difficult as participants would sit in the same spot for minutes trying to orient themselves, moving only when a good mental image of their current virtual environment was created. Testing one's peripheral and focused vision emphasized the necessity of having both visual cues available while navigating space; however, navigating the space was still possible, just more difficult. Unknowingly this experience became a model of empathy as the simulation was described to emulate visual impairment such as cataracts or glaucoma.





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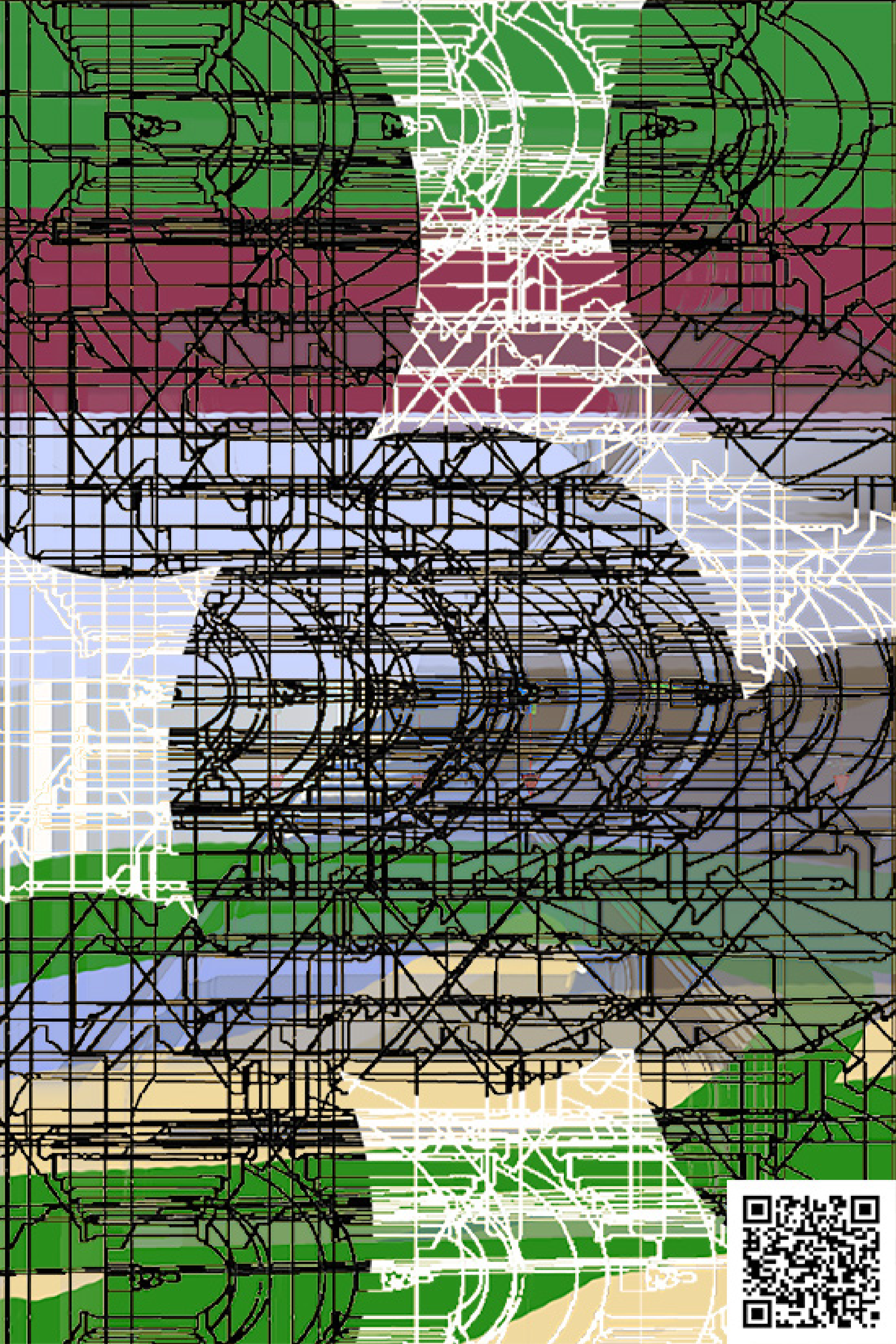

## False Perspective

Tricking one's vision to perceive things the virtual world as real is the main illusion of virtual reality. Introducing other optical illusions within a virtual environment emphasize the realistic qualities of virtual reality as illusions are common knowledge in the physical world. Testing how illusions are perceived in virtual environments became the aim of this experience. Recreating Francesco Borromini's Palazzo Spada illusion in Rome to scale, allows users to experience a large illusion that is known for tricking an observer's perception. Only one participant can experience this virtual environment at a time so a series of 6' – 0 "tall interactive blocks were placed in the experience. The interactive blocks allow the user to create scalar references throughout the virtual environment by placing them along the wall at various points within the interactive illusion.

## User Response

Perceptually the Palazzo Spada is viewed as a 37-meter-long gallery, as individuals traverse this gallery the slowly compressed in on them, proving to be only 8 meters long; the statue at the end of the gallery appeared to be large in the context of the gallery begins to shrink to a 60 centimeter tall figure. Participants experiencing the Palazzo Spada in virtual reality explained the virtual environment was convincing and accurately mimicked the illusion of the real gallery. A participant who has visited the Palazzo Spada in Rome before compared the two experiences.

> "The real Palazzo Spada is much more convincing due to the materiality and design detail etched into the surface; however, I was surprised with how well virtual reality was able to capture the illusion that Palazzo Spada creates."
> – Noah Resnick Master Thesis Professor/Advisor UDM-SOA

Virtual Reality proved that replicating illusions from the real world with no distortion or flatness is possible in a virtual environment. Maintaining spatial immersion within the experience once again was amplified by participant's ability to pick up and move objects within the space.

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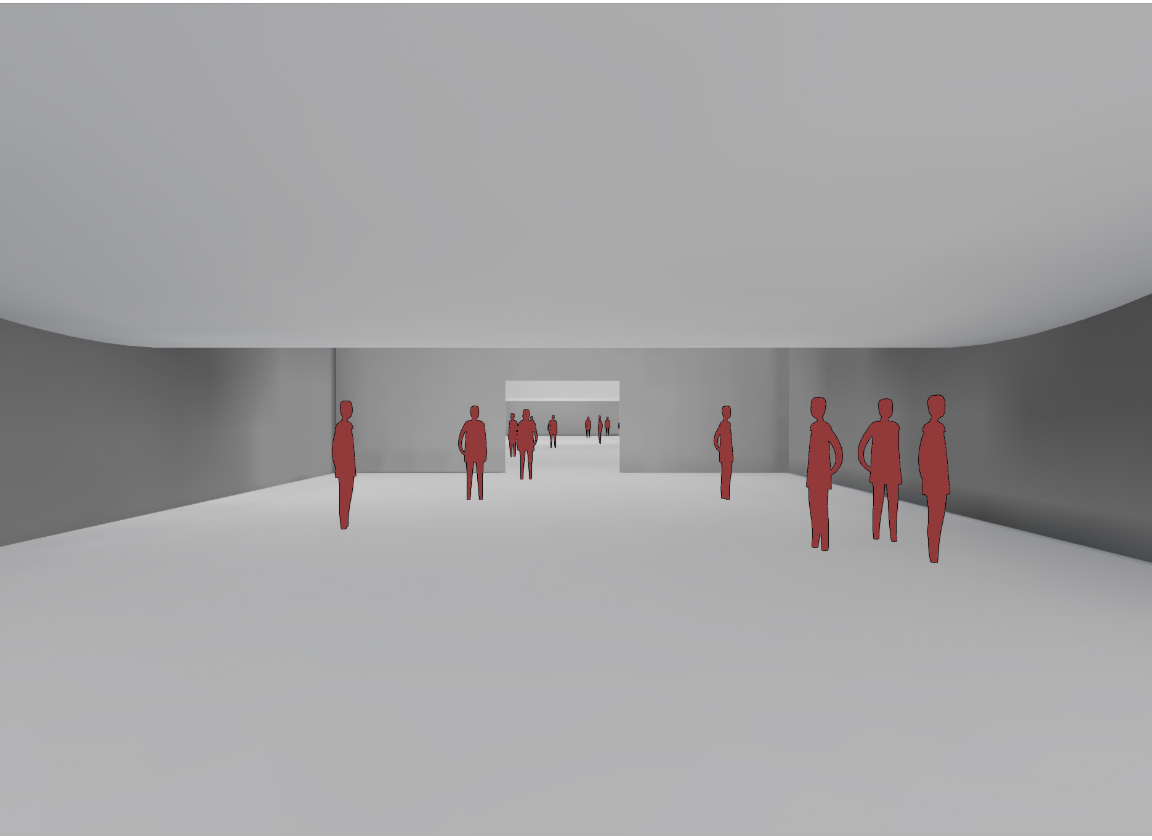
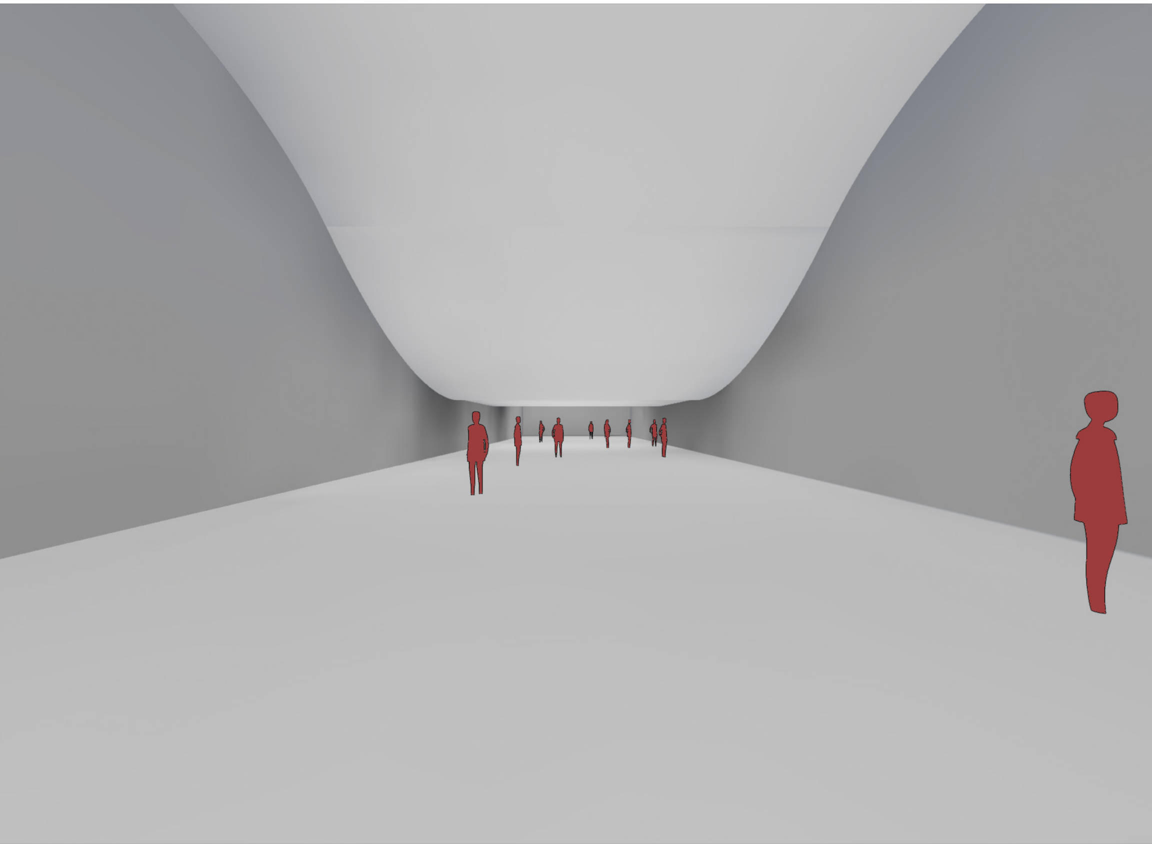


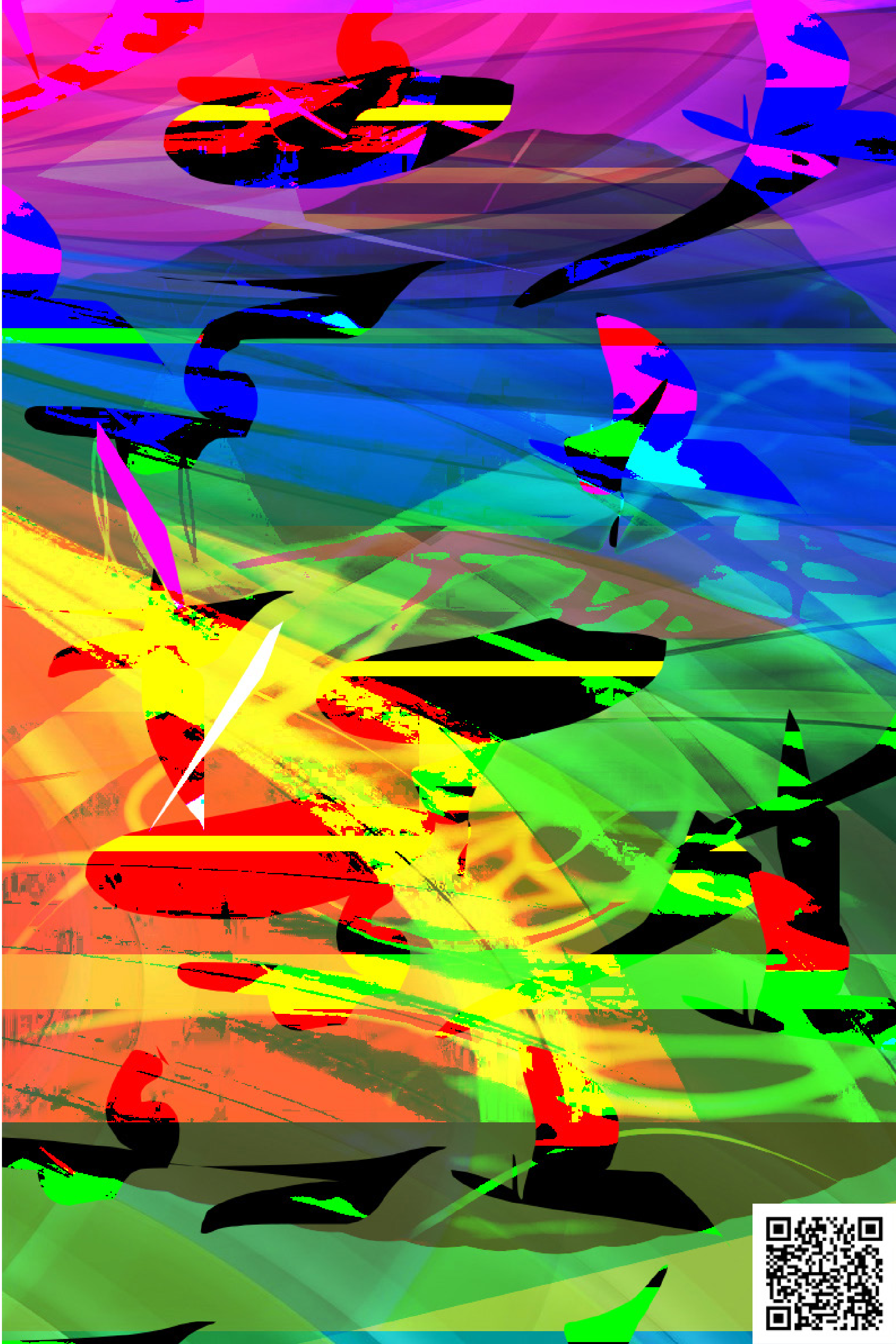


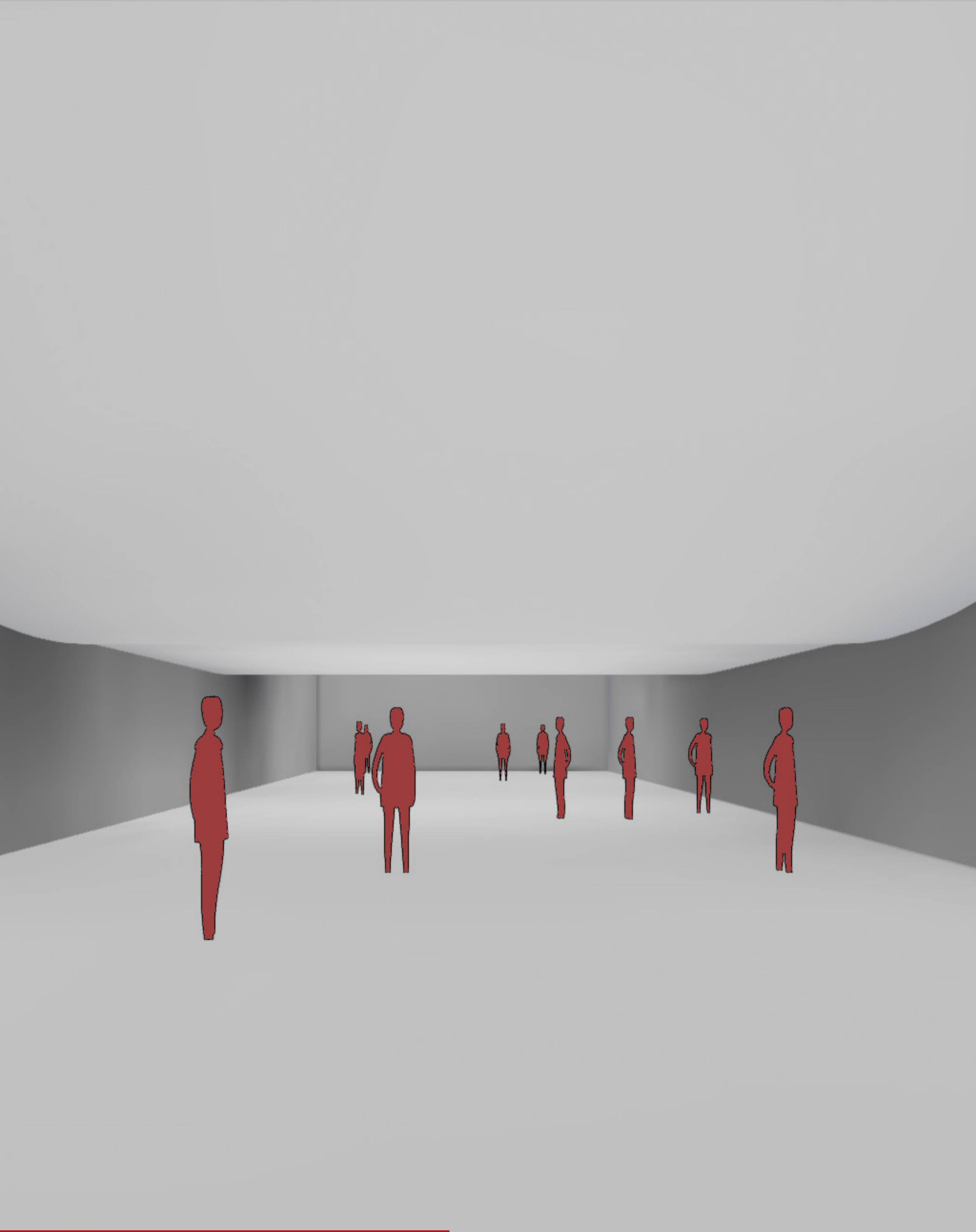
## Curved Ceiling

Individuals in space make relationships with all objects around them, these relationships become apparent when an individual recognizes or thinks about the object. Common experiences like walking through a threshold or sitting down at a desk changes the relationship the individual has with the object. Exploring this concept in virtual reality, a curved ceiling was modeled and placed within a virtual environment. Significant ceiling heights changes within the environment in collaboration with human mannequins located on the ground attempt to visualize the scalar relationships that individuals make with objects. Although the virtual environment is shaded in grays it is expected that a sense of presence and immersion will be expressed in the virtual environment due to the distraction of the ceiling and thought process behind understanding what is happening.

## User Response

Participants approached the experiment initially at eye level, traversing the space without looking at the ceiling or anything above their eye height. After inspecting the mannequins and crossing the middle threshold into a separate room is when Participants noticed the vertical changes happening in the ceiling. Located behind the middle threshold the ceiling compresses into a flat plain eventually curves upward creating the illusion that there is no apparent end to the ceiling. Participants began cognitively changing their location in the virtual environment to experience a multitude of ceiling heights, explaining that the experience was interesting because the mannequins are experiencing space in a different way than the participant. Through the compression and release of the ceiling, users were observed creating new relationships with the ceiling at different heights often standing still and shifting their vision to a mannequin and comparing the spatial appearance of the two areas. Participants explained that they would have forgotten they were in virtual reality if the space had been textured with realistic materials, but once they began interacting with the illusion through the ceiling the space became more immersive and could be worthwhile as a social experiment.





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**Redirected Walking**

Locomotion within virtual reality has been limited to a 15 x 15-meter walkable space and the ability to 'blink' from one place to another. Limiting virtual reality to an unnatural way of movement within a virtual environment. Google and the University of Minnesota have identified two significant walking methods and suggestions for a third that allow for a more natural experience within the virtual environment.

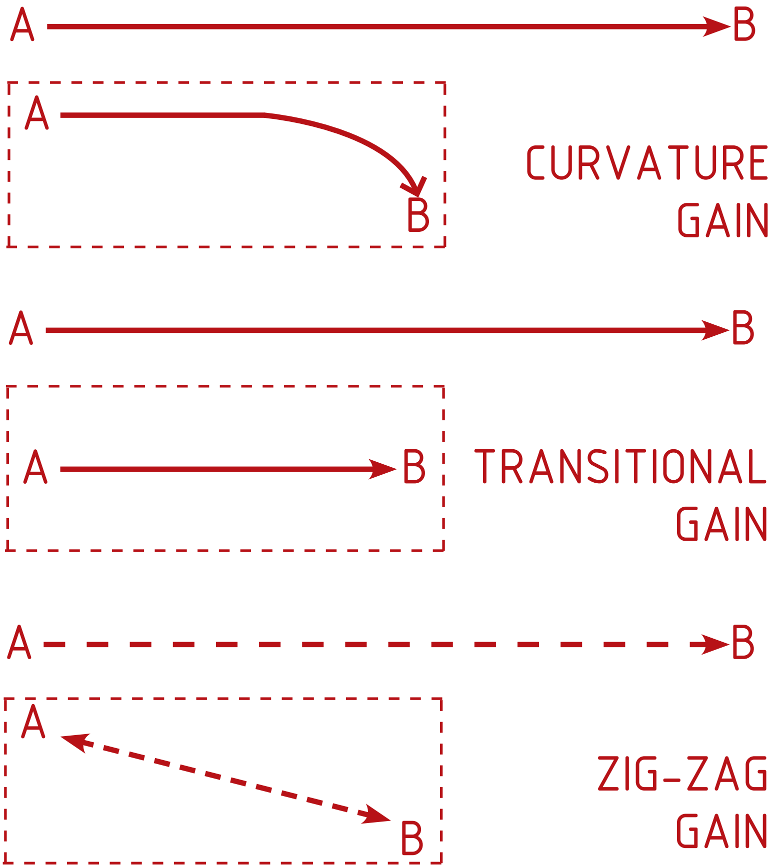
1. Curvature Gain
   a. Walking from A to B in a mapped-out area with a slight curve, translating to a long-distance walking path in virtual reality. Achieved by rotating the camera in virtual reality slightly per step, forcing the user to correct the camera and walk straight in virtual reality; while unknowingly curving the walking path in the real world.
2. Transitional Gain
   a. Walking from A to B in a mapped-out area in a straight line, translating to a long-distance walking path in virtual reality. Achieved by for every one step taken in the real world the user would walk 3-5 steps in the virtual world allowing 3-5x more distance to be covered in the virtual world.

Analyzing and combining the principles from the two methods above a third method was suggested, playing with camera rotation and reducing the number of steps that happened within Transitional Gain one could achieve a continuous walking path in any direction without the limitations of the 15 x 15-meter space.

3. Zig-Zag Gain
   a. Walking to and from point A to B in a mapped-out area, once the user reached point B they would turn 180° and walk back to point A. Traversing a 1:1 step ratio with that of the real world; however, when the user turned 180° the virtual reality camera would turn 360° so that relatively straight path can be maintained in virtual reality.

### User Response

Participants were tasked with walking from a sphere to a cylinder on the opposite side of a room, the distance between the two objects was far greater than what both Curvature Gain and Transitional gain. Utilizing Zig-Zag gain participants walked back and forth within the limited space where motion tracking occurs. Other than getting dizzy and a little motion sick, all participants completed the task and agreed that walking in virtual reality would be more preferred than teleporting via 'blinking'.




## Natural Light

Virtual Reality can be programmed to experience situations that are not realistic in the real world, one such anomaly would be experiencing the length of a day in a minute. By altering the sun within a virtual environment one can speed-up and slow down the length of a day within virtual reality testing the natural light quality that enters a space. Participants control the angle of the sun in relation to the given time of day, allowing for real-time feedback of how the light/ quality of light can alter a space. Design can benefit from such an experiment by avoiding conflict in design and suggesting solutions to enhance the comfort of a space by experiencing it first in virtual reality. Ultimately, the Natural Light experiment was designed to be a tool for architects and designers to aid in the schematic and programmatic portion of building design. Regretfully, the experiment was never tested; it can be hypothesized that the experience would aid the design process of any given building design and become a tool for visualizing spaces so that they can be designed with ideal lighting conditions in mind.

CHAPTER iii
# Conclusion

Virtual Reality is a considerably new technology making a statement in modern society, as an advanced form of representation and communication virtual reality creates immersive environments that personify simulated experiences. Limited only by the creation of the intended virtual environment, almost any experience can be recreated and emulated in virtual reality. Collaborating with a multitude of practices and professional fields virtual reality holds merit to educate, train, and prepare individuals for high-risk situations through simulation. Architecture can benefit from utilizing virtual reality as a software tool. Visualizing space and impossible situations in virtual reality allows architects to see design at a new angle, possibly leading to more cohesive design interventions within the real world. Virtual Reality may not be an end all be all for the architecture field, but it cannot go unnoticed and should be monitored and utilized when necessary.

**“People do not learn knowledge, they only apply it. They fail to understand what it truly is.”**
**-George Stubbs**

## Bibliography

Bertol, Daniela., and Foell, David., Designing Digital Space: An Architect's Guide to Virtual Reality New York: John Wiley & Sons, 1996. Print.

Cliento, Karen. "Renderings versus Realized." ArchDaily, 31 July 2010, www.archdaily.com/71402/renderings-verse-realized. Feb. 2017. Web.

Lewis, Paul, et al. Manual of Section. New York, Princeton Architectural Press, 2016. Print.

Luckiesh, Matthew. Visual Illusions, Their Causes, Characteristics and Applications., TheClassics Us, 2013.

Mestre, Daniel R. "Immersion and Presence." University of the Mediterranean. 2005. Web

R., Vitruvius Pollio. S. E., and M. H. Morgan. Vitruvius: The Ten Books of Architecture: New York: Dover Publications, 1960. Print

Sheer, David R. "Architectural Drawing: A Prospective Requiem." Acadia, 2011, acadia.org/papers/E7Y6ZP. Web.

Sherman, William R., and Craig, Alan B., "Understanding Virtual Reality – Interface, Application, and design" Morgan Kaufmann Publishers, USA, 2003. Print.

The Merriam-Webster Dictionary: International Edition. Springfield: Meriam-Webster, Incorporated, 2004. Print.

"Understanding Architectural Drawings: a Guide for Non-Architects." Visualization Insider, vol. 31, no. 05, Jan. 1994, doi:10.5860/choice.31-2474. Web.
Unity., Unity Developer 5.6 Documentation: Unity. Feb.2017. Web.

Unreal Engine., Unreal Engine 4 Documentation: Unreal Engine.Dec.2016. Web.

Sherman, William R., Craig, Alan B., "Understanding Virtual Reality – Interface, Application, and design" Morgan Kaufmann Publishers, USA, 2003. Print.

Whyte, Jennifer. "Virtual Reality and the Built Environment, Oxford: Architectural, 2002. Print.

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