Physical to Virtual: A Model for Future Virtual Classroom Environments

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A Thesis Presented

By

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DEDICATION

I dedicate this prose to Dr. Jordan B. Peterson, the man that opened my eyes to my potential.

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ABSTRACT

PHYSICAL TO VIRTUAL: A MODEL FOR FUTURE VIRTUAL CLASSROOM ENVIRONMENTS

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Virtual reality is a technology that has seen unprecedented growth since the turn of the century with increasing applications within business, entertainment, and educational applications. As virtual reality technologies continue to develops and markets expand, the world may see an increased demand for virtual classrooms: virtual environments (VEs) that students may access through immersive virtual reality technologies to receive guided instruction, conduct simulations, or perform tasks typical in a classroom setting. While many studies document how virtual reality is beneficial to educational processes, there is little discussion on how virtual environments should be architecturally designed. Thus one may hypothesize that physical design strategies translated to virtual environments may have similar results. This thesis investigates virtual environments for education by creating several virtual classrooms embedded within a selective digital twin of the University of Massachusetts Amherst campus. The design of the virtual classrooms was influenced by current architectural trends in classroom design while capturing unique abilities present within a virtual context. A physical teaching module was also designed to create a platform for educators within the university to deliver instruction within the virtual campus.

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CHAPTER 1

INTRODUCTION

The classroom remains an archetypical architectural space that is highly debated within contemporary society. The act of conveying knowledge, skills, and values between individuals and between generations is a ritual of immeasurable importance, yet many debate over the qualities that encompass proper education. Conventional standard public education models, such as chalkboard lectures, remain the norm for many colleges and universities. The heritage, basic skill set, and accessibility of traditional education establish it as the primary model. However, as technology has progressed, many universities incorporate advanced displays, audio projection, and online video recordings with real-time broadcasting to support students within the standard model. Contemporary education has also begun to feature sprouting non-conventional teaching methods, such as Team-Based Learning (TBL), with great success. Despite the options present in the current education landscape, several factors limit the growth and progression towards improved educational experiences for students. One factor integral to all modes of education is the classroom environment.

School architecture and classroom environments are a commonality that every educator must utilize to deliver a lesson properly. Architecture is a silent but powerful force in education, for it molds the habitat of discovery and functions to support instructors as they engage with their pupils. The classroom represents an isolated space designed to minimize distraction and focus student attention on content. Technology is deeply integrated within contemporary educational practices; thus, it is essential to understand the relationship between technology and classrooms. A classroom provides the space for students and teachers, and technology adapts to the space to perform certain functions. For example, a display, simulator, or projector are standard nonverbal communication tools. Although a relatively simple technology, chalkboards have claimed their positions on many classroom walls for their utility and flexibility for required wall space. Ideally, students and teachers have a pleasant experience working with both space and tools. However, one should be aware that classrooms and technology operate in different temporalities: classrooms scale much slower than technology in terms of modifications and upgrades. The rapid advancement in support-focused technology available to teachers within the 21st century may be a dominant factor contributing to adopting new educational models and evolution in educational practices. As technology continues to advance, it will provide needed utility and flexibility for both students and instructors. The classroom environment is relatively static in its progression by comparison.

Suppose flexibility for educators to choose an educational model or the adaption of new technology to respond to a chosen model would improve educational experiences. In that case, the relatively static nature of classroom development is a core issue within the educational framework and for architecture as a practice. Thus, despite the availability of technology and the willingness of educators to adopt technology, the classroom environment may be a restricting variable. Many factors determine if an educator uses technology ranging from personal preference to the cost of integration to content availability. Current architects have developed innovative spaces to respond to the cultural shifts in education by creating dynamic environments that respond to changing needs while also featuring technology as a significant design influence. As the current capitalistic machine continues within the global economy, the price of the technology will inevitably decrease while performance improves to meet market demands; technology will continue to become more significant within future classrooms.

There are many efforts to close the gaps between integrating classroom and technology, yet the rate of technological development trumps the development of innovative classrooms. Thus, if an educator had a more flexible learning environment that could be adapted to suit educators and student's needs, it might be possible to see more extraordinary academic performance from students and an overall more positive attitude towards education as a whole. While many technologies exist to support teachers in contemporary classrooms, one technology has the most potential for this goal: virtual reality.

Immersive virtual reality is a unique technology that bridges the gap between the physical and virtual, allowing users to explore new spatial dimensions. The creation of such an environment is directly linked to the practice of architecture. By default, the design and development of classrooms are inherently intertwined with architecture and the organization of space. Thus architecture becomes the common element between virtual worlds and functional educational spaces. The following document explores how virtual classrooms: virtual environments accessed through virtual reality technology, can be designed to support educators and promote student development. Through an architectural design process, a virtual environment will be designed within a digital twin of the University of Massachusetts, Amherst. This project aims to create successful virtual classrooms where students worldwide have access to classroom resources, granted they are provided the proper equipment. The design of virtual spaces will attempt to capitalize on virtual reality capabilities while maintaining a grounded experience to enhance immersion. Most importantly, this report will attempt to translate modern classroom design strategies to virtual classrooms. A physical design will also be addressed to facilitate educators at the university to teach within the virtual environment. This approach to virtual classroom design is a preliminary exploration, for the design nuances and distinctions between virtual environments and physical architecture have yet to be understood thoroughly.

CHAPTER 2

BACKGROUND

Virtual reality is a medium that has seen rapid growth in recent times due to increased investment, the availability of affordable hardware, and more powerful graphical capabilities embedded in modern computers. While many associate virtual reality with entertainment ventures such as video games, it has seen application in various fields. Within a broad educational context, virtual reality has been used to train NFL players, pilots, and surgeons aside from typical students. VR has been integrated into classrooms with new instructional packages such as the *ClassVR* that allows for accessible visualizations embedded into standard lesson plans. Virtual reality involves an individual inhabiting a virtual environment (VE) through an immersive experience that simulates a tangential reality apart from physical reality. Immersion in VE's is created by rendering the properties of various materials common in reality such as wood, metal, or brick onto 3D models and simulating physics in day-to-day situations. Rendering simulations combined with visual equipment create displays that encapsulate both direct and peripheral vision. Other senses can also be stimulated within a virtual environment but require different technologies.

People inhabit VEs with avatars, 3D models that represent the user. An avatar is a vehicle for an individual to explore a virtual realm. In typical virtual environments, an individual can explore a virtual world from a third-person perspective, such as viewing a 3D model from their computer screen. However, the difference in experience with virtual reality is a heightened degree of suspension of disbelief due to more robust immersion techniques. Immersion is the critical mechanism that enables VEs to fulfill their true potential and will be discussed further in section 2.2. After adapting to a VE, it is common for users to detach themselves from physical reality with the suspension of disbelief. Users act as if their virtual avatar is a one-to-one embodiment of their physical body instead of an extension. Those who have not experienced the technology firsthand may find it challenging to comprehend how a computer interface could be immersive. However, there is reassurance that the VR experience is similar to one's normal perception within physical reality.

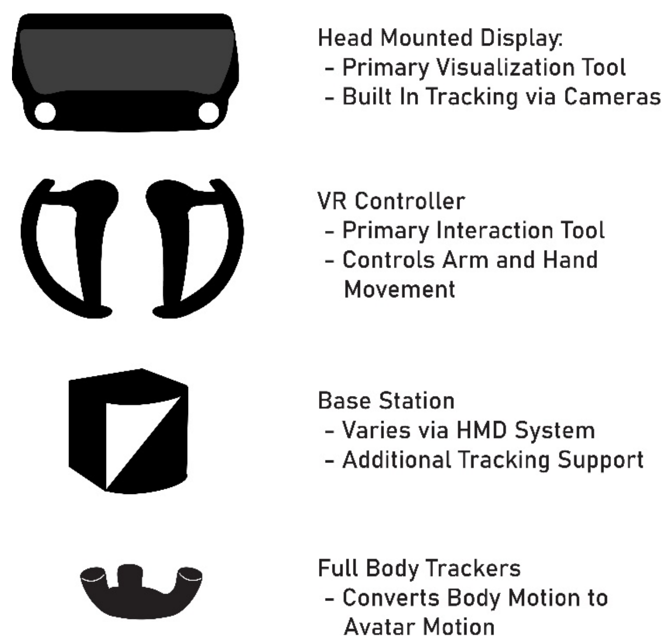

Figure 1: Common HMD immersive VR equipment available to the public. Figure by author.

Aside from immersion, virtual reality differs from other forms of representation since it allows users to interact and manipulate their environment. Individuals act as they would in a VE as they do in a physical environment. Occupants use their arms and hands to move objects, their legs to approach objects and move from place to place, and other body parts to initiate a sequencing of actions. While many are skeptical of the technology, once given time to adapt to the medium, people exhibit an intuitive understanding of VR since its parallel to how we experience physical reality. However, motion sickness is reported to be a shared experience for first-time VR users if one does not adapt to the medium properly (Thompson 2020). Current trends are projecting that virtual reality will become a mainstream medium, although it is still somewhat niched currently

(Roose 2020). Regardless, many echo the potential for VR along with a similar form of representation: augmented reality.

Augmented reality (AR) technologies have also seen tremendous growth in recent years alongside VR applications. Unlike a VR experience where one is completely immersed within a virtual context, augmented reality uses physical reality as an environment to host virtual objects. For example, if one were to stand within a field with their smartphone, an AR application would use the camera and other sensors to project the image of a virtual object overlayed onto the field as if it were physically present. AR is "a technology that 'presents a virtual world that enriches, rather than replaces the real world (Bryson 1993, 56-62)' " (Mazuryk and Gervautz 2014, 3). AR, like VR, has been used to a great extent within the gaming industry. Pokémon GO, an AR phone game, broke many records with its popularity, reaching 4 billion USD in revenue (Ramasubramanian 2020). AR also has practical applications as an interactive display to display instructions, data, or information for physical objects. AR within construction has been used as a clash detection mechanism and integration aid (Jacobson and Dray 2021). AR does not qualify as an immersive virtual reality experience, although it uses a similar technology to produce its effects. Since AR relies on physical reality to create the environment, it will not be focused on this document. Regardless, AR is another powerful representation tool that has great potential to be used within an architectural or building context.

While VR and AR equipment is a technological marvel, one may ponder the correlation between physical and virtual architecture and debate its relationship. The primary concerns of architecture address various challenges, including but not limited to the utility and aesthetic qualities of physical space. Shelter as a basic human need has led to the creation of built environments that have evolved with intellectual and technological progress. Throughout history, architecture and technology have always maintained a symbiotic relationship. As new technologies develop within a construction context, they are applied either as construction techniques, innovative forms, or materially. Technology segregated from construction still influences how people use space, creating design forces on architecture. The amalgamation of technology and architecture is an exciting relationship to examine throughout history; for example, as cars became mass-produced, there was a cultural shift to integrate car garages into single-family detached residences. As electricity was developed and became accessible for commercial and residential use, power outlets and electrical conduits were integrated into internal partitions.

One technology has differentiated the late 20th Century from any other period in human history: the internet. Since its advent, the internet has been a force that has shifted the cultural norms of contemporary society. People have access to limitless information and communication potentials. Libraries were the first architectural spaces for the public to absorb mass information; this function has now mostly transitioned to virtual space due to accessibility. While the internet itself has not directly influenced architecture, many secondary technologies that rely on the internet have their influences. The internet has been a catalyst for construction and the growth and development of businesses and e-commerce needing flagship storefronts. The internet has also led to improved collaboration between designers allowing for more ambitious projects. Architects, clients, project managers, and consultants engage in unprecedented discourse around design, integration, and production. The internet has become a great tool in many industries, leading to a paradigm shift in cultural development and progress.

Education, like other industries, has been deeply affected by the internet, influencing elementary school to college-level courses along with the daily lives of students. First, to establish a sample size, according to the National Center for Education Statistics, approximately 56.6 million students have attended elementary, middle, and high schools across the Unites States and 19.9 million students in institutions of higher education ("Back to School Statistics" 2019). Another report from the National Center for Education Statistics approximates that 91.6 percent of children ages 3 to 18 had internet access at home in 2016 and 93.9 percent in 2018 ("Digest of Education Statistics" 2019). These statistics demonstrate that the majority of students use the internet or media involving the internet. Even without internet access at home, students can access the internet via school networks, libraries, or other public terminals.

> "We live in a world that is becoming more networked every day, and the internet has grown into an essential medium for communication, socialization, and creative expression. Virtual worlds like Second Life represent the future of human interaction in a globally networked world, and students who have grown up with the Internet naturally swim in these waters" (Michael Rymaszewski et al. 2007, 318).

Unlike previous generations who have experience with and without the internet, the internet has ingrained itself into our culture to the point where pre-internet generations voluntarily embrace the internet, and post-internet generations have it fully integrated into their lives. It is almost inevitable that children raised in current and future generations will have the internet integrated within their education. From an economic point of view, it may be necessary for children to develop essential competencies with internet-based technologies to succeed within the job market.

To demonstrate how the internet has become ingrained with day-to-day life, a Nielson Company audience report from 2016 determined that adults in the United States consume virtual media on average approximately 10 hours and 39 minutes each day ("The Total Audience Report: Q1 2016" 2016). The range of media in this report varies from tablets, smartphones, personal computers, multimedia devices, video games, radio, DVDs, and TV. In the previous year, 2015, the report states that people spent about 9 hours and 39 minutes engaging with online media, implying an increasing trend in consumption. Another report from the Nielson Company claims that 4 billion people are connected to the internet, and nearly all 92.6 percent use mobile devices. The report states that 85 percent of users (3.4 billion people) connect to the internet and spend an average of 6.5 hours online per day ("Connected Commerce" 2018). Modern citizens have become well adapted to new technologies and media; thus, virtual reality may be considered another medium incorporated into this internet-focused culture.

The internet and its ability to host VEs have led to the creation of new communities formed online. Examples of VR platforms include *VRChat* and *Second Life,* where communities create and share VEs to serve various purposes. Some VEs on these platforms are dedicated educational causes, teaching sign language, mathematics, and scientific theories, while others for relaxing and business. If an increasing population use VEs and form from online communities or new classroom developments occur as a result, then architecture and interior design will play a significant role in the proper design of a VE to maintain users' health and well-being.

If the internet and current technology can propel virtual environments into sophisticated tools for education, there are many questions to address on user experience. For example, the potentialities within a VE allow for fundamentally different experiences compared to physical reality. Users may teleport to cross long distances with ease within a VE or walk on ceilings if programed correctly. Would the freedom to create new spatial experiences be helpful to the educational process? Perceptions can also be altered, manipulating how one experiences a space through filters or segmented sequencing. How do these variables impact immersion within VEs, and do they promote beneficial effects over long-term adjustment? With the increased accessibility of virtual reality with more affordable technologies, is it possible to consider a future in which more individuals spend more time within VEs? Thus, how should virtual environments and virtual architecture respond to a future where VR is a typical application and people spend an increased time within virtual space?

2.1 Is Virtual Reality Real?

> "Without a subject, nothing at all would exist to confront objects, and to imagine them as such. True, this implies that every object, everything 'objective' -- is being merely objectivized by the subject – is the most subjective thing possible."
>
> Medard Boss, Phenomenologist (Boss 1958)

In contemporary fiction, such as the novel *Ready Player One* by Ernest Cline, large audiences are exposed to the ideas of virtual reality through the main character Wade Watts and his adventures within virtual space. Within *Ready Player One*, VR technology is a mechanism to transport users to "The Oasis": a virtual universe where people perform educational, work, or entertainment-based ventures. Among many of the book's themes, one consistent parallel is the relationship between virtual and physical worlds. Virtual reality, in the book, is an enhanced version of physical reality where users have limited access to the unlimited. VR is used as a means of escapism for the public within the novel, a distraction from physical reality, a temporary solution to real issues. *Ready Player One* juggles its stance on this position until its conclusion. Wade is presented with a button that, when pressed, would effectively remove VR from his physical reality and consequentially strip humanity from accessing the virtual. Wade does not ultimately use this kill switch, in the end, implying that a healthy integration between virtual and physical is an ideal outcome for a world where physical reality has supplemented virtual reality.

Since the birth of consciousness, humanity has thrived to contend with physical reality and has expressed this engagement through books, prints, drawings, and other representation tools. One may say that representations were developed to enable humanity to record and convey information that we deemed valuable and essential. Technology has solved many fundamental problems for humanity and has also allowed us to innovate on previous forms of representation. Unlike other forms of media, virtual reality features the word 'reality' within its name, suggesting it is a form of representation that transcends others with its ability to represent reality or features another dimension of reality altogether. This raises a question about the nature of representation: is the goal of representation to express one's perception of reality? However, virtual reality also features the word "virtual," implying a fakeness or untruthfulness to its representations or an infinite or imaginative characteristic. As a result, some are dismissive of the technology. Section 2.2 will address these concerns in more detail by defining virtual reality more thoroughly; however, it is crucial first to understand what constitutes something as "real."

While the topic of what is 'real' and what is 'not real' can be considered an infinitely vast debate deeply rooted in philosophy and psychology, this section will provide a framework to create a general understanding and establish a position to move forward. While philosophers and scientists have attempted to define reality, it is almost an impossible venture because humans have limited knowledge and limited potential. Therefore, our conceptions of reality are built upon a set of assumptions, axioms, and platitudes. These assumptions and axioms range from low-resolution generalizations to high resolution and specific within a small domain. These assumptions carve order within a chaotic universe and are incomplete because they lack the complexity needed to encapsulate the fundamental nature of reality itself.

An example of this can be seen in the frame problem. As computer scientists discovered more about artificial intelligence, a common assumption was that the primary difficulty would be creating advanced algorithms and the hardware to support the technology. However, before they could approach this issue, they needed the computer to interact with physical reality. Contrary to their first assumption, it was no simple matter to program a computer to interpret objects and their differences (Shanahan 2016). This proved that our common interpretations of perception are far more complex than initially assumed.

One may begin with their questioning of reality by asking what the world is made of. Our immediate senses such as vision, taste, touch, smell, and sound and our emotions create an initial reference that forms a most immediate reality. From an extension of our senses, people begin to formulate perceptions of objects in space. During Antiquity, the Greek philosophers Leucippus and Democritus first stated the world was made of matter (as metaphysical substance) through the Atomist Doctrine, which stated the world is made of atoms (separate substances) and voids (space) (Berryman 2016). This is a common interpretation that has remained with humanity. Teachers often use this frame of view as a basis to teach physical sciences. However, this assumption leads to further complexity. If the world is composed of substances and space, then the position of matter within that space creates a new third entity: information (Klee 2015). Thus, one could say the "world is made up of information just as much as it is made up of matter or space" (Peterson 2014a). Information is not only limited to the identity of objects and their locations, but also includes the relationships between objects as they interact, their history, and their potential future.

With matter (substances), space, and information composing our reality, our perspectives can be divided between a general Newtonian or Darwinian perspective. Newton declared that the world operated like a deterministic machine, similar to a grandfather clock that would accurately predict the time through careful calibration of gears and pullies. If one understood all the information, matter, and space of the world (often through mathematical expressions), theoretically, one could predict the future since every sequence could be determined based on calculation. The Newtonian or materialistic perspective was influential to the advancement of science and technology, for it "enabled us to specify the structure of certain elements of the world, and we've learned to predict and control it to some degree" (Peterson 2014a). However, the Newtonian perspective was later dismissed by scientists since it was discovered that our reality has tangencies that are inherently unpredictable and do not fit under this assumption. If our reality is not ultimately deterministic, then there is no singular truth representing the nature of things but rather a conglomeration of partial truths that humanity must discover and rediscover as time progresses. Another flaw of the materialist view is that it does not determine how a human being should act within the world within morals or ethics; instead, it is a mode of pure objectivity as a description of reality. While understanding how reality functions is essential to interacting with reality, humans inherently wish to understand what actions they must take to properly influence the world—religion, and cultures from past to present to rectify this boundary.

Table 1: Perspectives of Reality Organized by Category. Adapted from the source lecture slides: (Peterson 2014a)

Newtonian	Darwinian
Objective	Phenomenological
Objective	Subjective
Materialistic	Mythological
Scientific	Moral

Contrary to the Newtonian perspective, the Darwinian perspective states that people are fundamentally bound to identify what is most real by what is useful for survival or what is potentially harmful. This can be relayed to the conceptualization of partial truths, implying that many partial truths compete against each other to form our impression of reality. The Darwinian perspective reflects on the evolution of reality in terms of birth and death. Organisms, cultures, and ideas perish if they cannot be supported or adapted to the continuous change of reality. Thus like biological genes that evolve through mutation and natural selection, so do ideas through memes in our culture. One can see this transition from Structuralism into Poststructuralism into Deconstruction with Jacques Derrida's criticisms (Fry 2009).

Recording conscious thought has allowed humanity to transcend past other forms of life via information pathways that embody experience, even if these recordings feature a mixture of truth and nontruth. We value the histories and stories of our past, for it informs us how we can approach the future based on the success and error of our ancestors. Thus we find history inherently valuable. Therefore people have been producing representations of ideas and symbols since our consciousness was conceived as a means to guide future generations or other motivations. In a sense, the information coded in these representations is a manifestation of what is 'most real' since people's actions reflect what they believe is most real. Existentialism is a philosophy defined by a person’s actions as a reflection of what they believe is “most real” (Crowell 2020). If one were to live by falsehood or ignore the information passed on from their culture, it is more probable that they would perish through a Darwinian lens. Therefore, it is in people's best interest to make correct assumptions of reality so they may prosper. An extension of the Darwinian perspective is phenomenological interpretations of reality.

The phenomenological frame of reality is complex since its primary axiom dictates that people as individuals define their subjective reality. For example, if there was a chair within a room, its shape may continually transform depending on the angle one views the object, which can be infinite in variation. Another example is if one were to enter a room, there are theoretically millions of things that could potentially grab one’s attention. If one were to observe a floorboard, one might look at its texture, color, indents, etc. This could be said about all things in the room; however, people do not behave in this manner. If one were to make a representation of the floorboard through a drawing, one would face a significant challenge: how does a person represent something infinitely complex with attributes such as scale (visibility resolution), temporality, and other non-objective or implicit qualities of an object. Thus to make a representation, one must ignore information and present other information, creating a value hierarchy for that individual. A frame is placed around the area of reality that is of interest. A person’s value structure determines what information is to be processed and what information is ignored. Thus, because people have different value structures, each person has a different view of reality inherently.

It is often believed that an algorithmic sequence is initiated to comprehend an object when people see an object. The algorithm flows as such: 1) there are objects in the world, 2) one sees the objects, 3) one thinks about the objects, 4) one evaluates the objects, 5) one decided how to act with the objects, and 6) one acts upon the object. However, this is incorrect; human and non-human neurological structures are wired to have multiple levels of interaction, ranging from reactionary to contemplative (Peterson 2017). This is why if we drop an object, we react to catch it before processing it in a more complex manner. This reflects phenomenologist Ludwig Binswanger's perspective: one detects meaning before object recognition. “What we perceive are ‘first and foremost’ not impressions of taste, tone, small or touch, not even things or objects, but meanings” (Binswanger 1963, 114). Humans are tool-using creatures and often identify objects with their potential to solve problems. Contemporary science attempts to strip the subjective qualities from our observations of the world to make objective claims in pursuit of truth. While this is unquestionably useful, it does not encapsulate the full nature of reality by ignoring the structures that make an experience an experience.

The ideas of phenomenology are not self-evident and may be counter-intuitive for people first pondering. In a sense, phenomenology states that our common day-to-day perceptions are an underdeveloped view of reality. Using Plato’s allegory of the cave, we see the shadows of more authentic reality, and we must not confuse our observations as the most truthful representation. The Treachery of Images painting by Rene Magritte in an image of a pipe with the caption “This is not a pipe.” The painting can be seen in Figure 2. While the image features a pipe rendering, it is not a pipe, simply a representation of a pipe within virtual space. The message addresses the irony between images and words. While we may view an image, that image itself is not what it represents, hence the caption “This is not a pipe.” The materials of the image create the representation. However, when we look at the image of a pipe, our first reaction is not to recognize the materials that create the illusion of the pipe first but, first and foremost, the idea of a pipe. We see a pipe. Plato would believe that the image of the pipe is akin to the shadows of the cave wall; however, even if we were to observe a physical pipe in our hands, that too would be a mere shadow as well.

Figure 2: The Treachery of Images by Rene Magritte. Image by the artist from source: (Magritte 1929)

However, there are times within a phenomenological experience where people within a cave see proper sunlight, continuing Plato's metaphor. For example, when discussing fantasies portrayed in mystical, fictional, or intangible representations, people state that they do not explicitly believe the ideas represented are inherently “real.” However, if one were to observe how people function and act in response to fiction or unreal ideas, they may demonstrate an implicit understanding of its underlying truth (Peterson 2014a). This explains why people are captivated by movies or immersive media, for these works contain high-level truths about the nature of reality that people subconsciously understand and are inherently find attractive. If representation does not represent this truth, audiences and viewers often implicitly dislike the representation's content. While fictional representations are not as complex as typically perceived reality, it portrays truth embedded within a more complex reality than steady-state awareness informs.

> “Did humans evolve to perceive reality? It depends on what you mean by perceive. Perceive might mean that we evolved mechanisms that allowed us to survive in the face of that reality. Yes. Is that what’s real? What enables you to survive in the face of reality? It’s a definition. Meanings are primary” (Peterson 2017).

If meaning determines how one perceives reality, a more significant issue emerges: what determines what someone finds meaningful? Ludwig Binswanger and Medard Boss disagreed on this point. Binswanger believed that one's history: biological, cultural, and individual colors one's perception of reality and what one finds meaningful. Boss, however, states that meaning is intrinsic to the object, and our perceptions sense the inherent meanings of the object (Peterson 2017). For example, if one were to examine a piece of beautiful architecture, is it one's history that makes the architecture appear beautiful, or the inherent beauty of the architecture that shines forth for one to perceive it as beautiful. Regardless of interpretation, another mystery involves the nonrandom nature of interest as unconscious forces that drives us; its origins are unknown. We understand that interest is nonrandom since schizophrenic people, by technical definition, have uncontrolled, random observations of meaning that call out for representation (sometimes in the forms of delusions) (Peterson 2017). Thus people's interests and what they find meaningful call out to them to interact with, but it is not under one's control. This phenomenon cannot be explained through a Newtonian, scientific view, for it is a problem outside of the scope of traditional scientific thinking. Like aesthetics and beauty, phenomena are a common element of reality but require a different interpretation to comprehend.

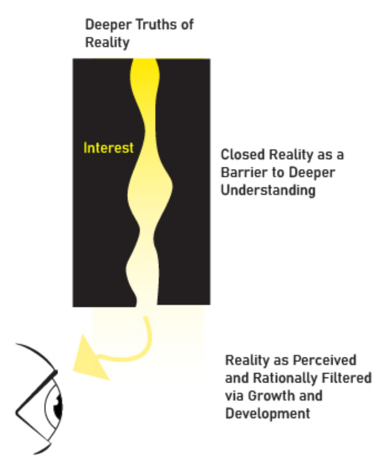

Figure 3: The phenomenon of interest expressed as phainesthai: the relationship between perceptions, reality, and how interest calls exploration of deeper truths while they may be hidden. Figure by author.

Fundamentally, virtual reality is defined by its nonphysical nature. Thus the first assumption through a Newtonian perspective would dismiss its significance as something that mimics physical reality but lacks one of the three fundamental elements that compose reality (information, space, and matter). Through a Darwinian perspective, or more specifically a phenomenological perspective, once people adapt to a virtual environment where their meaning perceptions may override their objective interpretations, allowing a suspension of disbelief and immersion, the mind accepts the virtual environment as a place to dwell with its own identity. A phenomenological perspective helps describe how and why virtual environments are significant and why people are captivated by them. One could argue that physical and virtual environments use the same perceptual systems that augment people within reality; thus, the experiential qualities of VR manifest it as an authentic experience.

Based on the infinite complexity of reality when it comes to objective and subjective characteristics all objects have, we can deduce that there are layers to which our perceptual resolution increases and decreases; based on the scope, we allow our perception. Figure 4 describes how the complexity of reality becomes contained when we are focusing or embedded within different frames. For example, a person existing somewhere on Earth would be represented by the far-left portion of the figure. A person within a house would move to the right. When a person is working on a computer within a house (maybe writing a thesis), they may occupy the center of the figure. However, within the virtual space, possibility and complexities reemerge. If a person is a backend developer for a website such as Google, there are many pockets of reality the developer could explore that are not accessible to a public client. Thus, with programming and digital creation tools, our perceptions allow for expanded complexity. Granted, no matter what strata a person may occupy, the infinite complexities of reality are still present. The figure is intended to represent a person's perception as they narrow the complexity of reality based on the frame they occupy.

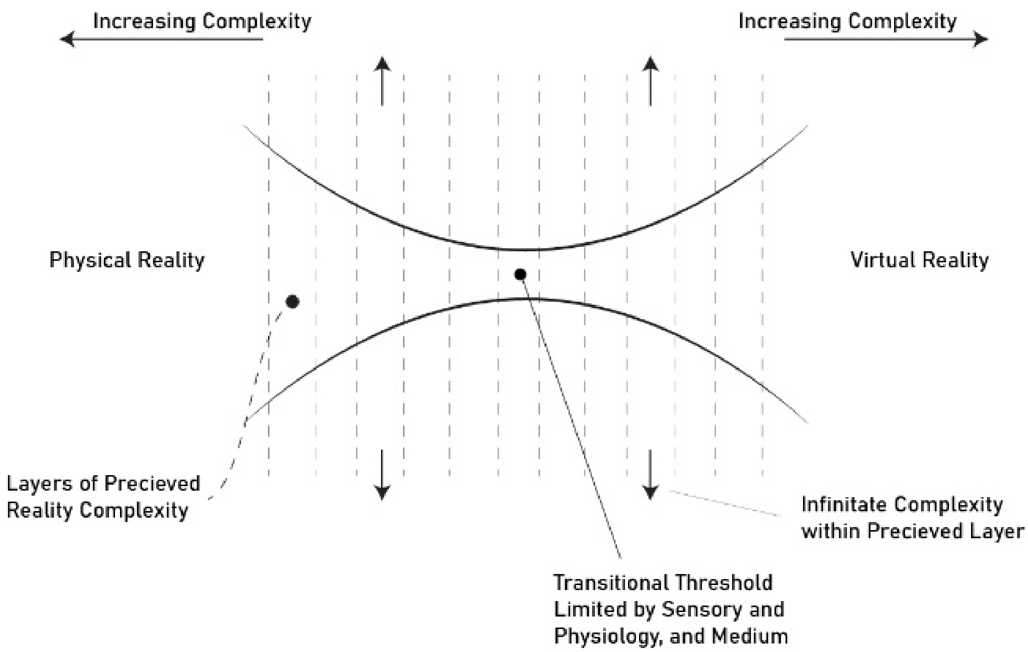

Figure 4: Perceived vs. actual complexity of reality from physical experience to virtual (digital) experience. Figure by author.

VR has opened the doors to many philosophical debates among questioning perception and phenomenological understandings. Thomas K Metzinger, a German philosopher, comments on ways that virtual reality is fascinating. He mentions how VR is related to the Lebenswelt (Life-world): a social world where people experience *togetherness* and numerous other phenological characteristics (Metzinger 2018). In terms of philosophy of the mind, virtual reality questions the themes of consciousness, embodiment, and bodily self-consciousness. In terms of epistemology, virtual reality is involved with amnestic re-embodiment, epistemic innocence, and personal identity. Virtual reality is also involved with new subfields such as digital aesthetics, contemporary philosophy of technology, media theory, action theory, and free will (Metzinger 2018). Overall, virtual reality has deep ties with social science, cognitive neuroscience, and experimental psychology aside from philosophy. Based on these connections, there is a high degree of parallelism between virtual environments and architecture. VR is embedded within a complex web of multiple dimensions that will continue to evolve as the medium develops. Ultimately, based on a phenomenological perspective, one could say that virtual reality is a *real experience* because the meanings presented through a VR experience parallel that of our lived experience. With this assumption, we can extrapolate that the phenomenology of physical architecture parallels virtual architecture.

2.2 A Comprehensive Definition for Virtual Reality

Because virtual reality is a medium that is still actively debated by philosophers and remains in relative infancy, a comprehensive definition of VR is challenging to pin due to its complexity and is dependent on context and application. The Webster New Universal Unabridged Dictionary defines the word virtual as "being in essence or effect, but not in fact" (Webster's 2003). Based on the previous discussion on reality, this definition is more situationally helpful. Webster defines reality as "the state or quality of being real. Something that exists independently of ideas concerning it. Something that constitutes a real or actual thing as distinguished from something that is merely apparent" (Webster's 2003). Thus if one were to rely on linguistic usage of the phrase *virtual reality* to form a definition, it would be incomplete and misleading.

Many forms of media and representation embody the virtual and can be classified as virtual reality. Giovanni Battista Piranesi was the son of a stonemason and master builder who trained to be an architect under the guidance of his uncle. Piranesi is remembered in contemporary circles for his series of illustrations: "Imaginary Prisons," where he contends with fantasy and virtual architecture (Dixon and King 2018, 252). Specifically, he imagines architecture of an evil aesthetic with nonsensical design patterns, such as pathways leading to dead-end walls. The virtual reality of Piranesi was expressed in penciled renderings shown in Figure 5.

Figure 5: The Well by Giovanni Battista Piranesi, the depiction of a prison. Image by the artist from source: (Piranesi 1749)

Images, in particular, are powerful in their ability to represent reality, for seeing is believing. The visual arts hold within a modern enlightened culture for their utility and accessible information pathways. Other forms of media, such as writing, create vivid images within our minds. The use of our perceptions is forever tied to how we generate representations. For example, in graphic novels, the juxtaposed sequencing of images activates gestalt psychology closure to create a sense of time progression (McCloud 1993, 67). Images and words can be compelling, for they bring us into a virtual world rich with detail. Although the ideas may not be physical, our reaction to the experience can be. In 1896 Auguste and Louis Lumière released *L'Arrivée d'un train en gare de La Ciotat*, a short 50 second film featuring a train pulling into a station. This film is associated with an urban legend: people who viewed the film were filled with terror as the train approached, for they believed the train would come out of the projector screen and crash into the audience. The reaction by the audience would have been an example of a phenomenological response.

While many understand the nature of media and technology after exposure, use, and application, there is little distinction between the image and reality for those whose experience is novel. We can see this effect in modern media as current trends demonstrate increased interest in photorealism as 3D technologies have boomed in recent years, allowing for believable virtual worlds. While understood as a medium, virtual reality evokes our sense to the point where its displays are compelling.

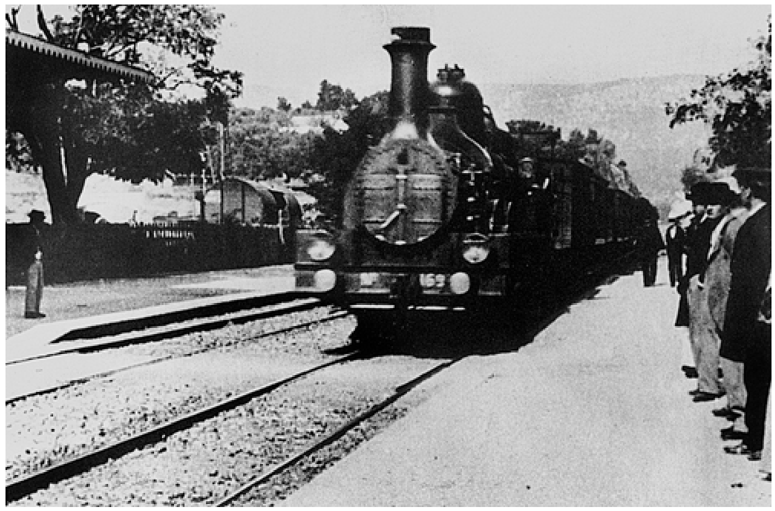

Figure 6: *L'Arrivée d'un train en gare de La Ciotat*. Film by directors. Screenshot by author from source: (Lumière and Lumière 1896)

The book *Understanding Virtual Reality: Interface, Application, and Design*, by William R. Sherman and Alan B. Craig, offers a definition involving four key elements that constitute a virtual reality experience: A virtual world, immersion, sensory feedback, and interactivity. Sherman and Craig define a virtual world with two definitions: "an imaginary space often manifested through a medium. A description of a collection of objects in a space and the rules and relationships governing those objects" (Sherman and Craig 2003). To further elaborate, Sherman and Craig state that a virtual world is the content of the medium; it can exist as an idea in the mind of the creator or be shared with others for them to experience. A virtual world does not need to be displayed to exist. The analogy Sherman and Craig use to describe the phenomenon is the script of a play. While the script can be thought of as a description of a play and brought to life with actors and performers, a virtual world is described within the simulation.

The second element of virtual reality is immersion, which can be classified as a different point of view juxtaposed to one's steady-state perspective. Sherman and Craig's definition of a medium involves a noticeable change in perception that requires outside influence. Immersion is the ability for individuals to transfer their attention to a new medium, essentially blocking out the medium of physical reality. While fundamentally, a person is unchanged physically while experiencing immersion, it could be argued that one's mind manipulates one experience. Imagination and suspension of disbelief are the main factors contributing to how easily someone enters and exits immersion.

> "Imagination is where virtual worlds begin and how numerous virtual worlds are experienced. The power of imagination can allow us to dwell where we choose, when we choose, and with whom we choose. We are limited only by what we can imagine and our ability to communicate it" (Sherman and Craig 2003).

Sherman and Craig specify that there are two types of immersion: physical immersion and mental immersion. In most mediums, immersion is a mental process where people actively imagine reality. Physical immersion, however, involves manipulating one's senses to create an experience. For example, the smell of gasoline may stimulate someone into thinking they are at a gas station. The medium of VR can capture both physical and mental immersive states.

The third element of virtual reality is sensory feedback. Virtual reality is unique compared to other forms of media because: "VR allows participants to select their vantage point by positioning their body and to affect events in the virtual world. These features help to make the reality more compelling than a media experience without these options" (Sherman and Craig 2003). By tracking the movement of the individual with a VE, the movement can be directed back to the display the individual experiences. This creates a feedback loop that allows the body to respond within a VE as it would in a physical environment, regardless of the level of immersion. Virtual reality can be localized within a visual display and can incorporate elements that can capture hand and body movements, further increasing sensory feedback.

The last and most important aspect that defines virtual reality is interactivity. If a person picks up and throws an object in a physical environment, they expect the object to follow a certain trajectory. If an individual were to attempt to throw a similar object within virtual space, how should the VE respond to such an action? To make virtual space authentic, a solution would be to simulate physics and replicate the physical experience. This is but one example of a way someone can interact within the virtual. Sherman and Craig state that there are two ways someone can interact with a virtual environment. First is the direct manipulation of the computer-based world via inputs and algorithms. Another form is: "the ability to change one's viewpoint within a world" (Sherman and Craig 2003). This could be interpreted as a change in location or action that would cause one's perception of the virtual environment to shift. Interactivity is an element that feeds into other elements that define virtual reality. For example, if someone were to interact with an object in a virtual space, that interaction may produce sensory feedback and ultimately increase levels of immersion. Interactivity is also a powerful aspect of virtual reality that makes it a tool beyond mere visualization. After combining all four aspects that compose virtual reality, the following definition can be created:

> "Virtual reality 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 (a virtual world)" (Sherman and Craig 2003).

With a clear definition of the medium of virtual reality, we can begin to understand the scope and potentials to create a successful VE. While the primary advantages of immersive VR branch from its interactional capabilities and the editability of the environment through programming and algorithms, the environment must be developed to promote immersion and instill proper sensory feedback to overcome the immersion barrier.

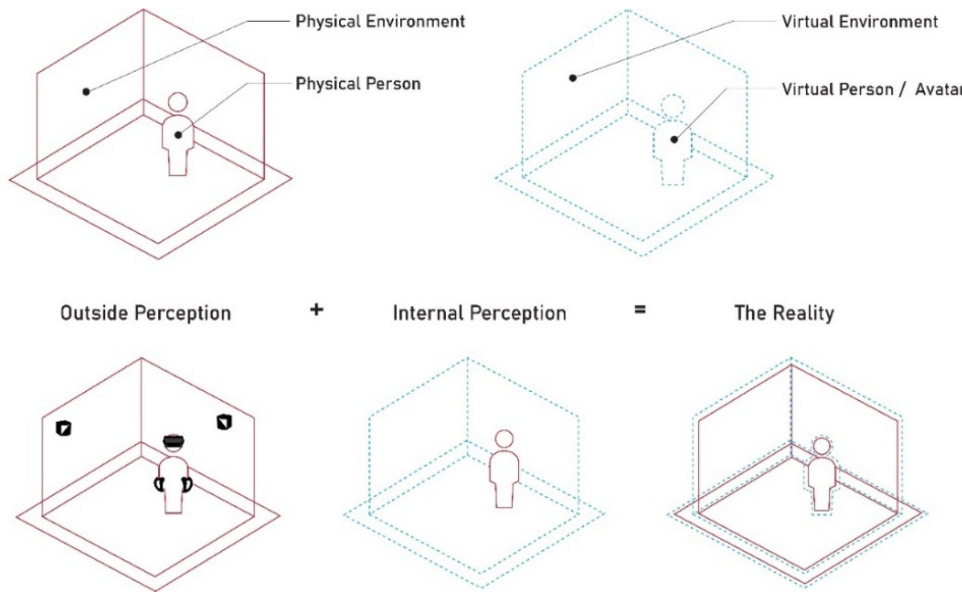

Figure 7: Relationship between physical and virtual reality in terms of spatial conceptions. Figure by author.

2.3 A Brief History of Virtual Reality Technologies

The ideas of virtual reality are not original to the 20th or 21st century, making it difficult to pinpoint precisely who coined the term or who was first to develop the concept. This is partly due to a non-established census definition and how other media attempt to create a virtual reality experience. To understand the history of virtual reality, it is vital to track the progression of VR technology. The US. Patent 1,183,492, established in 1916 by Albert B. Pratt, marks a device that would attach to a user's head and provide a periscope display (Sherman and Craig 2003). This marks the first documented Head Mounted Display (HMD), a type of hardware where virtual imagery is localized within a headset and immerses individuals by covering their eyes and blocking out additional light (Hezel and Veron 1993, 1). In 1956, inspired by Cinerama (a wide-screen motion picture process that used three images to make a large canvas), *Sensorama* was created by Morton Heilig. This technology created an experience simulated through artificial images, smells, vibrations, sound, and even a slight breeze (Sherman and Craig 2003).

The fifties were when technology was at a point where early concepts of virtual reality were possible. Ivan Sutherland was busy conceptualizing *The Ultimate Display*: a virtual environment concept that would use interactive digital graphics, feedback with force, sound, taste, and smell. Sutherland later transformed this concept into *The Sword of Damocles*, the first VR system that used an HMD with head tracking. Head position and orientation updated with the virtual system and provided feedback to the viewer (Mazuryk and Gervautz 2014, 2). *Videoplace* was an artificial reality created by Myron Kruger in 1975. This system first integrated the concept of an avatar within a VE and allowed people to perform specific actions by controlling their avatar with their physical bodies. This system may be considered primitive by modern standards since the avatar of *Videoplace* was a simple silhouette of persons, and the means of interaction was via light table technology. However, footage of this system demonstrates a high level of expression embedded with the system and a great deal of freedom within the 2D VE.

A small group of inventors in the late 80s and early 90s were highly motivated to expand VR technology since the personal computer was exploding at the time. In 1989, *Boom* was commercialized by Fake Space Labs and contained two CRT monitors displayed in two slits in a handheld box held by a small crane mount. Like a periscope, a user used handles attached to the box to guide the display box whenever the user moved. Boom was used for 360 panorama still images and is the precursor to 360 panorama displays of today. In 1992, the CAVE project or (Cave Automatic Virtual Environment) created an environment where individuals were contained within three to four walls with projected imagery. Individuals would wear LCD shutter glasses to complete the visual experience (Mazuryk and Gervautz 2014, 3). This form of display is of architectural interest because, for the first time, people were not required to strap hardware to their heads or remain static while exploring a VE. Instead, the VE was imprinted within a contained physical environment. While there were significant efforts to continue developing the technology during the 90s, these efforts were somewhat fruitless since the difference between crude computer graphics and the richness of physical reality was too significant (Schnipper 2020). While the buzz of VR began to settle down in the mid-90s, another technology took the world by storm: the internet. In 1999, Philip Rosedale created Linden Lab intending to create new VR hardware. Concepts learned from this project were later adapted into *Second Life*, a historic VE program (Au 2008, 9).

Modern trends of VR have gravitated towards Head Mounted Display (HMD) technology after Palmer Luckey began improving the technology in 2010 and a successful fundraiser that raised enough to fund his Oculus Rift. The Oculus Rift marked a shift in VR technology since its immersive capabilities and updated tracking were made accessible, pushing innovation. Facebook soon took interest and purchased Oculus for $2 billion (Schnipper 2020), sparking VR back from a development stall. In 2013, Valve made a breakthrough by creating low-persistence displays that reduced frame rate valleys and enabled smear-free VR displays (Scott Wasson 2013). Valve and HTC announced the HTC Vive in 2015 that included new tracking technology coined *Lighthouse* that used wall-mounted base stations for tracking the potion of controllers and headset with infrared light (Warren 2014). In 2015 Google announced *Google Cardboard,* created by David Coz and Damien Henry, a stereoscopic viewer made from cardboard where users can use their smartphones to power the display. This is the first mass production, low-cost platform for VR and was designed to be highly assessable to spread awareness of the potential of VR to a lay public. *Google Cardboard* proved influential with its ability to tap into the graphics of Google Earth, instantly transporting people worldwide (Pierce 2015).

By 2016, at least 230 companies were developing VR-related products, including Amazon, Apple, Facebook, Google, Microsoft, Sony, Samsung, Meta, the Void, Atheer, Lytro, and 8i. Facebook alone has over 400 people working on VR technologies and support (Kelly 2016). An upgraded model to the Oculus Rift, the Oculus Rift S, was released on March 20th, 2019. Valve soon entered the HMD market with the solo release of their hardware: The Valve Index in June

2019. The spark of competition between companies as they attempt to improve the design of the HMD interface in the present suggests the technology will further improve into the future.

2.4 A Brief History of Classroom Design

Schools and the classrooms feature an extensive and highly detailed history due to academics documenting their environments with their thoughts and opinions on ideal classroom environments. To compress the overall timeline and connect to the past to the current state of classroom design, it is paramount to examine the development of classrooms, specifically in the 20th century. Lindsay Baker, a professor at the University of California, mapped the history of classroom design with a primary focus on internal environmental factors. Her analysis began with schoolhouse design from the 1800s.

The classroom in North America began with the schoolhouse, an isolated structure with a single room to host teachers, students, and supplies. Schoolhouses may include juxtaposed support spaces for storage. However, the norm was usually a single room as the whole interior. The programmatic element coined the term: one-room school. One-room schools and can be found in Norway, Prussia, Sweden, Canada, New Zealand, the United Kingdom, and the United States. These schools were ideal for small communities in rural areas, for they were simple, used humble materials, and were easily integrated with other urban developments. The education model for one-room schools involved one teacher covering a range of subjects and often with an assortment of students of different grades. Students mainly were of elementary school age. Interestingly, one-room schools still exist today. In 1919 there were around 190,000 one-room schools in North America, but in 2005, there are fewer than 400 left, making them a historic but outdated teaching relic of the past (Ellis 2005).

Figure 8: Florham Park NJ Little Red Schoolhouse. Photo by the artist from source: (Josconklin 2012)

More complex school buildings aside from one-room schools were prominent during the mid-19th century. While the exterior of these structures may suggest these buildings were well designed, other accounts tell another story. At this time, schools in North America followed a Gothic or Georgian architectural style and were often built with stone or brick with minimal glazing (Nelson 2014). Henry Barnard, a government official and education reformer, described early school buildings as "almost universally, badly located, exposed to the noise, dust, and danger of the highway, unattractive, if not positively repulsive in their external and internal experience (Barnard, 1842)" (Weisser 2006, 198). Barnard continued his critic of school buildings as "too small, badly lit, not properly lit, imperfectly warmed, not properly furnished, lacking appropriate apparatus and fixtures, and deficient in outdoor and indoor arrangements" (C. Kenneth Tanner 2000, 2). Overall, the state of buildings was poor at the time and required change. The following passage describes Barnard's recommendations to improve interior arrangements and student experience applied after his criticism:

> "The teacher's desk—placed front and center on a raised platform—allowed an easy view of the entire space. Neat rows held fifty-six individual desks. Windows lined the two side

> walls. The design's spatial organization integrated Barnard's reform agendas: it placed authority in the teacher and narrated a clear pedagogical" (Weisser 2006, 198).

Barnard's goal was not only to improve school design but, like Horace Mann, set out to reform the curriculum and to promote further teacher education. The design strategy proposed by Barnard also applied to the one-room schoolhouse aside from larger institutions, despite the differences in communities and values. Barnard found an issue with rural learning conditions: "a child learned life experience on the farm, vocational skills during an apprenticeship, values from the church, and only literacy and arithmetic at school" (Weisser 2006, 198). These criticisms sparked interest in a unified school system that would uniformly educate and promote higher education standards for the public.

Large School buildings saw extensive growth with the industrial revolution and reformed the educational system to prepare a new workforce. Horace Mann was an early education reformer with an iron will and desire to create a universal education system to provide high-quality utilitarian education for the masses. Mann was from Connecticut and shared a similar position to Henry Barnard. The modern public school system established in North America began with Mann's influence in his legislation battles. Mann was avid about the art of teaching and popularized the idea of a "centralized bureaucracy to manage primary and secondary education" (Horton 2020). With a growing population, there was more need for more efficient and standardized schoolhouses. The dawn of the public school system originated from the Common School Movement, which was the catalyst for change. Under this reform, schools would be free for students and paid by local property taxes. This movement ballooned during the second half of the 19th century (Baker 2012, 4). The year 1874, in particular, marked a critical junction in the history of the Common School movement due to the Kalamazoo Decision, declaring it legal for public schools to operate based on the funds from local property taxes. This enabled the expansion of public schools for the coming years. With the adaption of child labor laws and the growth of cities and industry, the expansion of the public school system was almost inevitable. More children were attending school.

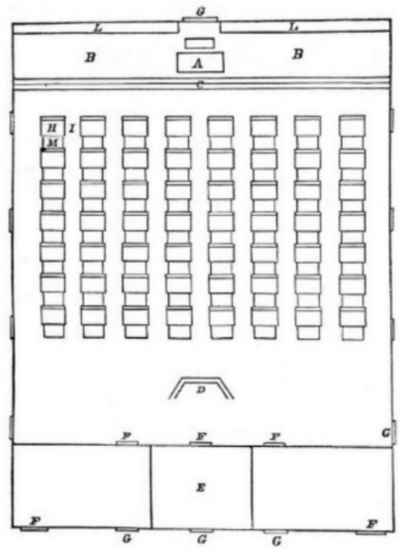

Figure 9: Horace Mann One-Room Schoolhouse Plan, 1838. Image from source: (Weisser 2006, 199)

Many schools appeared primarily in urban settings due to most citizens working in factories and living in urban developments. Schools emulated features standard in factories with "factorylike, dark, and dank" features as a preparation mechanism for students leaving school to join the factory labor force (Weisser 2006, 200). Even the iconic class bell that rings in many public schools to this day and remains ingrained in our culture originated from this period and was intended to mimic a factory bell. Conformity and discipline were the virtues of these schools; schools became factories for learning. To understand the growth of schools at this time, in the 1920s, over 200 school buildings were built in New York City alone (C. Kenneth Tanner and Lackney 2005). During this period of growth, new books were written on the design and construction of schools. The authors were critical of the environmental conditions in schools and argued the importance of a healthy environment to promote education.

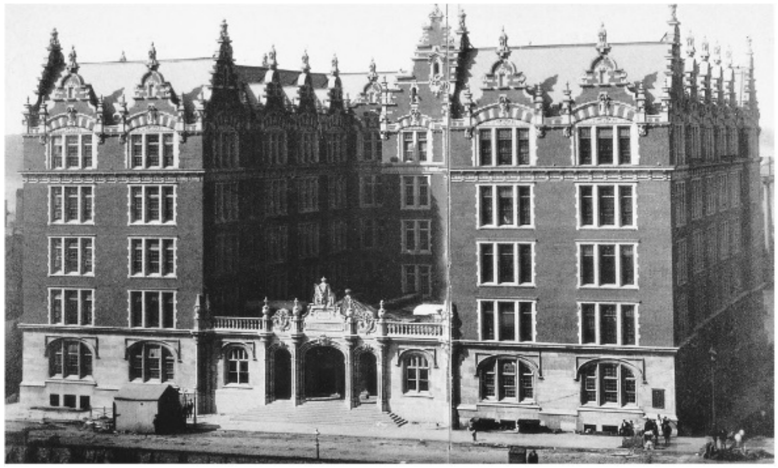

Figure 10: CBJ Snyder DeWitt Clinton High School - 1906 – Exterior. Image from source: (Weisser 2006, 201)

While the primary focus of the design was on plans and layouts, many cited the importance of proper lighting and ventilation throughout the whole school. However, much like how students were organized in rows, glazing was often applied through small, repetitive windows organized uniformly. The proposal of design solutions for acoustics, heating, and cooling would come later and were not of primary importance over this period. Without electricity, early schools relied heavily on daylighting and were planned to take full advantage of natural lighting since local lighting by candle was expensive. Many scholars suggested the following scheme: "light should come over the left shoulder of each pupil" (A. Hamlin 1910, 8). This assumption was derived from statistics that most students are right-handed. Window-to-wall ratios and window-to-floor areas began becoming standardized at this time as well. The aftermath of these standards can be seen today. The following is an example:

> "The total window area should equal from 40 to 50 percent of the total wall area of the long side of the room, and in general, one-quarter the floor area of the classroom. The windows should extend up to within 6 inches of the ceiling; the window stools should be

> from 3 to 3 ½ feet from the floor. Light from below that level is useless; it is the height of the top of the window that determines its lighting efficiency. The sill should, however, not be higher than 3 ½ feet from the floor, as it is desirable that the pupils should be able to rest their eyes at times by looking out at more or less distant objects, which is impossible for many with a sill 4 ½ or even 4 feet high" (A. Hamlin 1910, 8).

Window design at this time also suggested the importance of views for students to "rest their eyes at times" (Baker 2012, 7). The notion of improving student's quality of life within the classroom began to gain momentum. An increasing number of suggestions to improve student life appeared; school design was optimized in the coming years.

The period between 1930 and 1945 marked a critical movement in modern school design: the progressive era. During this time, many schools were built despite the effects of the great depression. To fight the downward spiral of the great depression, the Public Works Administration financed many schools from 1933 to 1939, accommodating around 70 percent of new school construction for local communities (Weisser 2006, 207). Student success was also increasing. By 1940, 50 percent of high school students were graduating (Glavin 2014). More liberal designs to maximize environmental factors such as sunlight and ventilation were the highest priority. Hence this period was coined the "open-air movement." The first open-air schools began in Europe in the 1910s. In Germany, the *Waldschule* was built in Charlottenburg, Germany, and aimed to relieve students from tuberculosis through sun exposure and fresh air (Nelson 2014). At this school, classes were held outside or in small structures with glass doors. It was common for open-air Architecture to feature classrooms with entire glazed walls, a radically different approach from past architecture. Other notable projects during this period include Eliel Saarinen's Cranbrook Boy's School (1937), Alvar Aalto's Tehtaanmaki School (1937), and Richard Neutra's Modernism (Baker 2012, 8). The philosophy of the open-air movement involved integrating easy movement between inside and outside of the building, exposure to natural light, and physical health into the design. Schools of the period featured desks in rows like past precedents but were looser and less optimized for space, providing students with more breathing room. More experimental designs were produced at this time, such as the "Gary Plan" used in Gary, Indiana that divided classrooms from support spaces with two general segregations and had students simultaneously use the whole facility in turns (Glavin 2014).

After World War II came a new period for school design known as the post-war boom. With the war over, a mass migration of soldiers returned home looking to start families, resulting in a surge of children creating the baby-boomer generation. With a mass influx to the population, the school system was forced to respond to the spike in enrollments. At this time, the plans and facades of schools began being standardized, and with architectural magazines broadcasting the philosophy of open-air architecture, many new schools adopted open-air techniques. Architectural standards of this period were much stricter compared to the past. It was also at this time that air conditioning was first introduced to schools (C. Kenneth Tanner and Lackney 2005, 12). Many new schools were built during this period, and approximately 20 billion dollars were invested in new construction by the year 1964 ("National Council on Schoolhouse Construction" 1964). The construction of new schools featured lightweight construction, making them easier to build and less expensive. However, this made the overall lifetime of the structure shorter and required more renovation work (Thomas Hille 2011, 91).

The wildly popular finger plan dominated this period of construction. Finger plans include extruded classroom sections from a central circulation core to maximize sunlight exposure, fresh air, and access to views outside for each classroom. These plans were relatively expansive and spread out on their sites; they rarely ascended over one floor, making the overall structure relatively flat. The role of technology during this time was more driven to improving occupant comfort. With an increasing data pool for mechanical engineers to analyze, schools featured increasingly improved control over interior temperatures and humidity. Artificial light also grew during this period with affordable fluorescent lighting. As a result, more schools adapted interior lighting instead of natural light through windows. Modern lighting standards have not deviated much from the protocols listed by the Illuminating Engineering Society since 1959. There was little evidence of teachers preferring artificial or natural lighting, but teachers seemed to prefer a balance between them (Baker 2012, 14).

Following the post-war period came the "impulsive period" between 1960 and 1980, coined by Hansen and Hanssen in their review on the history of Norwegian school construction trends (Baker 2012, 17). Unlike the previous period, with schools racing to accommodate a growing population, the trends during this period featured shrinking enrollments. Vandalism of school property was also increasing with the increasingly volatile public. Criticism was lock and loaded at the educational system, specifically the schools in urban areas accused of not providing high-quality education to minorities, poor, and disabled children. Tanner & Lackney note that the perception of schools was "stifling to creativity and destroying children's natural love of learning and self-expression" (C. Kenneth Tanner and Lackney 2005, 17). Researchers were eyeing the connection between educational outcomes and educational facilities, diving into the realm environmental psychology. The Educational Facilities Laboratory (EFL), a research organization funded by the Ford Foundation from 1958 through 1977, heavily influenced school design in the 1970s by promoting the use of open floor plans.

Open plans are multifunctional spaces that avoid creating boundaries with partitions. Instead, they invited its users to arrange the interior without restrictions. Instead of traditional rows, teaches began using cluster tables to arrange the classroom. While open plans created significant opportunities and potential space use, they also feature low glazing exposure. The research exploring how environments affect student performance found benefits with open floor plans. However, the results of the study are currently unpublished. Researchers believed that variable height ceilings and sound-absorbent partitions between classrooms significantly reduced classroom interruptions. However, many contradictions in the study left the researcher questioning the study's validity (Baker 2012, 18). EFL also supported the School Construction Systems Development

Program (SCSD), which supported prefabrication for school construction. This was an overall success, and many thought well of the project since it made more affordable and faster construction. Technology during this period was further integrated with construction techniques and school infrastructure. Heating, cooling, and lighting were increasingly driven by artificial means. However, it can be argued that the increased reliance on technology contradicted the movements to feature large windows and natural ventilation since technology could be used to subsidize their effects and were more affordable.

Another movement in the 1970s that still impacts contemporary design was the Baubiologie or (building biology) movement. Like the concepts of modernism and the idea of cleanliness and purity, the Baubiologie movement focused on healthy environments. There are 25 principles of Baubiologie design that influenced several structures. For example, architect David Eyer designed a kindergarten in Slustice of the Czech Republic with these principles. The building features natural materials, many daylit spaces, and a central courtyard (Nelson 2014).

Enrollments continued to decline in the 1980s, and few new schools were built. The 80s was a period of renovations. Facilities at this time were showing their age needed repairs. However, the drop in enrollment resulted in less funding for education and fewer resources to improve infrastructure. A report released in 1995 by the General Accounting Office (GAO, later renamed to the Government Accountability Office) stated an estimated $112 billion in the United States was necessary to bring facilities to an average, "good overall condition" ("School Facilities: Condition of American Schools" 1995). A large portion of this sum would be to excavate asbestos commonly used in schools, new access points to comply with new Americans with Disabilities Act (ADA) standards, and water contamination issues. The report from the GAO spooked many with the state of educational facilities. Another shift in education architectural developments was the critic of portable classrooms. While first intended to be temporary, these units were growing in large numbers every year. In California, there were 75,000 portable classrooms in the late 90s, and it was estimated that another 10,000 were produced every year (M. Apte et al. 2002). The quality of plywood at the time was being re-reexamined, for it was found that the glue used to bound the ply's released toxic gases over time. RVs and portable homes made from plywood were the first to discover this issue. Thus many portable classrooms made of the same materials were questioned. Other studies found that portable classrooms had higher amounts of CO_2, among other pollutants (D. Shendell et al. 2004). On a more positive note, Leadership in Energy and Environmental Design (LEED) certification took a foothold in the 90s and has been a significant contributor to sustainable and green building design for educational buildings. LEED had lasting impacts and largely influenced contemporary construction and the production of safe, sustainable facilities.

Classrooms and schools have seen a dramatic shift from one-room school to modern designs. For older facilities, the classroom remains unchanged since the industrial revolution. Newer constructions have adopted movable furnishings so that teachers or students can manipulate their environment as they please. The role of education, past or present, is tied to the necessities of the period; architecture reflects these values. Older models required students to be functional, obedient, and self-reliant. We see echoes of these themes today, but with the knowledge of environmental impacts on student performance, our new models are focused on student-centered classrooms. Team-Based Learning (TBL) classrooms, for example, feature layouts where students work in clusters to solve problems and absorb lectures via various media. New models represent a more dynamic classroom and have seen great success. TBL classrooms also feature technology integration with smartboards or projectors juxtaposed to students, built-in laptop stations, additional outlets for personal computers, HDMI input ports, and RJ-45 internet ports. Students can take control during a lesson to broadcast from their laptop and station to the whole classroom.

Team-based learning classrooms are just one version of a student-centered layout. As education curriculums continue to adapt to current needs, changes to administration and organization will inevitably follow. The educational infrastructure can be characterized as embedded in a progressive feedback loop. "Similarly, the ideas of educational reformers, if they are really to take effect, must sooner or later be expressed in organizational and architectural terms.

Changes in the curriculum and methods of teaching are also likely to be reflected in the layout of buildings and the arrangement of classes" (M. Seaborne and Lowe 1977, 2:277–78). Thus architectural forms influenced educational methodology and vice versa.

2.5 A Brief History of Virtual Worlds

Like the definition of virtual reality, virtual worlds suffer from a largely undocumented history with few primary sources and a loose definitional framework. Because virtual worlds arose from a nonacademic origin, there is little literature dedicated to the topic and an array of confusing secondary sources. Steve Downey, an associate professor from Valdosta State University (VSU), outlines the history of virtual worlds with rigorous attention to the validity of sources and constructs a high-level organization of history. Downey defines virtual worlds as: “Generic, overarching term used to describe online environments (text or graphical) in which users collaborate communicate for the purpose of gaming and/or socializing” (Downey 2014, 62). Virtual worlds are essential VEs but usually scaled for mass occupation. Downey divides the history of virtual worlds into three different generations, with each generation characterized by a significant change in representational approach and scale of users within an environment.

It was widely believed that virtual worlds began sometime in the 1970s. The first generation of virtual worlds began as packaged as self-contained games that used a text-based interface (command prompt inputs) for users to navigate (Downey 2014, 57). These worlds actively used a user’s imagination to paint imagery of the unfolding of events or scenes. These worlds are parallel to novels and written prose as a means to explore a different realm, differentiated with autonomy given to the user. There is little documentation of intent or design philosophy during this period since virtual worlds were a grassroots production with no formal collection of information. Virtual worlds at this time were designed for single users to inhabit but could inhabit multiple users within a single user framework. Downey’s investigation into the literature reveals that some of the first virtual worlds include: *Maze War* in 1974, *MUD* (Multi-user dungeon) in 1978, and *Avatar* in 1979 (Downey 2014, 57). Compared to virtual environments created with contemporary technology, the original virtual worlds appear archaic. However, early virtual worlds were innovative and historically significant as they opened the doors for new development.

While first-generation virtual environments we niche and catered to small communities, the second generation began to appeal to a larger audience. Feedback from the first generation combined with innovations in technology and growing economic trends became the catalyst for the next generation. *Habitat* was a virtual world developed by Randy Farmer and Chip Morningstar from LucasArts that incorporated the first avatars that could explore a virtual world. It could also host approximately 20,000 users (Morningstar and Farmer 1991). It could be argued that *Habitat* was the first socially oriented virtual world (Bruce Damer 2008). Following *Habitat*, *TinyMUD* was released in 1989 and focused on user cooperation and social interaction (Stewart 2000). While first-generation VEs were more focused on induvial agency and exploration, the second generation introduced multiple users for more social engagements and collaborative efforts to achieve a goal or general activity.

The third-generation virtual environments carve our contemporary conception of virtual space and are the tipping point for virtual environments to become mainstream. As business models evolved over the first two generations, the third generation featured much more significant capital investment into the development of virtual worlds. Budgets increased from a few million dollars (Cory Ondrejka 2008) to hundreds of millions of dollars (Chris Morris 2012). "They capitalize upon, and in some cases push the limits of, the increasing computational and graphic-rendering power of today's home computers to produce rich, vibrant visual worlds that draw users into the game and feed their desire to explore and play" (Downey 2014, 59). Virtual worlds within the third generation also enabled design tools that allowed communities to construct their virtual worlds through the framework of the developer's infrastructure.

Based on continuous innovation from the third generation into the present, Downey suggests that there may be a new age of virtual worlds currently in production. Since the growth of virtual worlds has grown exponentially, it is difficult to determine how and where trends will erupt. Regardless, massive corporations such as Disney and Activision Blizzard now support new virtual worlds with a continually growing user base. While these virtual worlds are mainly used within the context of entertainment (based on the complex business models that allow for significant revenues), the aftermath has paved new roads that have allowed for new potentials within other fields such as architecture and education.

Table 2: Generational Traits of Virtual Worlds with Summaries. Table adapted by the author from source: (Downey 2014, 57)

First Generation	**Second Generation**	**Third Generation**
(1978 – 1984)	(1985 – 1996)	(1997 – present)
• Small scale systems • Text-based displays • Fantasy-based games	• Larger scale systems • Graphical Displays • Games & social worlds • Avatars • User control over objects	• Massive-scale Worlds • Striking 3D presentation, Games, social, & educational worlds • Highly customizable avatars • User-driven communities • Adult & Child user bases

CHAPTER 3

ON VIRTUAL ARCHITECTURE

> "Since architecture is concerned with the condition of the built environment, the current state and development of virtual architecture is certainly not to be ignored by anyone who is concerned with the quality of the physical built environment. As the effect of online activities is gradually penetrating into our daily life, architects will be presented with a design situation that poses more complicated and interwoven problems" (Maher et al. 2000, 3).

3.1 Physical to Virtual – Defining Architecture in a New Medium

For some architects, the concept of designing virtual architecture as a means to itself may appear nonsensical or novel. The contemporary landscape of architectural practice uses software to address the inherent issues of communication and documentation of projects. The virtual model is a means to the physical creation. Because construction is a complex venture and requires coordination and technical analysis, among other needs, architects must use the best tools to help them through the challenges of practice. However, it is due to this demand that virtual models establish their value. If a virtual model does not accurately represent the design envisioned by an architect, then its purpose is void. One could say a virtual building model must represent the final building perfectly (although physical construction never perfectly replicates the virtual model). A crafted virtual model is only as perfect as the designer is intelligent or wise.

Thus, in the hands of a seasoned practitioner, virtual tools become invaluable to the architectural design process. Contemporary trends in architecture have been driven by the computational power of computers and CAD software. Within a relatively short period of architectural history, the methodology to address architectural problems has been transformed. Often in school, young architects are enthralled with the potentials of using software to create highly ambitious (and often unrealistic in terms of constructability or code compliant) designs. This reflects a generalized sentiment by Theodor Adorno that young architects value imagination while veteran architects value craftsmanship (Adorno 1997, 12). Nevertheless, the computer as a tool continues its amalgamation into the practice of architecture with BIM models and data-driven design as examples of innovation. Through this logic, the utility of virtual design tools is self-evident, but to design virtual architecture is a different question.

Virtual architecture is not physical architecture and cannot be due to the difference in mediums; however, because virtual architecture remains a growing phenomenon, architects should be aware of its development. Mary Lou Maher, department chair of software & information systems at the University of North Carolina at Charlotte, has outlined several distinctions between virtual and physical architecture. She begins with a general sentiment that virtual architecture, "as the design of functional virtual places is not well understood" (Maher et al. 2000, 1). She defines virtual architecture as follows:

> "Virtual architecture is an electronic representation of architectural design. The phenomenon of virtual architecture can have two purposes: a simulation of physical architecture or a functional virtual place. The simulation of physical architecture is the most common purpose of virtual architecture and is increasingly being used to visualize, understand, and present architectural designs. The second purpose of virtual architecture involves the design and creation of virtual places in terms of its functional organization and electronic representation. Architects design buildings to provide places for people to live, work, play, and learn. An emerging concept for designed virtual places is to provide an electronic location for people to [socialize], work, and learn" (Maher et al. 2000, 1).

While physical architecture requires attention to physical constraints, virtual architecture by nature does not need to consider these factors. For example, span distance, beam depths, force transfer, and other structural considerations are not within the scope of a virtual design but are paramount to any physical creation. Virtual architecture is also not preoccupied with secondary experiential characteristics of our environment, such as temperature and air quality. Maher claims that "users of virtual architecture do not have physical needs or extends; the geometric description of the space does not hold the same significance as it does in a physical building. This does not mean that it doesn't have any significance" (Maher et al. 2000, 1–2). Thus, virtual architecture demands that we reexamine the roots of architectural creation and its purposes to solve design within a realm where the creator defines the rules.

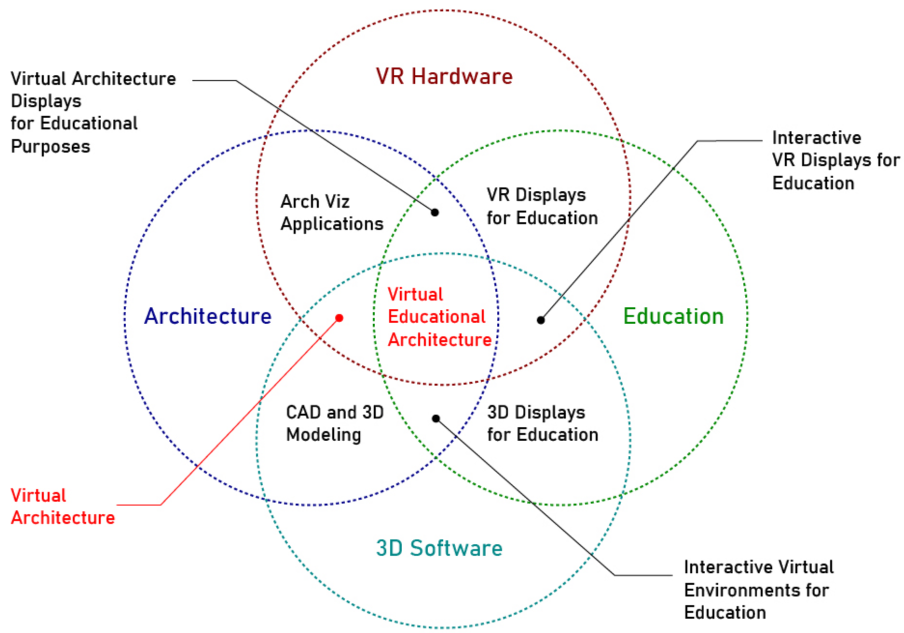

Figure 11: Relationship between architecture, VR, 3D Software, and Education. Figure by Author.

Architecture as a practice is multidimensional, meaning there are many avenues to approach the topic since it is embedded within many intellectual spheres. Contemporary architectural research has become highly multidisciplinary. Architecture is deeply intertwined with construction; thus, an immediate definition of architecture may be an artful approach to construction. However, construction as a verb has no destination, construction to what end? Thus the definition of architecture may expand to include the design of functional spaces for living and other uses. However, space is abstract compared to the materiality of construction; the construction itself molds the space but space alone is not architecture. Architecture is also deeply intertwined with culture and societal value structures, making it an artistic artifact regardless of intent. Juhani Pallasmaa comments on the nature of architecture:

> "The timeless task of architecture is to create embodied and lived existential metaphors that concretize and structure our being in the world. Architecture reflects, [materializes], and eternalizes ideas and images of ideal life. Buildings and towns enable us to structure, understand and remember the shapeless flow of reality and ultimately to recognize and remember who we are. Architecture enables us to perceive and understand the dialectics of permanence and change, to settle ourselves in the world, and to place ourselves in the continuum of culture and times" (Pallasmaa 2012, 76).

One could say that the difference between architecture and building is the intent to express an archetypical pattern of reality or express an ideal of how we as humans should live our day-to-day existence. From this assumption, one can overlay a deep connection between virtual and physical architecture, for they both may attempt to serve this goal.

If the definition of architecture is updated to the intentional creation of functional space through construction, the primary difference between physical and virtual architecture is the medium to which we construct. *Virtual* space can be confused at times. Architect Ali Rahim examines the use of the term *virtual* in philosophy and mathematics. He states that the "virtual comprises all that an object can be imagined to become," and "the virtual is a space of potentialities" (Rahim 2016, 76). By this definition, Rahim claims that it must be quantitatively measurable or brought into existence for something to be actual. This use of the term *virtual* in this context is different from the common use of the word in this document to describe virtual reality, yet its meanings are echoed within contemporary culture. Virtual space and architecture for VR applications must be manifested before they can be used. Thus there must be intent to manifest the potential of the *virtual* as Rahim would define. Virtual architecture can then be defined as the intentional creation of functional space to be experienced through immersive virtual technologies using virtual tools as a means of construction. Although different materials are used, the product serves the same end. We can then extrapolate that the essence of virtual architecture is of a similar fabric to physical architecture. Bruno Zevi describes the essence of architecture with the following passage:

> "The essence of architecture... does not lie in the material limitations placed on spatial freedom, but in the way, space is organized into meaningful form through this process of limitation... the obstructions which determine the perimeter of possible vision, rather than the 'void' in which this vision is given play" (Zevi 1993, 30).

Virtual architecture is a form of architecture akin but distinct to physical architecture: both share a dualistic nature. Similar to the taijitu of eastern philosophy: one is symbolic of man, permanence, tangibility, and limitation; the other is symbolic of god, ethereality, ephemerality, and the infinite.

3.2 On Virtual Architectural Functionalism and Aesthetics

Among many of the elements that we use to criticize and discuss architecture, a building's functionality and aesthetics are two primaries. Since Louis Sullivan's "form follows function" principle has permeated the design community, the formal aspects of modern and contemporary buildings are often designed inherently around the intended use of space. This design principle, like any other architectural principle, can be applied within a virtual context. However, because virtual space can be considered the ultimate tool as a manifestation of the computer as space, the functionality of space takes on a new meaning. Virtual spaces can be designed through a social organization approach and the intended use of tools embedded within the software framework (similar to physical architecture). Thus space is shaped not only by what users intend to use it for but also by the range of tools that have required spatial dimension. If one is a competent software developer or programmer, the virtual world becomes an unmatched sandbox. However, for the architect, infinite freedom becomes an issue. Using the analogy of infinite possibilities, one's vision of functionality can often contradict another's. Thus the value of function becomes the limiting factor rather than creating the functionality (unless the tools in question are outlandish such as artificial intelligence). Regardless, the functionality of virtual space is paramount and offers a new way for users to interact with digital tools. Mahar comments on the functionality of virtual space:

> "A consistent description of the frame of reference and topology of the space can help in the orientation and navigation within the place, whether we refer to a room, group of rooms or other part of the place. It also contributes to setting the ambience and indicates what the place and different parts of that place feel like. The design process, however, must necessarily focus on provision of functionality. Without a provision for functionality, the space is not useful, whereas neglecting the geometric description of the room does not affect its functions although it may result in a less user-friendly environment due to the lack of sense of place and presence" (Maher et al. 2000, 2).

Architecture, among other design objects, also features embedded aesthetic elements to realize an artistic vision or stimulate its users intellectually. However, aesthetic elements of a physical building may not directly transfer into the virtual context. The evolution of aesthetics in architecture began as a representation of transcendental or cultural ideas embedded within different functional elements of the building. Dentils, for example, are an expression of protruding joists, a fundamental structural feature. Architectural elements in the past were rich with ornamentation; modernism striped ornamentation hoping to create a more honest architecture via abstraction of essential architectural elements. Within the debate of ornamentation, virtual architecture can be designed with a high degree of ornament for the argument of construction costs, wastefulness, and debatably efficiency dissolve. However, the fundamental axiom of architectural aesthetics via the expression of necessary building components also dissolves. However, any range of these elements can be translated and represented. The virtual architect should instead look towards the significant components of the constructed space: walls, floors, roofs, and thresholds for an expression of aesthetics.

Aesthetics as a philosophical topic, similar to discussing the nature of reality and phenomenological experience, cannot be fully encapsulated within a single dedicated segment. However, because the phenomenology of virtual architecture is parallel to physical architecture, some level of aesthetic semblance must transfer. Thus the following will attempt to reflect on architectural aesthetics and if they can be transferred into a virtual context. Roger Scruton, a philosopher who has written on traditional architectural aesthetics, describes the aesthetic experience based on our sensorial capacity.

> "We may begin our enquiry then, from a distinction (as yet only partly characterized) between sensuous and intellectual pleasures. The pleasure in architecture belong to the latter class, partly because the experience of architecture is dependent on a conception of its object. But in elucidating this relation of dependence we shall have to consider certain difficult questions in the philosophy of perception. I shall try to show that the experience of architecture is by no means the simple matter that it may appear to be. To see a building as architecture is not like seeing it as a mass of masonry. There is a distinction, which I shall attempt to clarity, between ordinary perception and 'imaginative' perception; I shall argue that the experience of architecture is essentially of the latter kind, and that this fact must determine our entire way of understanding and responding to buildings. We must

> begin, however, by attempting to dispel some of the obscurity involved in the assertion that the experience of a building depends upon a conception of its object" (Scruton 1979, 68).

Scruton refers to imaginative perception as an anchor for aesthetic experience. This experience is a dialogue between one's imagination with the perceived, often extrapolating its significance. A phenomenological perspective within a psychological frame can help us determine that virtual space experience is a real experience since our brains manifest the meaning of our perceptions unconsciously before we can rationally process them. An aesthetic experience follows this vein, for the aesthetic qualities an object may possess are experienced through the same perception. However, our interpretations of aesthetic experience also contribute to our perception, meaning that open dialogue on aesthetic qualities can shift one's perception. Scruton reflects on this point: "there is a familiar point, made by both philosophers and psychologists that, in perception, experience and interpretation are inseparable" (Scruton 1979, 69). Scruton continues this point by arguing that architecture encapsulates both an imaginative and literal experience of architecture, stating that these types of experiences are inherently different. Like video games, architecture occupies the active part of the mind rather than the passive, making intellectual discourse an interactive aspect of our experience as specific thoughts and ideas amend our perceptions (Scruton 1979, 95).

In the past, ornament was an essential aspect of the architectural experience, molding interiors with elaborate patterns and populating facades. The Traffic Tunnel Administration Building, built in a Georgian Revival style in 1931 and designed by John M. Gray, exemplifies this with the grouped columns on the four corners of its cupola combined with the classical orders used on the main façade. Columns as an architectural element have a long history of being used as an ornament and structure. Columns create a flare of vertical gestures to architecture, an idea that Scruton suggests is fundamental to architectural aesthetics. Past styles have pushed this trend to the point where columns were integrated purely as an ornament and held no-load and thus were purely ornamental. The modernist perspective was highly critical of building elements that did not represent their function. Referring back to Figure 2, the pipe within Rene Magritte's painting illustrates a similar issue. The image is "treacherous" because the image cannot perform the functions of a pipe, nor does it have other characteristics of a pipe that we may perceive through senses other than vision. Hence it is not a pipe. The function of the pipe and its perception contribute to the essence of an authentic pipe.

Figure 12: Traffic Tunnel Administration Building by Nicolas Janberg. Photos by artist. (Janberg 2008)

If one were to interpret the aesthetic qualities of an architectural object as patterns ingrained within architectural elements, then it is a simple matter to transfer those patterns within the virtual context. However, there must be careful consideration to this end. One may choose to represent architectural elements within the virtual context to create an aesthetic experience; however, to do so while ignoring functionality means these elements are purely ornamental. If a designer wishes to embrace the ornamental expression of architecture within the virtual (while creating functional spaces), they are more than welcome to do so. However, the combination of the functional and ornamental one could argue is where true architectural essence lays. Our imaginations explore and question the shape and composition of architectural elements, why they are there, and what do they do. This could be a path to architectural beauty. Roger Scruton refers to the principle of exploring the architecture and other objects in this manner as the "creative imagination," an experience that only conscious beings may partake (Scruton 1979, 73). Architecture satisfies the functions that allow us to prosper in a chaotic world and offers intellectual curiosity and meaning through aesthetic expression or symbolism. Creative imagination and imaginative perception allow conscious individuals to explore what is observed on a more profound level.

3.3 On Virtual Materiality and Simulation

Since virtual reality is a medium that primarily activates vision (aside from touch with haptic feedback or other artificial stimulation), visual characteristics of virtual architecture hold great significance, for it is the most immediate sense that impacts a user's experience. In the previous section, architectural aesthetics as a visual conception was lightly discussed; this section will focus on visual conceptions and crafted experience. It is a primary axiom that architecture heavily relies on vision among other senses to manifest itself to its occupants. However, it is just as paramount for the architect to consider how other senses participate with one's experience of space. Given the status of current VR technology, many of the senses an architect may consider for typical designs dissolve when integrated into the virtual. This does not mean they cannot be replicated or simulated in the future as technology develops, but even as the technology progresses, the visual elements of design remain paramount.

Sight as vision is arguably the most profound sense for humans through a biological lens. Research from William G. Allyn, Professor of Medical Optics from the University of Rochester, has found that "more than 50 percent of the cortex, the surface of the brain, is devoted to processing visual information" (Hagen 2012, 35). Vision is the most advanced perceptual sense for humans and is one of the most advanced senses among living organisms. Vision, physiologically, is deeply integrated within human neurological networks. It should be noted that the majority of one's nervous system does not only occupy the brain but rather is distributed throughout one's body; thus, vision and brain function alone does not account for the majority of one's "sight" (Peterson 2014b). This is arguably how other senses integrate with vision and impact our experience. Sight is not only limited to vision per se.

The complexity of sight creates new phenomena apparent within a virtual context. Phantom sensations, an experience where someone is experiencing a sensation without a typical trigger, are other phenomena reliant on our visual and cognitive systems (Heinzel and Heinzel 2010). The touch of the material textures compliments our vision since both works to create the experience of the object as it appears. Smell and hearing also influence our experience to some degree but can be argued to be less significant, for they are reliant on interactions between materials. Taste is most likely the least impactful sense within an architectural lens since it can be classified as non-typical. The richness of a concrete texture, the smell of aged wood, and the echo of opening and closing doors: many elements compose our architecture experience. However, because technology has advanced to create a highly accurate visual representation, the immersion factor for these environments is highly respectable. If phantom sensations and other phenomena are to be factored within an architectural VR experience, the philosophic nature of virtual design increases in complexity. However, before a philosophical dialogue can begin, the virtual designer must confront the problem of virtual materiality.

Physical architecture is composed of materials gathered from our natural environment and transformed into new objects. Hence the visual recognition of materials is a profound element in architectural experience; some may say that these conceptions are built into our DNA. However, within the virtual environment, the computer uses data to substitute physical materials. Contemporary 3D technology has advanced to the point where physics-based rendering allows computers to simulate the characteristics of physical materials in a highly believable manner. Current trends in virtual creations strive for ideal photorealism. During the production of the 2012 movie Wreck-it Ralph, Walt Disney Animation Studios developed a single BRDF shader to render all the materials within the film under different lighting conditions, a significant advancement in computer technology (Burley 2012). In software such as Blender, an open-source 3D modeling and rendering program, this technology has adapted into the principled shader that has allowed 3D artists a single tool for PBR (Physics-Based Rendering) material creation. Figure 13 below illustrates how a principal shader appears to the creator and how data inputs create the desired material. Textures, 2D images imprinted onto 3D surfaces, create the illusion of materiality and are fed directly into shaders. Some textures are sampled directly from photo references, while others are automatically generated.

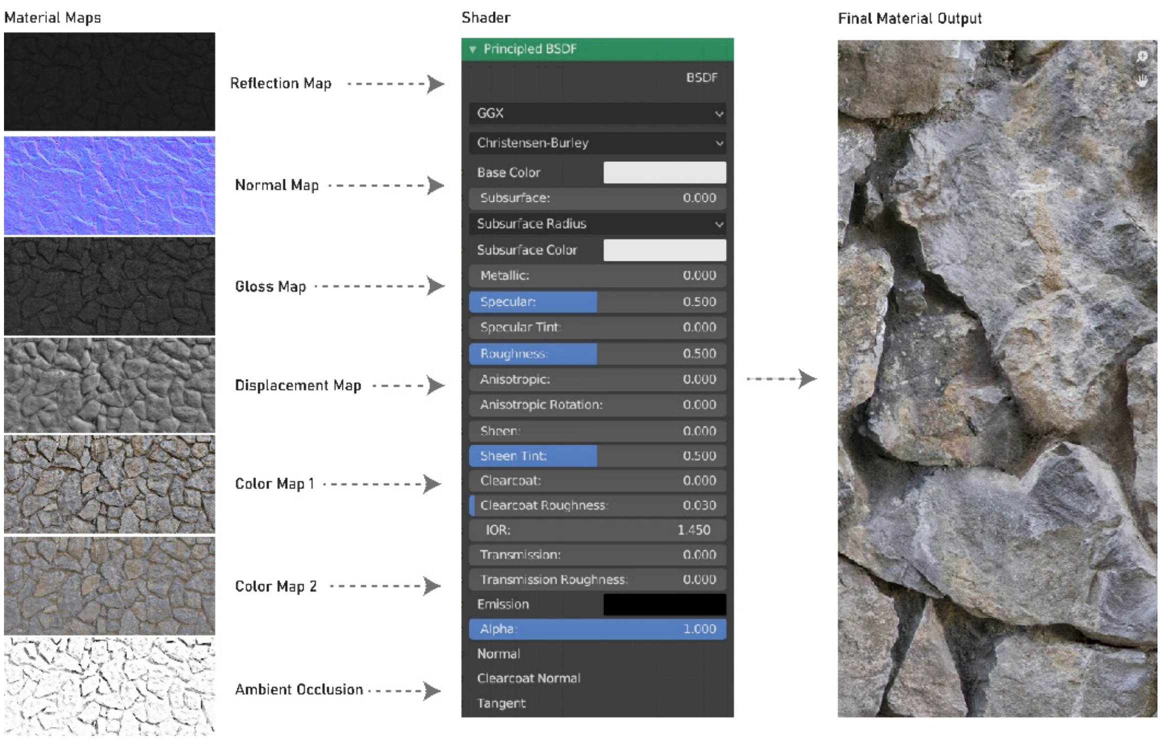

Figure 13: Blender Principled BSDF Shader Node, a tool that allows 3D artists to combine different textures to create photorealistic materials. Figure by author.

Thus far, the design of 3D environments has been attuned to skeuomorphic design, where virtual materials are used for their aesthetic signification. Thus virtual materiality generates a similar essence to physical materials based on past lived experience. One could say that virtual materiality only works because we have physical reality as a baseline to define our relationship with materials. One could also say that the materiality of architecture is lost in the translation because of the incomplete dimensions of virtual materials and lost functional significance. However, another view may reflect the familiar mantra: imitation is the sincerest form of flattery. A singular view on materiality may involve functional determinism: a material should only be used for its functional characteristics. However, based on subjective experience, there are aspects of materials that hold meanings. Stone is a material that can withstand many storms and is interpreted as solid, robust, and everlasting based on its historical use. Steel performs better than stone in terms of physical constraints (withstanding higher stresses and can be formed into robust shapes and profiles more easily) but features an entirely different experiential quality. Steel is also an artificial material not found in nature, similar to virtual materials, but has been adapted to contemporary construction based on its efficiency. The functions of materials become symbolic within the virtual realm; thus, a designer may select a material pallet to represent specific ideas during a physical design process. Ultimately it is up to the designer to decide their approach to virtual materials.

Physics-based rendering is an example of simulation within virtual space that attempts to replicate specific patterns of our physical reality. Technology has also grown to incorporate other simulations of physical reality within the virtual experience. Space, time, gravity, and other fundamental forces are becoming more robustly adapted within virtual space. While the range of these simulations is currently limited by computational power, it may be possible to see these aspects as real-time simulation tools for designers in the future. This raises the idea that virtual environments will follow Moore’s law and slowly evolve into something attuned to the 1999 film, *The Matrix*. While this movie features a dystopian future, it raises questions about the potentials of virtual space. Some may say that authentic experience is not a simulation; however, the equations that govern the simulation originate from mathematical definitions, which model experienced reality as the highest truth. Hence science establishes its value. Mathematical descriptions of a physical phenomenon are beneficial since they can predict how reality will behave. Engineers use these equations to verify structural stability or thermodynamic relations. Photorealism in virtual renderings would not be possible if mathematics untruthfully represented reality. Thus, the perspective of virtual environments as a microcosm to a matrix-like development is a complex dialogue that virtual designers should ponder as technology continues to improve.

Virtual technologies, despite their achievement and progress, are still incomplete. Hence the term “uncanny valley” has emerged to describe a particular phenomenon coined by Masahiro Mori. The uncanny valley describes how something appears more fake the closer it attempts to replicate a physical counterpart. This makes photorealism a difficult task and is something contemporary designers continually attempt to avoid. While some virtual technologies have yet to climb out of the uncanny valley, current technologies progress towards an improved realism. Designers sometimes opt to make more abstracted designs to avoid the uncanny valley effect. However, the cost of this is more significant separation from lived experience via low resolution and could debatably lead to poorer immersion. Because an architect designs for both the public and the individual, it is difficult to reach a consensus on which approach is more appropriate. Figure 14 describes the nature of low-resolution materials and the sizes of different resolution textures used for PBR approaches. Higher-resolution materials, while effective for photorealism and capturing detail, require more memory than abstracted materials.

While the technology is growing towards more advanced simulations of non-visual dimensions, one may ask if it is necessary to adapt them within a virtual context. Is it worth it? Some may say that the integration of advanced simulation is unnecessary since it required too much computational power to benefit. However, another perspective may be that more advanced simulations improve the immersive qualities of the virtual environment. When an avatar inhabits a VE, gravity is a typical default force applied. Why? Because as one dresses into their avatar’s skin, they inhabit the virtual space and thus expect gravity to be present on their avatar and themselves. As a user occupies a VE, they remain in a physical space where gravity is present. Although we are not continually aware of the presence of gravity, the moment it disappears, we become aware. This is true for other typical forces and is paramount to the immersive qualities of a virtual environment. There are simple models for gravity, and there are complex models. A designer should determine the best approach for their intended project. A designer can easily break gravity within virtual environments, but in terms of architectural experience, it is not a typical way we experience space (unless one is within the International Space Station).

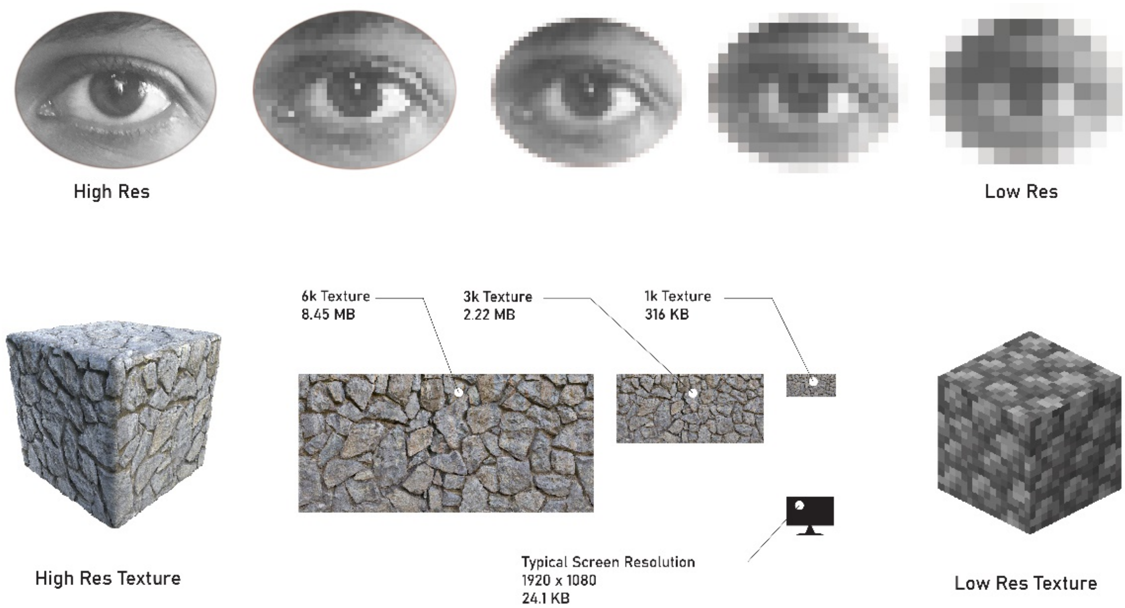

Figure 14: An example of a 3D Texture, Size Variations, and Resolution Comparison. Figure by Author

Space, as it is, can be phenomenologically defined by the freedoms that it allows us and our bodies. It creates a feedback loop that translates to an understanding of our limits. People subconsciously associate their limits with the limits of the physical world. The following expert is a dialogue from Michael Benedikt on the limits of space and our experiences of it:

> "We can define 'space' in phenomenological, operational terms. That is to say, we can talk about how space appears/feels to us, and what both space and various concepts of space are 'good for' objectively. We can ask: What operations does space permit or deny? What phenomena would be different if space were not "constructed" in this way or that? In what elusive physics are we so embedded that we cannot report on its laws? And if physical space has a discoverable and constrained topology, what of spaces of the imagination? Is not our ability to construe the latter precisely that which throws the former into relief" (Benedikt 1991, 126)?

Ultimately, virtual spaces are a simulation along with any additional forces or elements introduced. The debate will continue: is a simulation truthful or not? Is it truthful as a representation of patterned reality, but not truthful, for it is a representation? Phenomenology counters again by saying that regardless of representation, the experience is real for the one experiencing the space. Imaginative conceptions extend this further, making the questions of simulation a deep web of interwoven ideas. For this document, an introduction and discussion of this topic are essential as a foundation for the virtual designer and a base for further contingencies.

3.4 The Role of the Architect in the Creation of Virtual Architecture

Contemporary architects hold great responsibly for the design and management of construction, acting as a conductor for a broader orchestra. Architects organize stakeholder intent and design solutions to construction managers, consultants, specialized design professionals, and legislative bodies. With the ever-expanding complexities within construction methods, code updates, and competing design forces, the architect attempts to tie many variables together to achieve the vision of a project. For example, sustainable design interventions may contradict programming or site conditions. Although Frank Gehry can be considered a controversial figure within the architectural landscape, he echoes a sentiment about the current state of the profession: "Within all those constraints, I have 15% of freedom to make my art" (Gehry 2017). Even with limited control on project outcomes, architects are paramount in creating marvelous works that elevate our experience. Since architects are professionals in the creation of functional space, they should be aware of the potentials of virtual architecture and their role in this growing development.

Despite the difference in mediums, the design phases for a traditional architecture practice apply directly to a virtual context. Designs emerge from a central organizational methodology that uses active creativity within boundary conditions. A higher resolution of the scope increases complexity. Within the pre-design phase, a team gathers insight on a particular project, including but not limited to the site, program, existing conditions, zoning, and feasibility. This information informs higher-level decision-making that will remain over the lifetime of a project. Virtual architecture at this phase features a review of many of the same variables with some caveats and freedoms. Virtual architecture may be site-less or include a site and surrounding context. Site-less architecture would feature a complete interior experience or self-contained space (similar to being in a room within a room). Establishing a site within a virtual context depends on design intent but can range from a complete transformation to exact reproduction with minor excavation. Independent sites could also be created with no location with a physical counterpart. While clients would be the determinate of the pathway of the designer, site analysis is a common architectural practice, and one could argue that architecture and site are inseparable. Program analysis, climate studies, and other variables can also be transferred to the virtual context and significantly impact design choices.

The work of the architect is complex, not only for the responsibility the title holds but because of the infinite possibility of a project. From one perspective, the architect determines the form of the building from large massing placements to tiny ornamental details. The choice to move a single atom from one position in space to another can be placed under the architect. Although an exaggeration, no one can question the infinite frame of a creative endeavor. The architect is a painter on a blank canvas, and like a good painter, the architect must prepare paints and be intentional with every stroke. The blank canvas can be intimidating, but based on the initial conditions and design variables, an architect can confidently move forward. Limitation is the breeding ground for innovation. VEs also require an underlay of meaning to hold relevance in the near-infinite potentials that space may exhibit. The freedom of virtual spaces is liberating and frustrating since there are no existing boundary conditions to synthesis initial design ideas, only what the designer intends and what the computer and its tools may limit. Like Picasso in his piece 1956 illustrated in Figure 15 below, the plank canvas holds infinite potential (Friedman 1989, 15).

Figure 15: Untitled painting from the Studio at La Californie series by Pablo Picasso in 1956. The blank canvas in the center representing the infinite potential a painting may go and the paralysis an artist feels when beginning a new piece. Image by artist from source: (Picasso 1956)

Moving from a physical canvas to a digital canvas does not undermine the integrity of the painting; however, new abilities combined with a release on limitation is a new dimension for the tectonic creative. In a sense, what does one do with an infinite canvas? Many students crave this freedom while in design studios, yet they are unaware of the advantages of limitation. A seasoned architect knows how to work with limitations. As stated earlier, virtual realms have their limitations but are within a different scope; the virtual provides a freeing to traditional physical limitations and creates new challenges. For example, the different capacity of VR platforms becomes a formal challenge for virtual architects that may impact design decision at the schematic level; similar to how an enormous building requires more material, and an enormous virtual building requires more extensive data storage and optimization. Professional consultants are hired to help inform architects of potential hurdles or delegate specific tasks; this also translates to a virtual context.

Architects hire consultants for many reasons, but the most apparent reason is reducing complexity and maximizing professional competence. A seasoned builder may exceed within their domain but may struggle to perform the architect's job (although in the past, the roles were blended). Education allows specialization so that one may exceed within a narrow domain. The creators of virtual architecture feature programmers, environmental artists, and software engineers: all potential consultants under the architect. While these professionals are experts within their respective domains, few have a traditional architectural education. This is not to say that architects are not becoming more involved. However, architects are a minority of virtual designers. Maher echoes the fact. "The metaphor of buildings and rooms can be revisited and used in virtual places, suggesting the potential for virtual places to be designed by architects and then constructed by programmers" (Maher et al. 2000, 1). Architects can easily translate their experience and offer design services for clients that wish for a professional virtual design. The next step is simple since large architectural firms already outsource their renderings and animated walkthroughs to 3D specialists. Working with consultants and managing different teams is often an overlooked responsibility of architects.

Working with consultants is a necessary aspect of design phases and feeds into the current trends of the 3D industry. The term "pipeline" is often used within the 3D industry to illustrate the different phases an asset goes through during the production process. Architects within this pipeline would be responsible for conception during the pre-production phase and foresee the refinement of assets as they are produced. If architectural design phases were integrated into this timeline, it would involve a continual refinement of design as the concept develops. Architects would hire outside constants for this production process to implement their designs. Thus, programmers, 3D artists, and software engineers would aid the architect and client in achieving the desired final product as the virtual world's builders.

Table 3: Typical 3D industry asset pipeline. Table adopted by author from source: (Collins 2018)

#	Phase Name	Description
1.)	Pre-production	Generally concepting, idea iteration, and planning
2.)	3D Modelling	Creation of 3D models based on final pre-production concept.
3.)	UV Mapping	Preparation of Texture Overlay on a 3D model
4.)	Texturing & Shaders	Texture overlay on a 3D model
5.)	Rigging	Bone integration with 3D model and refinement of vertex groups
6.)	Animation	If an asset is dynamic, animations created via timeline
7.)	Lighting	Global Real-Time or Baked Lighting in Scenes
8.)	Rendering	Realtime or Baked Lighting Setup for the scene
9.)	Compositing	Refinement of Rendering Layers and Finishes

The architect within the virtual context would be responsible for the formal and functional arrangements of space and be directly involved with the embedded technology and how occupants interact with those tools. Because the 3D industry is heavily tied to the video game industry, the term “hero prop” appeared to indicate the interaction between user (as avatar and user) and artifact. We must not confuse the virtual architect with the game designer, despite their similarities in their creative pursuits. Video games are a common virtual reality experience that features a plethora of virtual spaces and virtual architectures. As a result, our culture has identified video game creators as the de facto designers of virtual spaces.

While intent for both the architect and game designer can be reduced to the singular axiom: to create an experience for the user, there are fundamental differences in design philosophy between them. The design of virtual spaces for games is strictly attached to the narrative of gameplay or the intended experience of the game designer. Video games and other media have a goal to provide a predetermined experience for their users. Although there may be freedoms and opportunities for unique expression for users within a game, ultimately, the game designer creates the foundational rule set that allows for controlled freedom. It is for this very reason that architects dislike the use of renderings as a representation of space. Renders can be manipulated and may not convey the range of experiential details of a space. Renders can also become a glorification of experience that the final project may never deliver.

Regardless, game designers focus on manifesting their artistic vision for their game experience, while architects are more concerned with how people function daily, safety, and how a design provides for the user. It can be argued that some architects impose their vision of how people should live through their manipulation of space, and to that end, they are no different from game designers. Game designers also borrow architectural design elements for their projects to protect players and other times with experimental intentionality. For example, the game *NaissanceE*, released in 2014 and developed by Limasse Five, is an experience that is designed to express harmful architecture that alienates and makes the player feel uncomfortable. Video games such as *NaissanceE* demonstrate how our virtual environments can be designed in a hostile manner. One paramount responsibility of the architect is to ensure user safety; thus, a virtual architect would also be responsible for user psychological safety as far as environmental qualities may influence.

Lastly, the virtual architect shares the fundamental role of the physical architect: to create the space of everyday experience. Based on phenomenological evolution in the 20^{th} century, many architects have adopted the stance that it is their responsibility to create spaces that manifest unique experiential qualities. Whether it be a ray of light across a hallway or the texture or shape of a handrail, the architect considers the interaction between person, object, and environment. While architecture has a long history with spirituality that has evolved into contemporary phenomenological views, the atmosphere of profound architecture may spark a unique experience. The narrative of life is an inescapable force that drives us into the future in search of our potential; architecture is the stage for that narrative. Within a virtual context, the narrative of day-to-day life remains just as profound. Although many office workers dread working in computer stations during working hours, UI and graphic design are intended to create an ergonomic and simplified virtual workspace to support its users naturally. Virtual architecture translates this principle into immersive 3D space; thus, virtual architects should strive to create virtual spaces designed to support the day-to-day functions over prolonged use.

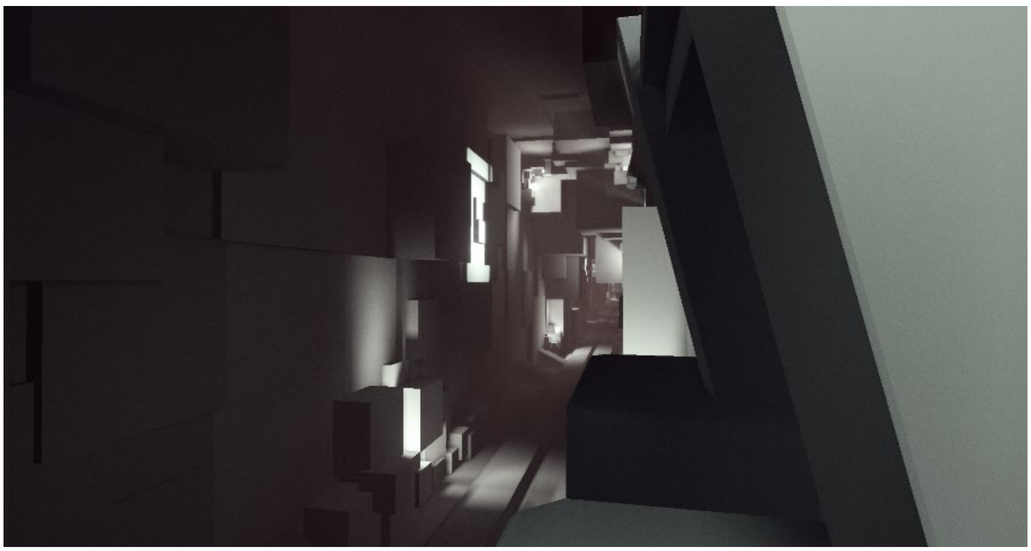

Figure 16: Screenshot of a *NaissanceE* interior. Image by developer from source: (“NaissanceE” 2014)

3.5 On Immersive Architecture

Disney is one of the largest media empires within contemporary culture and features two of the most iconic immersive spaces in history: Disneyland and Disney World. Both Disney theme parks are spaces where visitors can immerse themselves within the different narratives from Disney’s filmography, relax, and have fun. It is known as a place where one can forget the troubles of life and free their imaginations. Many virtual worlds attempt to do what Disney theme parks do, recreate a crafted narrative as a lived experience for entertainment purposes. We can extrapolate and state that many virtual worlds follow the design philosophies oriented towards immersive architecture and design based on this relationship. Video games are a prime example. Virtual spaces in games have adapted design elements from past, present, different cultures, and fictional landscapes to facilitate identity and established creative vision. With the introduction of VR technology allowing one to inhabit virtual spaces, it makes logical sense that space design would continue to follow the same trends, now with more immersive technology as a catalyst to design intent. Many nonprofessional, grassroots, and community-driven virtual spaces adapt popular media or archetypical places (such as historical monuments) as references for space design. This extends beyond the use of space for entertainment ventures. The freedoms virtual space offers are quite profound, and many creators have taken advantage. If virtual spaces follow immersive architectural trends for all functional programs, it is paramount to understand the difference between immersive architecture and traditional architecture to make a proper conclusion if this is a positive or negative development. To start, the most profound difference between immersive and traditional architecture is the design goal: immersive architecture wishes to create a fantastical setting or embellish a narrative more so than traditional architecture.

Immersive architecture is synonymous with theme park attractions and consumer spaces in terms of design approach since audiences are primarily attracted to the narrative of place. Design trends of this nature are reoccurring since it makes attractions highly profitable. These spaces use a tactical phantasmagoria to transport occupants to a seemingly different place while embedded within a current location. For example, a theme park attraction that is reminiscent of a jungle setting may feature diverse wildlife and architecture reminiscent of building design within that global context. These spaces rely on the visual aesthetics and details of cultural heritage to fuel the narrative and create immersion. Representing critical environmental details is paramount to captivate inhabitants and make their creative imagination soar. Virtual spaces have also adapted this approach, using digital tools as the means of production.

Physical immersive spaces follow a similar design trajectory compared to traditional design, with the main difference being the integration of narrative. Figure 17 below, sampled from

The Immersive Worlds Handbook, illustrates three different needs that immersive spaces must consider. Typical design objects are typically concerned with the first two hierarchies: human needs and human needs adapted for design. The third hierarchy reflects different narrative elements that are required to immerse someone within a fictionally influenced space.

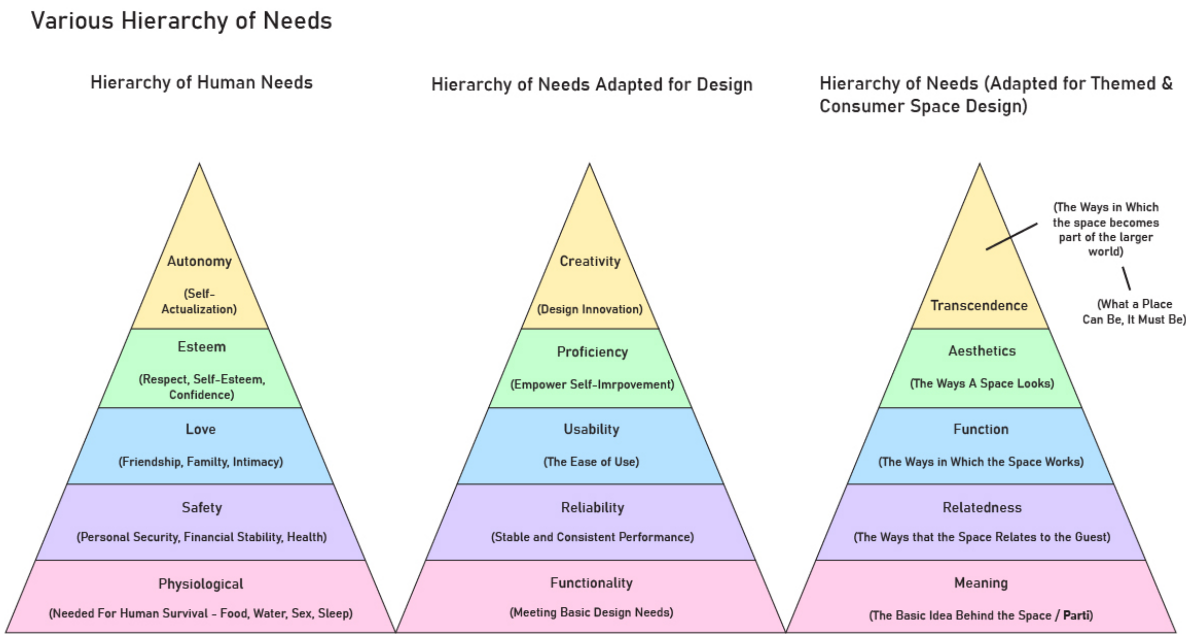

Figure 17: Various Hierarchy of Needs for Human, Design, and Themed and Consumer Spaces. Figure adapted by author from source: (Lukas 2013, 82)

Virtual environments also adapt these hierarchies with the exclusion of elements present only in physical reality. For example, one cannot drink water within a virtual space and cannot support physiological needs. It is debatable if physical architecture also adopts this third hierarchy as a design influence. However, instead of an external, individual, or fictitious narrative as the influence, one could say that physical architecture adopts a locational, cultural, or societal meta-narrative. Traditional architecture uses abstraction to facilitate a narrative. Many designers of physical architecture would dare say they intend to immerse their occupants within a deliberate narrative, for such intent can be interpreted as egotistical and manipulative. However, regardless of intent, the intended narrative may be a paradoxical by-product of architectural creation as an art or design object. Regardless, architects often do not articulate how their designs deliberately immerse their occupants. Few, if any, architects adopt an external fictitious narrative into space formulation and are mostly reserved for theme parks, consumer spaces, and virtual worlds. This leaves virtual architecture in a limbo that can be pulled to either side of this debate depending on the creator's intent.

The line between fiction and reality for occupants becomes increasingly blurred the more detailed and refined an immersive space reflects the narrative it attempts to represent. Thus it is helpful to distinguish the different *worlds* that compose immersive spaces if an external narrative is used as the origin of design influence. Figure 19 illustrates the four different *worlds* of storytelling that are involved with immersive architecture. The first world, World A, is the *real* world, the world of everyday life, and the realm of architecture and experienced reality. The second world, World B, is created, the conception of a world driven by narrative. The term *virtual* used in a classical sense would best describe this type of world; it is the world one enters when reading a book or the world of thought. The third world, World C, is a manifestation of the second world. Given flesh, one can now inhabit World B through World C. Lastly is the fourth world, World D. This world is the amalgamation of the individual within World C, bringing their values, perceptions, experience, and interpretations as mediation with World C, creating a unique identity for every individual. The four worlds act in a feedback loop. Coincidentally, this feedback loop is similar to a hero's journey in terms of user experience. An individual departs from everyday life to experience something novel, only to return to a steady-state existence and be changed by the experience.

Immersive architectural experiences are also subjected to a Darwinian determinism. As cultures experience an immersive space, they either reject the experience as authentic or accept the experience and treasure it. As a result, the created experience either dies or is modified to accommodate its users better. Disneyland and Disney World were two significant financial endeavors with no precedent wisdom to guide their creation. Architects contracted for the creation of Disneyland at the time did not understand the vision of Walt Disney. They provided traditional architectural solutions when Disney wanted something far more ephemeral and crystallized than abstracted (Iwerks 2019). Disney was soon rewarded for his efforts, gaining mass cultural acceptance. The result of Disneyland and Disney World has created a culturally accepted icon and a precedent for future immersive architectural projects, including virtual worlds.

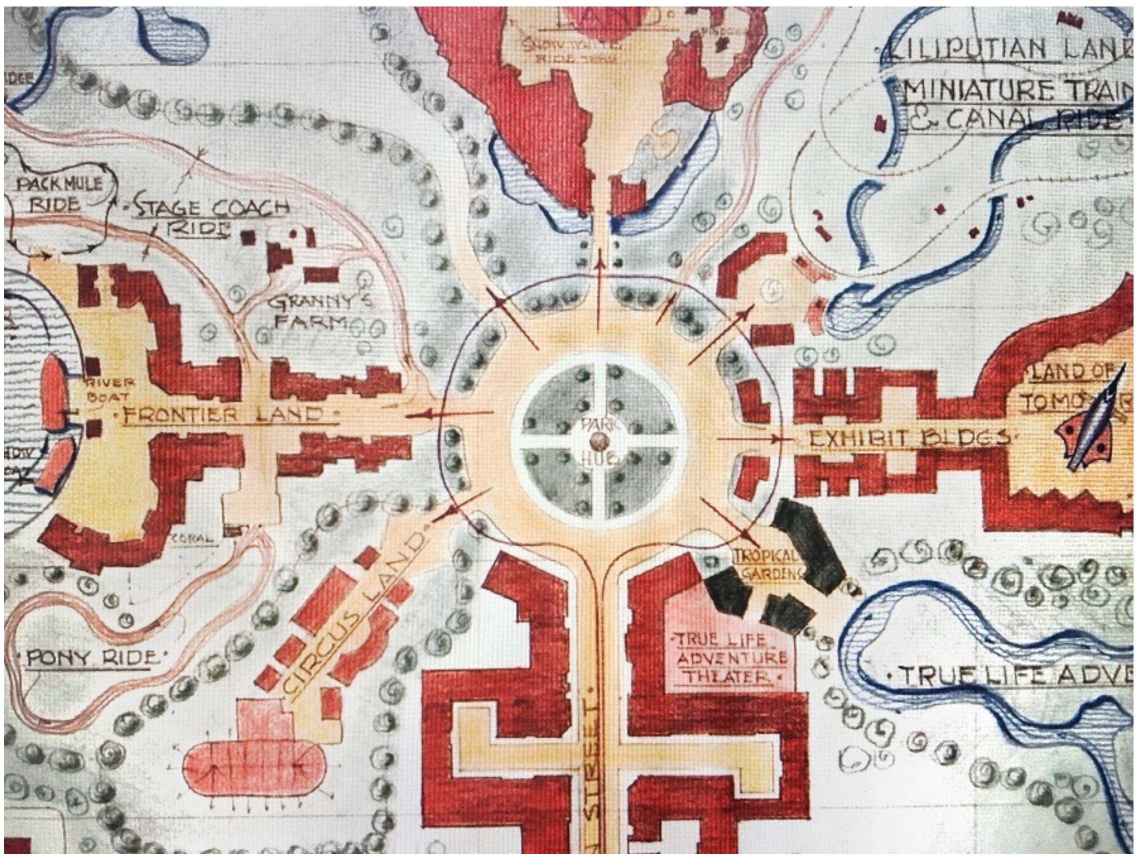

Figure 18: Disneyland following a hub and spoke pattern. Image from source: (Iwerks 2019)

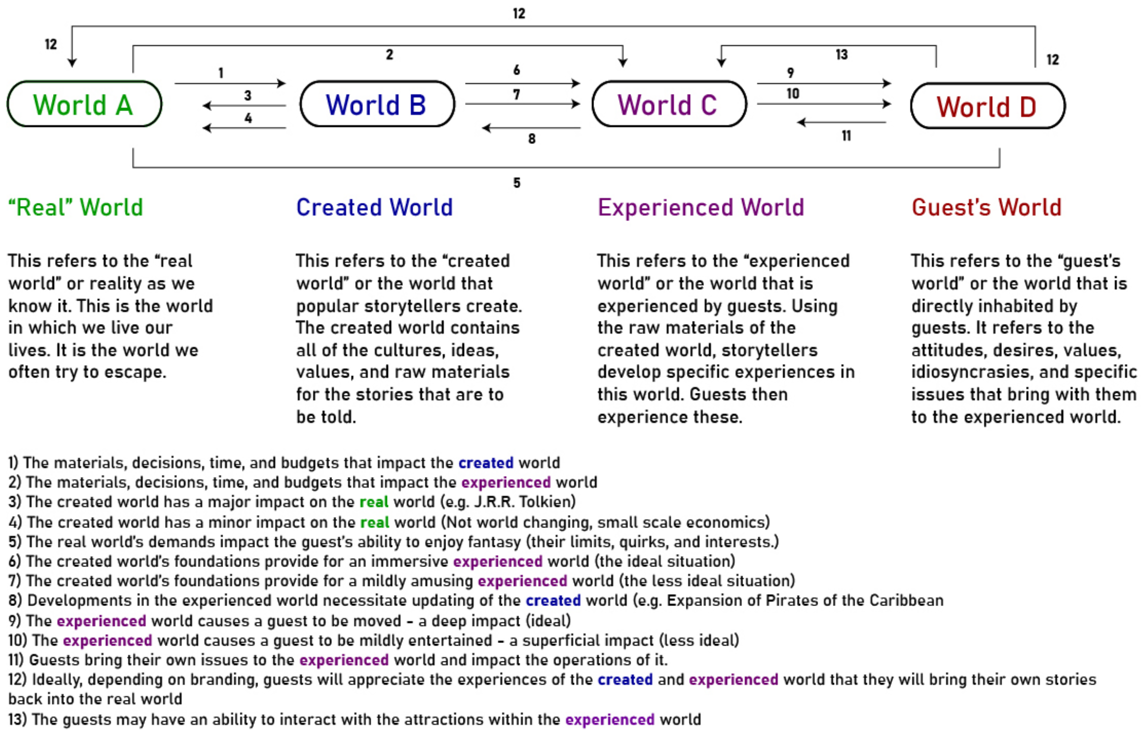

Figure 19: The Four Worlds of Storytelling and Interactivity. Figured adopted by author from source: (Lukas 2013, 230)

The consequence of immersive spaces on culture is a vast and highly debated topic. Some say that the creation of immersive spaces has created unmatched artistic experiences; others are more critical. For better or worse, creating immersive spaces has resulted in a new perception of what ideal architecture should be. While Disneyland may not be the direct culprit for this perception, it has undoubtedly influenced a younger generation that grew up in a culture saturated with media and refined immersive spaces. In a public now conditioned to desire ephemeral experience, these demands inevitably influence culture. Figure 20 illustrates how an immersive space evolves from a trial conception into a profoundly significant cultural artifact. Other works of art, architecture, or cultural icons can be substituted within this diagram but feature a similar influence on culture. Many popular immersive spaces, such as Disneyland, now occupy the "Traditional Stage" and thus have deep running ideological roots that now strain architectural understanding. Moving forward, it may be best to interpret immersive architectures as akin to artistic expression, physical architectures as spaces for every day that use abstract expressionism, and virtual spaces/architectures as a medium for both. As an artistic expression, Disneyland is a grand historical accomplishment. The issue now lies in the aftermath. As a global society overloaded with information and an increasing desire for an immersive experience, boundaries are now being crossed in an unproductive manner.

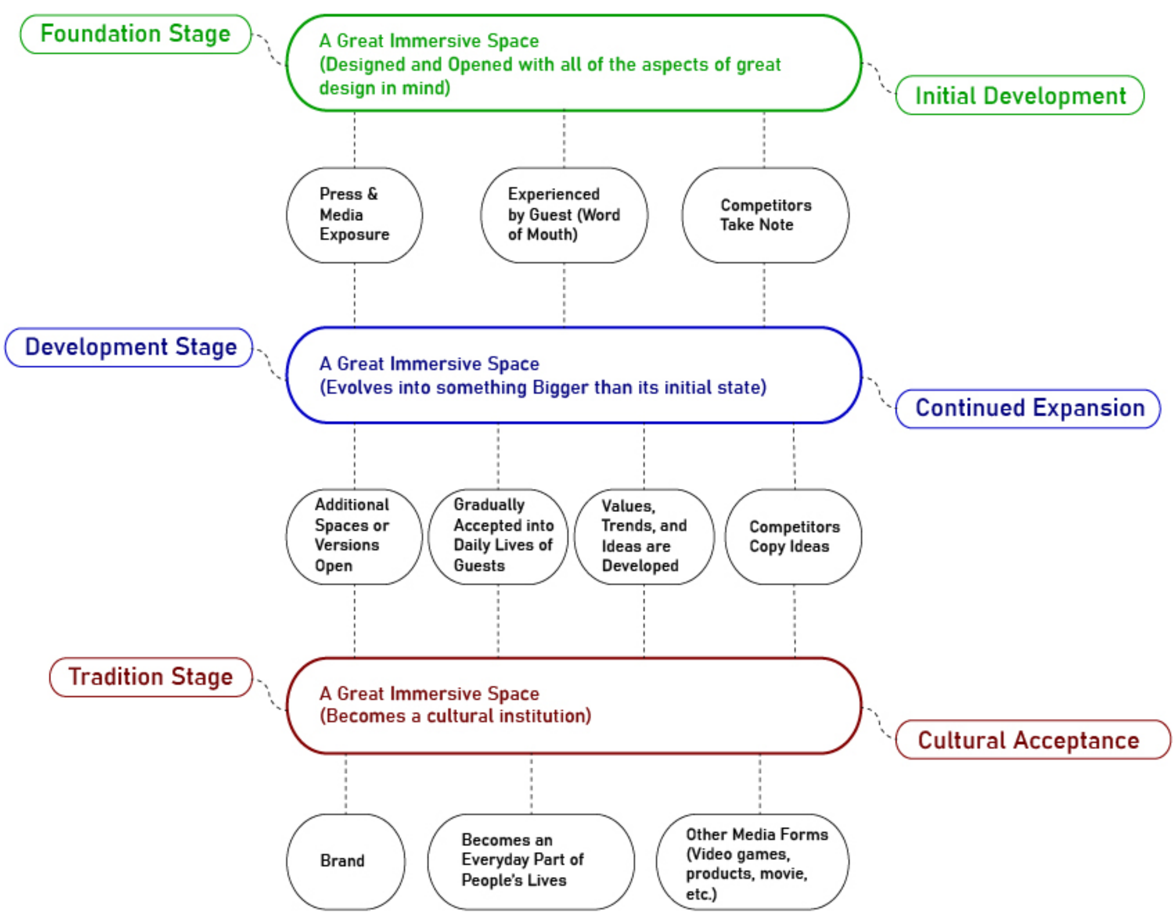

Figure 20: How immersive space traditions develop from initial conception to significant cultural icons. Figure adopted by Author from Source: (Lukas 2013, 241)

Michael Benedikt is a distinguished professor of Architecture at the University of Texas at Austin and has commented on current trends in architectural development. In his 2020 book, *Architecture Beyond Experience*, Benedikt analyzes how contemporary attitudes towards architecture have evolved from ideologies rooted within phenomenological and sacred origins. Benedikt references past religious ideas as paramount to the idea of architecture as a religious experience. These ideas have been excavated and refined into a phenomenological understanding during the 20th century. Benedikt argues that phenomenological ideas wrongly interpreted within a contemporary landscape have evolved into solipsism. Solipsism is, "in philosophy, the name of this individualistic, experience-centric, many-worlds idea taken to its logical extreme" (Benedikt 2020, 4). Phenomenological perspectives have given rise to solipsism, but the two should not be identified as the same. Since a phenomenological experience by definition is highly personal, there has been an increased focus on the individual and their importance within contemporary culture. Hence referring back to Figure 19, "World D" represents a world of the individual; there are as many of these worlds as there are people and possible experience. Thus, solipsism emerges from individual egotism: one's experience is of fundamental importance.

Contemporary culture is obsessed with individual experience, fueling immersive space design attitudes embedded within the day to day: experience on demand. Counterintuitively, while modern culture maintains an air of solipsism, objectivity has never been more valued. We live in a framework where we articulate our continued devotion to objectivity while demanding that the world manifests itself in as a novel narrative whenever possible. The rise of technologies such as the internet, social media, and smartphones is a catalyst for this development. People now have access to streaming platforms, video sharing sites, and limitless blog posts. Benedikt refers to VR's place within this trend specifically as: "Headphones for the eyes. Experience on demand" (Benedikt 2020, 9). Technology has given us access to our individualistic desires for novel experiences; this development has also influenced architecture.

Within the landscape of contemporary construction, there have been many buildings designed by star architects that attempt to capture public interest through expressive designs. Buildings like the Royal Ontario Museum (ROM), while praised for their contemporary construction in contrast with their historical surroundings, have also received an immense amount of negative criticism for their ephemeral characteristics and extreme expression. Buildings such as the ROM follow trends of the Bilbao effect to attract attention from technologically obsessed and solipsistic individuals. The Bilbao effect can be described as a phenomenon where "cultural investment plus showy architecture is supposed to equal economic uplift for cities down on their luck" (Moore 2017). Essentially the economic prosperity that arose from the construction of Frank Gehry's Bilbao Guggenheim museum created a model for economic rejuvenation. The profitability of such buildings has been proven but sets a dangerous precedent for the practice of architecture. Within an attention economy, the more outlandish the design, the more profitable the venture. Thus star architects become public icons, and their buildings are designed with the primary intent to attract attention instead of being human-focused or functional. Physical architecture that follows the Bilbao model can arguably follow immersive design trends outside of the proper context, even if the designs are more abstracted. As Robert Venturi would say, a duck is still a duck (although postmodern architecture can arguably also be guilty of this). Immersive architecture relies on established architecture as a basis for its ephemeral qualities. If both attempt to propel a singular narrative, we as a society become confused about our identity, what is real, and what is fantastical; satire becomes the actual, and the actual becomes satire.

Figure 21: The Royal Ontario Museum in Toronto, designed by architect Daniel Libeskind. Image from source: (Viola 2017)

Virtual architecture is at the crossroads of solipsistic, technologic, immersive, and Bilbao effect developments. Thus virtual architecture can be harshly criticized through multiple lenses. However, instead of virtual architecture being a victim of its surrounding circumstances, it may be the solution instead of continuing these problems. A shared sentiment among designers is that architecture by its nature should avoid being an overly expressive medium, like sculpture. Although a glass of wine after a long day's work is refreshing, prolonged drinking may have negative consequences. As architects, we must pace our creative vision over the prolonged life of a building and its numerous historical encounters from individuals. The abstract nature of architecture makes it something to appreciate continually but never tire from experiencing. Architecture should not avoid expression outrightly, instead of filtered through the proper contexts. The experiential aspects of architecture should be examined from phenomenological roots to avoid any ideological corruption. However, as designers, the temptation to create architecture that abides by solipsism and its nature is difficult to resist. Although the sentiment of this document is that virtual architecture should embody the principles of physical architecture, the possibilities of the virtual medium allow for multiple approaches. Virtual architecture may be an outlet for star architects to shine with their highly expressive conceptions. We must also not forget that despite the negative trends that have emerged from recent technological developments, there are many positive trends. Virtual architecture should embody these positive trends and use them as the origins of design intent. Virtual architecture designed through a solipsistic lens is doomed to become irrelevant and forgotten by society as new trends emerge.

CHAPTER 4

LITERATURE REVIEW

4.1 Literature Overview

VR is a recent development in retrospect in comparison to virtual worlds and architecture. Because there is little research that corresponds to the design of virtual architecture specifically, the literature review section will attempt to create a narrative based on selected studies from more developed intellectual spheres. The intent is to create a web of interconnected ideas related to the desired topic: virtual architecture. Before a design can be crystalized is first essential to address the dilemma of design forces. Some strategies may directly apply to virtual architecture, and others may not. Nonetheless, it is crucial to understand current intellectual developments from various sources to create a larger narrative for both virtual and physical architecture. The following section will address developments in VR with architecture, VR with education, and architecture with education.

A review of the existing literature exploring virtual reality, architecture, and classrooms / educational environments reveals many stems of cross-pollination within the intellectual landscape. Many academic articles review virtual reality integrated within the architectural design studio, and several articles discuss virtual reality as a means of representation to present architectural designs. However, there is sparse literature about virtual spaces or virtual environments and how they are distinct but parallel entities concerning physical architecture. There is an abundance of information on the significance of virtual reality and its applications to many disciplines such as education, social science, medicine, and psychology. Likewise, there is ample research dedicated to architecture's influence on education. Thus, the following literature review provides a narrative of VR concerning its current architectural applications and how VR can support educational purposes. This review will also explore developments in contemporary classroom design to integrate modern strategies for virtual environment application.

4.2 Literature on Virtual Reality in Relationship to Physical Architecture

Among its many uses, VR technology has been integrated into the design studio as a tool for architectural representation in recent years. Traditional architectural representation is most commonly associated with drawing and 2D formats to articulate ideas about 3D spatiality and includes sketch models and massing studies with various materials. Examples of the 2D tools architects use include sketching, photography, collage, material assemblage, drafting, and rendering. Although there are advantages to each form of representation, each also has shortcomings. The original intent of architectural representation is to simulate the experience of a project or articulate specific ideas. This inherently creates a disconnect between the image and the idea, meaning that the information one gathers from a form of media is an imperfect representation of the subject itself. This is fundamentally why, for example, multiple floor plans, elevations, sections, and perspectives are generated to create an overall narrative of an architectural idea to be constructed. An architect must synthesize these different representations to establish a holistic image of the project and desired intent. Virtual Reality interjects into this formula since it does what other media cannot; it places the architect within their building and allows them to experience their project from the lens of an occupant. Many envision architects as creators equipped with similar powers of the transcendent: creating and destroying the potential of a building with a simple eraser to paper. Figure 22 displays Corbusier's placement of an apartment section within the larger building. The hand representing the architect imposing their will upon the structure, morphing and forming the space with ease as an outside force.

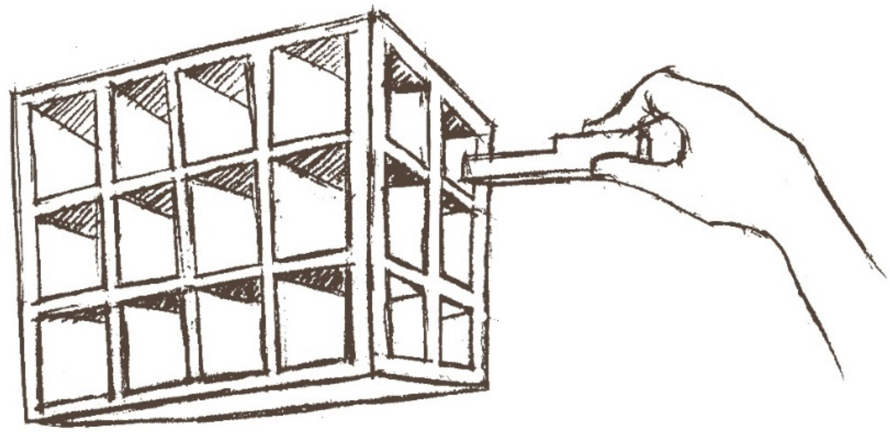

Figure 22: Plugin Concept by Le Corbusier for 1947 project Unite d'Habitation. Concept adapted into drawing by author.

Virtual reality adds a spin to the design process, for it allows the architect to transition from external perspectives and shift inward into experiencing the inside. When working with clients, architects have a limited ability to articulate their spatial ideas in real-time. VR allows for a shared perspective to make for streamlined communication. VR is one of many tools for architects to visualize, diagram, and manipulate the interior of their structures, but the true advantage of virtual reality is the immersive qualities. Immersion creates another paradigm for architects to review, criticize, and modify their work for the better.

In the article "Deliberations on the Imagined: Exploring the Virtual Body in Architecture," Stephanie Liddicoat expresses the potential advantages VR technology has over traditional media to convey architectural expression through a study investigating how people respond to virtual environments. Liddicoat references criticism towards 2D representation from Wodehouse and Ion (2010) and Spurr (2009), citing 2D representation lacks the "ability to express light effects and material effects. With recent developments in technology and advanced modeling systems, novel forms of architecture and representation are now possible, freed from the limitations of the orthogonal drawing system of plan, section and elevation" (Liddicoat 2019, 17). Liddicoat also references Alatta and Freewan (2017) to argue that 3D representation such as physical models, "indicate form and massing but cannot be inhabited. 'To assess human spatial experience, feel and spaces' functional relationships, designers have no choice but to imagine themselves in that mini-model" (Liddicoat 2019, 17). Liddicoat's study revolved around how individuals respond to virtual environments; she tests three different interiors designed by famous architects, re-created virtually. Participants were granted as much time as they wished in each environment and completed a survey to compare associations between the virtual and physical environments. Findings from the analysis were organized into three categories: volume, materials, and other design aspects. While participants expressed a wide range of reactions, the study concludes that:

> "VR experiences were commonly overlaid with imaginings of sensory encounters or affective states. The VR experiences are prompting an imaginary engagement via the human sensorium; the participants are experiencing virtual spaces and conceiving sensory stimuli perhaps to [fulfill] what is not possible to provide via a virtual encounter" (Liddicoat 2019, 25).

While VR experiences are purely visual, the immersion of VR triggers the body to respond to visual cues as if they were in a real environment. From this study, it was found that "participants viewed wooden interiors and commented on how they could "smell the oil varnish;" they explained that it was "hot and bright in the kitchen" or that it was cool and breezy" (Liddicoat 2019, 25). Although some participants had some adverse reactions to being in a VR environment, there were also many positive reactions. Thus, if individuals can overcome the shift in cognition to a VR environment, their experience can be used as a basis to compare to an authentic experience. Thus, there is a high potential for individuals to use virtual spaces to predict a user's reaction to physical spaces.

While virtual environments are helpful to an architect for design, non-architects have created a plethora of virtual environments for other applications. VR technology has seen great application in the realm of video games, where players can explore community-made worlds. Video games such as *Second Life* or *VRChat* allow a player to take the form of an avatar to interact with various virtual spaces. The article "Actual v. Virtual Venice as Constructed Environments: Place, Space, and Narrative Architecture in Second Life" by Alison McKee discusses the relationship between the city of Venice and the reconstruction of Venice within *Second Life*. *Second Life* is not a traditional video game in the sense that there is an objective or goal for the player to fulfill. Instead, *Second Life* promotes user agency to explore, socialize, work, and relax through interactive, user-created, sandbox virtual environments. The recreation of Venice within *Second Life* invites visitors to the virtual world in a similar manner to the original, with the virtual representation attempting to capture the character of the authentic Venice. The article reflects the concern that virtual environments may lack substance since they may not be *real*. McKee references Edward Castronova and Tom Boellstroff's ideas about virtual worlds to convey a more pessimistic perspective. Castronova and Boellstroff exclaim the difference between the words real, virtual, and actual. "To [reduce] the complexity of culture and cultural constructions of place to insist on a binary opposition of 'real' v. 'virtual.' Rather, to replace that binarism, he maintains poses a continuum between the 'virtual' and the 'actual,' asserting that both are equally 'real' " (McKee 2011, 170).

The creation of the city within the virtual world creates many parallels with the physical, most notably a sense of place. "Second Life is, first and foremost, rooted in a sense of place. Place, above all else, makes virtual worlds what they are: 'they may simulate abstractions of reality; they may be operated as a service; creating them may be an art; people may visit them in games. Ultimately, though, they're just a set of locations. Places' " (McKee 2011, 171). A sense of place may be based on historical, sentimental, or memorialized factors and is paramount in architectural design. Thus, a sense of place is a primary goal for virtual design.

While a virtual space developed on its own may create its sense of place, it may be possible that a design that integrates both the virtual and actual may evoke a greater sense of place. Does a place that is constructed physically hold the same value if constructed digitally? Is it possible to translate the essence of physical space into the virtual? While it may be impossible to recreate a physical space in a detailed manner, the truth is that they are two distinct entities that will never perfectly match. The McKee article does not answer these questions; instead, it highlights the nuances of the question and its difficulty. McKee exclaims the ability for virtual environments to adapt to user or community input adds, creating an additional layer to the design process. She claims it is possible to optimize a virtual space to create a genuine sense of place. “Like actual places, locations within virtual worlds tend to evolve constantly, though the rate of change is generally vastly greater than in the actual world” (McKee 2011, 173). With the capacity to change a virtual space, there is an excellent possibility to actualize an evolving architectural experience. This article also brings in a historic preservation perspective. Venice is a city that is destined to be submerged by the ocean. In the future, new generations of people will not experience the city's greatness and only witness other interpretations of the Venice experience. Venice as a concept reconstructed in VR eternalizes the memory of the city before its unfortunate fate. As a form of representation and thus a separate entity, it is not easy to compare the experiences between physical space and a virtual recreation, yet there is value in the recreation within itself. If a painting attempts to capture the essence of its subject, then a virtual environment can do the same.

Virtual spaces seen within massive multiplayer online role-playing games (MMORPG) involve a massive collection of avatars representing players in virtual space. MMORPGs are a relevant case study to understand how people interact in virtual space. The article “Spatial Poetics, Place, Non-place and Story Worlds: Intimate Spaces for Metaverse Avatars” by Elif Ayiter connects the question of place and non-place to virtual spaces. Ayiter defines metaverses as “collectively shared, three-dimensionally embodied online spaces populated by avatars that use the metaphor of the real world, however without many of its physical limitations” (Ayiter 2019, 155).

The term metaverse can be used interchangeably to describe virtual spaces or VEs; the only specific attribute a metaverse may contain is an active population. The appeal of a metaverse originates from the independence and agency granted to players where they can actualize creative expression within the space. Players can create "highly personalized homes furnished with the utmost detail – some quite palatial, but more in the nature of small intimate cottage-type dwellings – to vast forests, dainty parks and gardens, and windy seashores" (Ayiter 2019, 157). These players can then share these spaces with their friends or the public. Ayiter references *The Poetics of Space* by Gaston Bachelard, an analysis of architecture and phenomenology, as benchmark literature for architectural place-making. Specifically, Ayiter references the house as "the place in which personal experience reaches its epitome, as a place of intimacy and memory that is manifested in poetry" (Ayiter 2019, 159).

However, Bachelard also comments on non-places: places of circulation, consumption, and communication; examples of non-places include "airports, the shopping malls, supermarkets, highways and public transportation systems, the public spaces of all manner of institutions and workspaces" (Ayiter 2019, 161). Ayiter comments that individuals are increasingly spending more time in non-places in response to the grandness of their scale (making them attractive based on their formal scale) coupled with people's desire for solitude and private spaces. Although nonplaces lack intimacy, we are often drawn to them. Does this beg the question as to what category virtual spaces occupy? Place or non-place? The first impression of virtual spaces within a game such as *Second Life* may lead to the conclusion that virtual spaces should be classified as non-places. However, many spaces within virtual spaces are derivative from physical architecture and are recreated to add familiarity, creating a sense of place.

Contrary to this argument, many virtual places are relatively empty and are often temporary. Thus it is difficult for players to create meaningful connections to such spaces. Ayiter predicts that there will be a decline in interest in virtual worlds in recent years, for they create unnecessary complexity for individuals navigating them while other alternatives are available to perform the same functions. Despite this prediction, virtual spaces continue to thrive and even grow.

While architects and designers are busy with physical projects, online communities have dominated the construction of virtual environments. While it is positive for users to create and share their spatial creations, specific trends and narratives from internet media have embedded themselves within virtual spaces. While McKee analyzed the physical into the virtual, another challenge is introduced: should immersive virtual environments embrace the fiction's portrayal? Dave Gottwald and Greg Turner-Rahman from the University of Idaho published "The End of Architecture: Theme Parks, Video Games, and the Built Environment in Cinematic Mode" as criticism towards architectural developments influenced by fictional storytelling. Gottwald and Turner-Rahman begin with a profound statement: "We now exist in a multitude of spaces, both physical and virtual, that have not been conceived of by architects" (Gottwald and Turner-Rahman 2019, 41). This statement refers to creators of non-architecturally trained animators, storyboard artists who contributed to the creation of Disney theme parks, and any creator of immersive media with the intent to manipulate a user's experience of reality. "This trajectory of immersion – a sense of being fully engaged in an activity or fictional space – runs from animation to the theme park model and its dark ride attractions and follows a similar path from video games to virtual reality" (Gottwald and Turner-Rahman 2019, 41). The theme park is a specific point of entry for the author's argument, for it was a deliberate act to manifest the fantasy of cinema into the reality of space. In particular, as a design element, darkness adds a mysterious element to space, thus aiding in the immersive qualities of a theme park ride.

Gottwald and Turner-Rahman argue that architects face a new design challenge they call "cinematic subsumption," described as an altered, immersive state of perceiving reality colored by the fictions and narratives of media. Gottwald and Turner-Rahman analyze the role of the architect of the future when public perceptions of design are being manipulated in the present to favor fictional tendencies. They argue that the "thematic design of virtual and physical spaces are shared by a cinematic lineage" (Gottwald and Turner-Rahman 2019, 42). People now have warped expectations of architecture as a result, and the two authors fear that this is an irreversible trend. From the first cinema to the integration of the TV into the home to the first theme park created by Walt Disney, the public has been exposed to animation and its themes. The birth of Disneyland saw a radical shift in architectural planning, rejecting many traditional approaches. Walt Disney was skeptical of architects and used concept art to inform the park's craftsmanship. When Italian philosopher Umberto Eco visited Disneyland, he remarked: "Walt Disney had finally managed to achieve his own dream and reconstruct a fantasy world more real than reality, breaking down the wall of the second dimension, creating not a movie, which is illusion, but total theater" (Gottwald and Turner-Rahman 2019, 51). This statement is more relevant than ever within our current data scape. With mass communication and social media, people can share content in a way unprecedented in human history. Technology has blended into our lives, and the media we consume is just as blended. Fiction has composed a great deal of this media. One could say humanity has immersed itself in the media fantasy that only technology could achieve, a true fantasy.

The trends established by Gottwald and Turner-Rahman are extensively applied to virtual environments. In current internet culture, it is common to share portions of media through memes. Memes are a common element shared between viewers of a particular piece of media often used to indicate a commonality between sender and receive. Video games create an ample supply of memes, and thus the reaction of video game worlds recreated for free exploration as VR experience is common (partly due to a cross-pollinated community). One could say a user's connection to an environment based on meme interpretation creates a shallow connection; however, this can be easily debated. Memes are a common element in physical design. For example, the romanticism of Greek and Roman architecture and the plethora of recreations until the 17th century is a meme present in physical architecture. Also, while some memes are shallow, others may manifest much more profound connections. Regardless, if one were to explore the landscape of VEs, themed levels based on mass cultural icons often receive the highest visitors. The attraction of the meme can be overpowering. “Current videogame spaces suggest coming complexities in the future built environment and a further subsumed role for architecture. Our conceptual trajectory implies a desire for further immersion into media and a tighter integration between physical reality and storyworlds” (Gottwald and Turner-Rahman 2019, 52). While Gottwald and Tuner-Rahman reflect the sentiment that more individuals wish to be immersed within fantasy, it may be possible that these desires may spark more profound interests in physical architecture and its meanings.

While immersive trends may remain within contemporary culture, there is optimism that the richness of architecture can claim a foothold with virtual environments. Gottwald and Turner-Rahman reflect on Robert Venturi’s quote: “Disney World is nearer to what people really want than anything architects have ever given them” (Goldberger 1972). The desire to be immersed within fiction or dreams is powerful. However, these qualities are present within physical architecture: it is not something that Disney has monopolized but capitalized. New media and mediums have influenced the public perception of ideal architecture based on colored fantastical perceptions, but architecture can take advantage of the people’s desire to manifest fantasy through new forms and evolved design, both virtual and physical.

Although non-trained individuals and communities create virtual environments, academics are beginning to take an interest in virtual architecture. The article “Project Anywhere: An interface for virtual architecture” by Constantinos Miltiadis outlines the development of Project Anywhere, the creation of a mobile and easy-to-use virtual space. Precisely, the team wished to create a virtual museum for the display of virtual art and artifacts. The proposal for Project Anywhere intended to “surpass the intention of previewing, and utilizing (sic) the fact that VR can produce believable environments, we suggest that there can be another use of VR, as an architectural choro-poietic (space-creating) medium to design and experience spaces solely intended for that purpose” (Miltiadis 2016, 388). Project Anywhere began in 2014 and was developed by the director of ETH Zürich, Professor Ludger Hovestadt. Hovestadt is deeply involved with the relationship between technology and architecture and has written abundantly on architecture within the digital renaissance. While the initial goal of Project Anywhere was to create an enjoyable virtual environment for VR users, a secondary goal was to make it mobile so that anyone could access the space within various physical environments. Three main pillars of the research involved: including more properties of human-based movement into virtual environments (aside from vision and head movement) to create a greater degree of immersion, creating new means of interfacing with space and performing actions, and enabling multiple users to coexist simultaneously with a shared virtual space (Miltiadis 2016, 388). HMD displays were used as the primary VR technology because other virtual technologies (such as the CAVE project) restricted the ability for multiple people to occupy a single virtual environment. The primary software used to create the virtual space was the game engine Unity 3D; it was selected due to its ability to GPU render and its compatibility with various VR devices and plug-ins. Results of the study have led to several insights into the capabilities of virtual space. To create a museum space, the creators found that the virtual environment did not necessarily need to follow spatial requirements typical for museums. There were no constraints to the medium (image, audio, video, 3D geometry, 3D animation) to be displayed as long as they were digital reproductions. The study ultimately demonstrates a successful creation of a virtual space that serves a function and reveals potential for virtual spaces in the future.

In a similar manner to Project Anywhere, the article "Physically Walking in Digital Spaces - A Virtual Reality Installation for Exploration of Historical Heritage" by Luis A. Hernández describes another virtual space named the Empty Museum. This article reviews the process of establishing an immersive virtual reality system that would allow users to walk while exploring a virtual world physically. To overlay a physical environment with a virtual space greatly empowers the experience of perception of space; the goal for the Empty Museum was to maximize immersion through this principle. This article provides guidelines to establish a multiuser virtual space set up along with a pipeline description for creating the virtual space itself. This article also provides guidelines for creating large virtual spaces and ways to aid users in navigating such spaces. Three different models have been developed: Scaled User Movement, Teleporting, and The Magic Carpet.

Scaled user movement involves scaling the stride distance of a user's virtual avatar in proportion to a benchmark standard step to allow them to take "giant steps" (Hernández et al. 2007, 493). Teleportation creates a dynamic where one primary space can activate other secondary spaces via designated sections of a space. The Magic Carpet feature allows a user to point in a direction and activate a command to rapidly move an avatar in that direction, allowing quick travel. While these movement techniques may break the immersive qualities of the virtual reality experience by literally breaking the laws of nature, they provide new mechanisms for users to circulate within and around virtual structures. Virtual architectural design should consider these mechanisms for circulation as critical design forces, as they fundamentally transform the relationship between spaces. Project Anywhere and the Empty Museum are steps in creating more academic interest in virtual environments, and they outline the process of creation, advantages, and limitations of virtual environments.

4.3 Literature on Virtual Reality and Education

> "Schools are influenced by political and social movements, new technologies and trends, the growing awareness of what makes us learn better and thus our notions of what makes a great school are constantly shifting and adapting to new ideas. Yet, we are still surrounded by the schools that matched the ideologies of over a century ago, when the world and our understanding of education was quite different; we lit buildings with the sun, we heated with massive oil and coal furnaces, and children were to be seen and not heard."
>
> Lindsay Baker, Lecturer in Architecture (Baker 2012, 3)

Although virtual architecture for education is the primary focus of this document, it would be paramount to discuss VR and its unique benefits as a tool for education aside from its potential as a medium for architecture. VR has been used in many different contexts to train surgeons, football players, pilots, and other educational ventures. Research has also been performed to create unique educational tools that use VR technology to interact with different subjects such as chemistry and molecular science (Bailenson et al. 2008). The following describes different studies that document the effectiveness of VR learning.

The Department of Biosurgery and Surgical Technology at Imperial College, London, partnered with the regional vascular unit from St Mary's Hospital to create a study to determine how well VR could be used for endovascular training of surgeons. The report became: "Virtual Reality Simulation Training Can Improve Inexperienced Surgeons' Endovascular Skills" by R. Aggarwal, S.A. Black, J.R. Hanace, A. Darzi, and N.J.W. Cheshire. For specific surgical procedures, it is necessary to move a controlling wire to perform specific tasks while viewing the wire's position on a two-dimensional screen interface. The control of the wire takes skill and time to develop baseline proficiency before attempted on physical patients. VR has been introduced as a training mechanism for surgeons to reach baseline competency. The simulation setup for this experiment was based on aviation models of training. The study used two groups: surgeons who performed over 50 endovascular procedures and another group that performed less than ten procedures. The tools used for this experiment involved a VR simulator with physical operation tools with active force feedback, otherwise known as haptic feedback. The study results found that experience surgeons were much faster at the simulation with an average of 571 seconds to completion than inexperienced surgeons who took an average of 900 seconds (Rajesh Aggarwal et al. 2006, 590). Over six training sessions, the inexperienced group made progress towards the time factor, clocking in times similar to the experienced group: 571 seconds for the inexperienced and 456 seconds for the experienced (Rajesh Aggarwal et al. 2006, 591). The article concludes that surgeons with minimal experience can improve the time to perform the procedure with short-phrase training in VR and that the training has the most significant impact on those with less experience.

In terms of athletic training, the article "A Case Study on Virtual Reality American Football Training" by Yazhou Huang, Lloyd Churches, and Brendan Reilly explores how VR could be applied to improve player reactions to calls and simulated plays. Over three days, this case study explored the effectiveness of VR training on athlete performance. This article created a proprietary football training software SIDEKIQ, designed for professional and student-athletes to recreate 3-minute plays. The VR setup can be applied via HMD or immersive environments such as the CAVE system. For this study, a four-walled CAVE platform was used with an Oculus DK-1 HMD. Heavy emphasis was placed on obtaining "high-fidelity motions" for the virtual football plays combined with highly detailed renderings with "multi-layer shader materials, real-time lighting, shadow, and SSAO" (Huang, Churches, and Reilly 2015). The study results saw 17 football players who play as a quarterback over three days of training answered the correct assessment questions by the end of the third day. The study claims that certain subjects: "have improved their decision making by as much as 60%, including improvement in pre-snap reads and in-game decision making" (Huang, Churches, and Reilly 2015). The football players received the training relatively well, with subjects describing the study as "super cool, very realistic and extremely interesting" (Huang, Churches, and Reilly 2015). This study articulates how VR as a tool can develop not only one's cognitive knowledge but also one's body-oriented physical skills.

The application of VR for learning in specific skill-based environments shows excellent potential within those respective fields. However, it is crucial to address how VR can be used as a tool within a general educational context. To understand how VR has been integrated within the educational system and to see what studies have been performed, the conference paper, "A Literature Review on Immersive Virtual Reality in Education: State of The Art and Perspectives" by Laura Freina and Michela Ott, surveys the intellectual landscape between 2013 and 2014. Applying the search term "Immersive Virtual Reality Education," Freina and Ott found that 54 papers were published in 2013, 37 in 2014. Two papers were released in 2015, but those papers were discarded because of the review's timeline (Freina and Ott 2015, 2). The majority of papers were produced in the United States, followed by the United Kingdom. Computer science was the most popular field associated with the search results with 60 percent of results. The second most popular was engineering at 20 percent, then social sciences and medicine with 24 percent and 11 percent, respectively (Freina and Ott 2015, 3).

When shifting the search term to "Head Mounted Display Education," only 18 results appeared, with ten referring to 2013 and eight to 2014. The United States and Germany had the most results for this search. The distribution of fields that the articles applied to is roughly the same as the previous search aside from mathematics in third place at 22 percent (Freina and Ott 2015, 4). The authors chose selected papers to read and assess and discovered many refer to university or pre-university learning. The majority of papers involve university-level topics or pre-university training; few papers were associated with early education. Only one paper was discovered to teach students between the ages of 10 to 12, published by C.A. Eleftheria and P. Iason. The authors suggest that since children are still developing hand-eye coordination and vision, VR is less impactful for education; the warnings attached to VR products do not permit children under 13 from using the technology. Little has been published on the relationship between VR and people with disabilities and VR applied at a high school level curriculum. VR has been applied as a visual aid tool for computer science and architecture at the college level. Between college level application and adult training, VR has been applied to the medical field most of all, with a wide range of applications from medical training and patient support education. The authors conclude with a list of applications where VR can greatly aid education in critical areas (Freina and Ott 2015, 6):

- Time Problems: problems involving traveling in time to allow students to experiment and visualize different historical periods or locations (Maria Roussou 2004).
- Physical Inaccessibility: Exploring normally impossible or impractical areas for human exploration, such as the solar system via moving around planets (Jan Detlefsen 2014).

- Limits due to Danger: For example, training firefighters to make fast and effective decisions in a situation in which the physical and psychological stresses are analogous to live firefighting situations (M. Williams-Bell et al. 2015).
- Ethical Problems: For example, training to perform a severe surgery by non-experts (Yuan Lin 2014).

Conclusions from this study suggest optimism for the application of VR for educational purposes in the future. The review of academic papers in the review suggests that STEM-related fields (Computer Science, Engineering, Mathematics, Medicine) would directly benefit from VR application in the classroom, however as mentioned in the author's list of applications, VR can be used for humanitarian subjects as well. For adult education and specific skill development, "VR and AR offer the possibility to move safely around dangerous places, learning to cope with our emotions while experimenting the best solutions while far away from the real dangers" (Freina and Ott 2015, 4). In a classroom environment where there is little risk for harm to oneself and others, VR aids in user engagement since "thanks to the game approach, it increases the learner's involvement and motivation while widening the range of learning styles supported" (Freina and Ott 2015, 6). The use of VEs and implies making learning a more engaging activity.

VR can place people in situations that may be hazardous in our physical reality; however, other factors contribute to the advantage of using nonhazardous virtual environment setups for educational purposes. The article "The Use of Immersive Virtual Reality in the Learning Sciences: Digital Transformations of Teachers, Students, and Social Context" by Jeremy N. Bailenson, Nick Yee, Jim Blascovich, Andrew C. Beall, Nicole Lundblad, and Michael Jin discusses four different experiments where the social interactions between student and teacher affect student performance within VEs. People may interact with one another in a VE through the use of avatars. However, people can also interact with "embodied agents," or computer algorithms that control 3D models of characters (Bailenson et al. 2008, 105). Most new video games use non-playable characters (NPCs) to create a likeness to a lived environment; people interact with NPCs to engage with game mechanics or progress to new spaces. NPCs are a form of an embodied agent. According to the authors, most research involved with VEs and learning involves interacting with embodied agents instead of avatars using Bailenson and Blascovich from 2004 as reference. However, the beauty of VR is the ability for people to communicate through nonverbal gestures and body language with their avatars. While the technology was still in its infancy, the technology has progressed to where avatars can mimic users' small and particular movements. It is difficult for an embodied agent to replicate the nuance of a controlled avatar without procedural motion capture and is often impractical in application. Technology in the future may potentially create believable algorithms, but the divide is just the same; embodied agents can never be avatars. Research on avatar interactions is still developing due to the technology gap that has been filled with innovations. Unique to VEs, embodied agents can substitute teachers to deliver lessons.

The potential for VR allows teachers to interact with their students anytime and anyplace. However, the authors of the article argue the importance of a social environment within educational spaces. The authors reference Wagner, 1998 to articulate the drawbacks of removing peers within a learning environment. The Johnson, Johnson, and Skon study of 1979 confirms that individual learning conditions underperform compared to social learning conditions with a cooperative or competitive context. The Wood, Willoughby, Reilly, Elliot, and DuCharme study of 1995 verifies that students studying with a partner outperform students studying by themselves (Bailenson et al. 2008, 107). These results suggest that VEs should allow multiple students to interact as they are learning. Reeves and Nass suggested in 1996 that people may respond to an embodied agent in a similar matter to an avatar in a virtual classroom.

The article by Bailenson, Yee, Blascovich, Beall, Lundblad, and Jin discusses VR classrooms through four different experiments. The first experiment involved teachers within a VR setup teaching a standard lesson but provided an enhanced perception and monitoring interface to indicate the amount of focused attention they provided to each student. When teachers instruct, they may fall into a rhythm of applying focused attention to specific areas or students, leading the rest of them within their peripheral vision. The test allowed teachers to be more aware of where their attention lay and distribute it more evenly. The second and third experiments involved the breaking of spatial proximities in physical space between teacher and student. For example, when a teacher is presenting to a group of students, their attention can only focus on one student at a time. However, in a VE, students' perceptions can be augmented so that it appears as if the teacher is focusing on each student individually from each student's perspective, even though this is physically impossible. The authors refer to this principle as "augmented gaze" (Bailenson et al. 2008, 118).

The second experiment focused on the visual angle between the teacher, and the third experiment focused on the distance between student and teacher. The study found that a reduction in the proximity between student and teacher resulted in improved learning. The fourth and last experiment published in this paper involves conformity. The authors reference Swinth and Blascovich from 2002, where it was determined that people "conform to the behaviors of other people in immersive virtual reality, regardless of whether they are avatars (representations controlled by other people) or agents (representations controlled by the computer)" (Bailenson et al. 2008, 125). The objective for the last experiment was to determine if a lecturer and embodied agents could influence student attention to lecture material. Three groups were established. One group would have randomly assorted embodied agents with positive behaviors mixed in with student participants, one with negative behaviors embodied agents, and one neutral. Questions were distributed to participants about lecture material and environmental details; it was found that the experiment with negative behavior embodied agents allowed participants to answer more questions about the environment than about the lecture. These results imply that these students were influenced by the embodied agents and were distracted from the lecture material. For the other two cases, it was found that lecture recall was more significant than environmental recall. Overall, between all four experiments, the primary design factors that affected student performance were proximity to teacher, teacher attention, unique configuration, and attitudes of co-learners via social influence.

Memory Palaces are a classic memorization technique that uses special awareness in three dimensions to help people remember information. The core principle behind a memory palace is the association between information and position. Key features within an environment become aspects that allow information to be coded and extracted more easily with the addition of spatial organization. The journal article "Virtual memory palaces: immersion aids recall" by Eric Krokos, Catherine Plaisant, and Amitabh Varshney explores the application of a memory palace within a VR setup. The primary goal of this study was to compare how a VR experience through an HMD would compare to someone using a traditional desktop to memorize the same information with a memory palace. The authors reference Godden and Baddeley from 1975 to state that recalls are more significant when someone is in the same environment where they encoded the information. These finding has led to the authors speculating the use of VEs to exploit this phenomenon; there is little literature present on this topic. The authors also reference Repetto and others from 2016 and their discovery in cognitive psychology that suggests that "the mind is embodied," meaning that "the way we create and recall mental constructions is influenced by the way we perceive and move" (Krokos, Plaisant, and Varshney 2019, 2). VR allows for immersion and a cognitive shift that creates the sense of space. Thus there is more significant potential for VR to create better mental constructions compared to desktop applications. The study results concluded that virtual memory palaces explored with an HMD VR experience were superior to desktop interfaces in the ability for participants to recall information. The difference between HMD and desktop use was 8.8 percent (Krokos, Plaisant, and Varshney 2019, 8). The authors comment on the study results and suggest that future VEs will create more memorable experiences that increase productivity through better recall of information, specifically through virtual memory palace applications. Even without the memory palace to memorize information, it can be inferred that VEs are better at conditioning memorization than desktops.

NOVA Science Publishers released a package of virtual reality-related articles in 2011 that describe scientific advancements related to virtual reality. One article within the collection was written by Laura Tampieri, an economics professor from Bologna University, Italy. Her article, "Second Life as Education Space for the simulation of Enterprises' Start up and for Managerial Culture Development," explores how VEs can simulate an organizational culture development and be used as an educational space. Tampieri highlights the increased interest in using VEs for professional educators, managers, social scientists, and policymakers since VEs allow for collaborative activities such as team meetings, employee training, product prototyping, sales activities, and customer relationship management (Tampieri 2012, 5). The pool of users active on *Second Life* makes for an exciting platform to test economic theories and mass social interactions. To understand the statics of Second Life users, Tampieri references Duffy & Penfold from 2010 that highlighted that Second Life "provides thousands of simulators and a resident population of over 15 million (and growing). Residents come to the world from over 100 countries with a high concentration in North America and UK. Demographically 60 % are men, and 40 % are women, and the main span of age is 25-34" (Tampieri 2012, 5). This article aimed to simulate the components of multiple businesses and apply them within a VE between 2008 and 2009 for business management educational purposes. While there was no conclusive evidence to determine the effectiveness of VEs on student abilities to adapt to the simulation, the project's ambition sets a precedent for future VE commerce and educational opportunities within such an infrastructure.

Lastly, Jason Jerald, Ph.D., is co-founder and principal consultant at NextGen Interactions who published *The VR Book: Human-Centered Design for Virtual Reality* in 2016. In this book, Jerald reviews many core principles involved with creating a VR experience as comments on many topics tangentially related to the potentials of VR. In one section of this book, Jerald comments on the future use of VR. Aside from the standard and uncommonly known applications to "oil and gas exploration, scientific visualization, architecture, flight simulation, therapy, military training, theme-park entertainment, engineering analysis, and design review," Jerald states that VEs can be used for safe learning environments (Jerald 2016, 12). Jerald references Edgar Dale's 1946 publication "Audio-Visual Methods in Teaching" to exclaim that "using more of the human sensory capability and motor skills has been known to increase understanding/learning for some time" (Jerald 2016, 12) (Dale 1946). Jerald also references Dale's Cone of Experience to express the different levels of experience from concrete to abstract. This can be seen in Figure 23. Jerald concludes that VR is a medium with embedded mediums such as text and video as abstract learning material. The experiential learning that can occur with VEs makes it an unmatched tool for education.

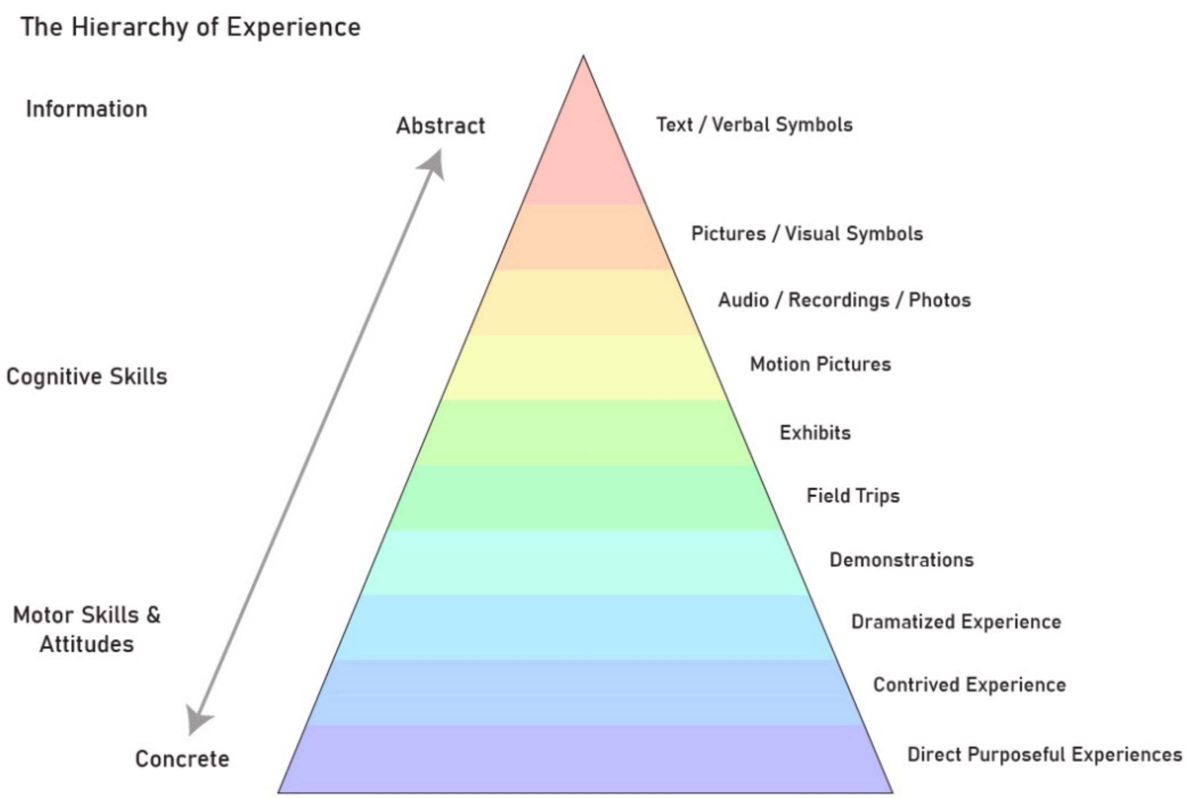

Figure 23: The Hierarchy of Experience from Abstract to Concrete. Figure adapted by author from figure by Jason Jerald: (Jerald 2016, 13). Original figure "Cone of Experience" by Edgar Dale: (Dale 1946)

4.4 Literature on Classroom Design Factors

> "The average high school graduate has spent about 13,000 hours within the walls of a public school building. These 13,000 hours are potentially the most impressionable and valuable hours of his life... Through this environment. The whole costly process of education may be encouraged or nullified. The school building is the tangible and visible evidence of the attitude of the public towards education."
>
> William G. Carr, National Education Association, 1935 (Weisser 2006, 196)

Schools are an institution that is critically important to the development of children and young adults, making the design decisions that dictate school design impactful at multiple levels. Even within higher institutions and adult learning, it is necessary to create environments that promote positive attitudes to learning, discovery, and creativity. How then is it possible to create a virtual environment that promotes a physical classroom's same values? Although VEs range in scale, style, pipeline, platform, and philosophy, many follow and reference foundational principles of creation that architectural professionals use. To create an authentic and successful VE, one must observe physical reality and successful design (Price 2020). While the effectiveness of physical design translated into a virtual context is still under study, the precedents and lessons learned towards improved classroom design make for a practical foundation for virtual designs. Thus, the following section will explore different studies on classroom design to assume that design solutions and principles can successfully transfer to a virtual counterpart.

There are many objective and subjective factors that influence student experience within the classroom. However, test scores have been the primary factor in determining a student's success in contemporary society. As a result, the primary variable used in modern research to analyze the performance of the built environment is student test scores. While using test scores alone as a measurement tool to determine how a learning environment performs is a flawed measurement criterion, the objective nature of the variable makes it significant for scientific analysis. Studies have incorporated surveys to capture the more subjective experience of occupants to account for the subjective.

Test scores were the primary variable in the question of the HEAD (Holistic Evidence and Design) study of U.K. primary schools. The goal of this study was "to explore if there is any evidence for demonstrable impacts of school building design on the learning rates of pupils in primary schools" (Barrett et al. 2015, 118). In this study, 3766 students from 153 classrooms and 27 schools in the UK were evaluated. The study was performed in 2015 by Peter Barrett from the University of Salford, Fay Davies, Yufan Zhang, and Lucinda Barret. The publication was titled: "The impact of classroom design on pupils' learning: Final results of a holistic, multi-level analysis." The study attempted to track student progress by averaging the test scores from the beginning to the end of a school year. The study also attempted to isolate classroom influence on student performance through "Pupil Level" vs. "Classroom Level" influences (Barrett et al. 2015, 123). Because it was expected that a student-to-student comparison within the same classroom would lead to a more significant correlation than to students in different classrooms, a multi-level linear regression model was utilized to allowed data to be clustered in groups.

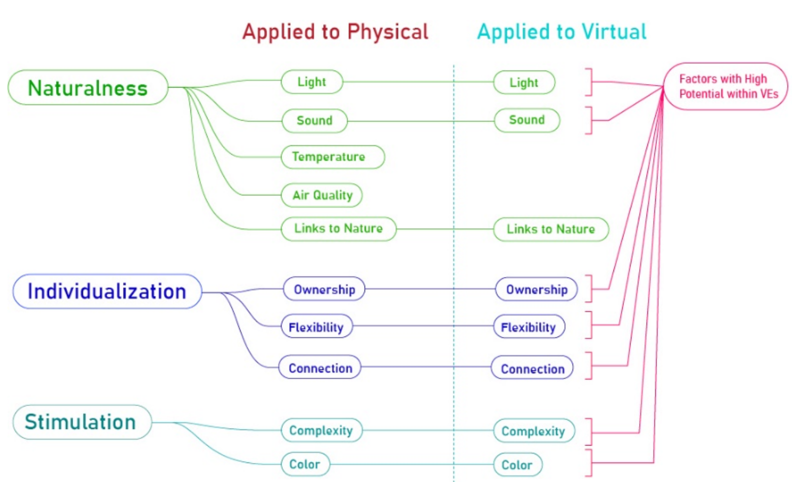

Figure 24: Classroom Design Factors and their translation into a virtual context. Figure by the Authors adopted from design variables from source: (Barrett et al. 2015)

The results were then compared to a multitude of different design criteria organized into three different categories. These categories are Naturalness, Individualization, and Stimulation; the complete list of design criteria with descriptions nested within these three main categories can be viewed in Table 4 of the appendix. Naturalness parameters involve aspects of the classroom environment that are required for physical comfort. Examples include light, sound, temperature, air quality, and links to nature. Individualization parameters relate to how well the classroom meets the needs of a particular group of children. Examples include ownership, flexibility, and connection. Simulation parameters relate to how exciting and vibrant the classroom is to the senses. Examples include complexity (level of visual detail) and color (Barrett et al. 2015, 122). The Barrett Study concluded that design variables under the Naturalness principle were 50 percent more influential on student development than Individualization or Simulation, with the other two categories occupying 25 percent. Among all the design parameters in the Naturalness category, sunlight penetration was the most influential. Light, temperature, air quality, ownership, flexibility, complexity, and color account for 16% of the variation in academic progress achieved (Barrett et al. 2015, 130). The statistical model results approximated that 55% of the variance in student grades was affected by pupil level and approximately 45% into the classroom level.

The HEAD study continued in 2017 and focused on extending the results from 2015 further to analyze educational subjects such as reading, writing, and math. Both articles highlight the contribution of past literature as they relate to different elements of the three main categories of influential variables. For example, within the Naturalness principle, there is extensive research documenting optimum: lighting levels (Mahone 1999), acoustics (Dockrell et al. 2015), learning temperatures (NASUWT 2012), and air quality levels (Bakó-Biró et al. 2007) (Dejan Mumovic et al. 2009). Also within the Naturalness category is a "connection to nature" that Barret refers via Rachel and Stephen Kaplan's publication in 1989 (Kaplan and Kaplan 1989), Kenneth Tanner's publication from 2009 (C. Kenneth Tanner 2009), and Wells (Wells 2000). Although Naturalness design parameters can be simulated in virtual reality, their application within a VE may need different studies to test their effectiveness. Individualization design parameters, however, can be directly translated into a VE and have tangible application. The Barret 2017 publication refers to (Killeen, Evans, and Danko 2003) and Skinner 1990 (E. Skinner, Wellborn, and Connell 1990) as references for the importance of individualization of space and its educational benefits. Barret also refers to Hattie (Hattie 2009) to illustrate the importance of student participation and willingness to learn; motivation is necessary for education. Even if students are placed within a perfect environment for learning, they will not learn if they do not have the will or motivation. It is believed that individualization design parameters allow students to feel included within a learning environment and thus facilitate a positive attitude towards the classroom and the learning community. The final category, stimulation, Barret refers to Engelbrecht (Engelbrecht 2003) to articulate how color affects "mood, mental clarity, and energy levels" (Barrett et al. 2017, 427). More visually complex environments were found to make children distracted based on a report from Fisher. Thus there should be a balance of complex and basic detail embedded within the environment (Fisher, Godwin, and Seltman 2014). While the 2017 study successfully associated student development in all three different subjects (reading, writing, and math), based on all of the previously mentioned design parameters there were issues. First, the Barret study only used test scores and grades as a metric to determine student development for these subjects, which can be debated. Second, by focusing on subjects of learning, it is questionable if the same assumptions remain in this new frame of study. Although the Barret approach is rigorous in frame and successful in identifying variables, it is hard to determine how certain variables relate to one another and if there was a feedback loop between these variables. Barret comments on this point:

> "It is notable that generally, the individual correlations between the 10 design parameters and learning progress are relatively small. It is a feature of this study that it has successfully isolated the influence of these multiple factors in holistic, naturalistic environments and revealed how there are typically multiple factors at play. That said, if resolved successfully,

> the return can be great, as although the individual correlations are small, the combined impacts on learning have been modeled as being substantial" (Barrett et al. 2017, 445).

Ultimately the Barret study created a comprehensive framework for design parameters that affect learning in physical environments that can be transferred to the virtual. While the approach of the studies is somewhat debatable and the primary demographic studied was children, these factors remain of paramount importance for educational facilities of all kinds.

The Barret study mentioned daylighting experiments performed by the Heschong Mahone Group in 1999 that concluded the importance of lighting (focusing on sky lighting) within an environment towards human performance. It was found in this study that students in classrooms with the most daylighting were found to have 7% to 18% higher scores than those with the least (Mahone 1999, 20). The Mahone Group is known for its studies with office lighting and its correlation to increased worker productivity. The Heschong Mahone Group prepared a second study commissioned by the California Energy Commission in 2003 that analyzed how daylighting affected students in the Fresno Unified School District. This second study, "Daylighting in Schools Reanalysis Report 2," was completed for further investigation to determine whether better teachers were being stationed in more daylit classrooms, and thereby inflating the importance of the daylight variable. Specifically, the study attempted to isolate how daylighting affected math performance vs. reading performance via test scores. This study used a "Daylight Code," previously used in the 1999 study, as a metric to determine how much sunlight was being received within a classroom. The building types within the Fresno district were also accounted for and classified as: Finger Plan, Double Loaded, Grouped Plan, Pinwheel, Pod, or Portables as a means to compare environments with lighting (Mahone 2003, 20).

The study results found no bias between better teachers to more daylit classrooms and that window tint (for sunlight penetration into a classroom) affects math scores while the total number of windows affected reading scores (Mahone 2003, 65). While the study primarily focused on daylighting, other physical parameters were measured. Mean Radiant Temperature, the uniform temperature of classroom determined when radiant heat transfer between a student and their environment is steady-state was also measured. The finger plan-type classrooms showed slightly higher temperatures in the summer months than other plans. With the addition of high-performance glass to the finger plan classrooms, there is a significant reduction to the mean radiant temperature with an average drop of around 10 degrees in the fall, spring, and winter month peaks. Extreme temperature gradients within classrooms have led to student discomfort and are negatively correlated with student performance.

Along with thermal comfort, the acoustic environment is also significant for learning. Situations where there is noise pollution may compromise student focus. Noises such as reverberant spaces, annoying equipment sounds, or excessive noise outside the classroom have discernable adverse effects on learning rates. Reverberation time, defined as the time for the sound to die away to a level 60 decibels below its original level after multiple interactions with the room's surfaces, was also measured. It was found that the reverberation time for finger plan classrooms is 0.77 seconds, and for the pin-wheel plan, classrooms are 0.48 seconds (Mahone 2003, 98). Poor ventilation and indoor air quality are also correlated with lower student performance. However, these variables are almost hopelessly intertwined with thermal comfort, outdoor air quality, and acoustic conditions, making it difficult to establish the degree of influence each variable may have individually.

Kenneth Tanner is a prominent voice in the discussion about school architecture, releasing several articles on the impact of schools on students. In the article “The influence of school architecture on academic achievement” published in 2000, Tanner asks: how do architectural design choices affect student learning? Before this question could be answered, Tanner first addresses school design patterns, referencing the University of Georgia’s School Design and Planning Laboratory (SD&PL), who reviewed the educational and architectural literature to create a foundational rationale. After the review, several axioms were made, including school environments influence behavior and attitude, behavior and attitude influence learning, and therefore the physical environment must affect learning (C. Kenneth Tanner 2000, 3). There are several design points described by Tanner created by the SD&PL and shown in Table 5 in the appendix. These points would be assigned values and formed into a scale used to survey the study population. “The population for this study included 44 elementary schools (representing 22,679 students) in 13 contiguous school districts in the State of Georgia” (C. Kenneth Tanner 2000, 9). The study used math scores to determine students' performance and select the student population, an extensive range of scores from the Iowa Test of Basic Skills (ITBS), to ensure that design variables were of paramountcy. The study found issues with two design patterns: compatibility with context and clearly defined outdoor rooms; these variables would require additional study due to their vague nature.

The study also found several patterns that predicted student achievement. The first significant factor was technology for teachers. If teachers had better access to technology, it was found that students performed better. Schools with the highest scores had designs that provided computers in several convenient locations for both students and teachers to access. The second factor was pathways. Freedom of movement allowed for less congestion and fewer restrictions, leading to fewer distractions. The third factor was the overall impression of the learning environment. Tanner references Hansen (Merrell and Childs 1998) and states that “a positive climate sends subtle messages telling students and visitors that a school is not sterile, empty, or lifeless” (C. Kenneth Tanner 2000, 11). Overall the common themes from this Tanner study echo themes of access to technology and flexibility for students.

The American Institute of Architects, Committee on Architecture for Education, and “Learning By Design” magazine created a series of publications titled “DIALOGUES to combine recent research with recent architectural design. To date, there are four issues of “DIALOGUES” that detail educational space research aimed at an audience of practicing professionals. Articles within “DIALOGUES” range from a variety of sources. The HEAD Project by Peter Barrett was featured within the 2017 issue, and an article by Jeri Brittin titled: "School Architecture + Physical Activity: A Tool for Exploring the Connections." While this article is mostly focused on the importance of physical activity regarding student health and how the built environment is influential, this article highlights ten core principles for design. These principles were derived from "229 full-text sources and retained 184 for review" with "77 sources that were empirical studies or reviews of empirical work" (Brittin 2015). The ten core principles are as follows:

- 1) School siting and community connectivity: Strategies related to walkability, recreation, and safety around the school and commuting routes.
- 2) Building Massing and Programming: Examines massing of building components, spatial patterning, daylighting, and space per student allocations.
- 3) Smart Fitness Facilities: Provides guidance on the type and number of fitness spaces and recreational areas to incorporate.
- 4) Active Classrooms: Addresses the layout of indoor learning spaces to support physical activity.
- 5) Outdoor Learning Areas: Attributes of outdoor classroom spaces and gardens.
- 6) Active Play and Leisure Areas: Preferred qualities of indoor and outdoor play and gathering areas.
- 7) Active Navigation Areas: Addresses the role of school navigation (e.g., stairs, routes, pathways)
- 8) Signage and Wayfinding: Describes how signage can reinforce appropriate types of activity.
- 9) Furniture Specifications: Highlights furniture options that encourage appropriate ergonomics.
- 10) Mobile Technologies and Virtual Designed Environments: Examines the use of virtual reality in conjunction with physical space to support physical activity.

The ten principles address movement potentials and diversity of architectural features for to consider during design. These principles address student movement within the classroom and around the classroom, and within an external context. While these principles are practical for physical architectural design, several principles can be integrated within a virtual context. For example, wayfinding within a virtual environment is necessary as it is in a physical environment. In addition to the ten principles, the study also provides subpoints for each category with an evidence rating based on direct evidence to a "best practices" methodology. Addressing principle number 10: Mobile Technologies and Virtual Designed Environments, it was highly recommended to consider "designing virtual reality spaces in conjunction with school physical spaces to support PA across the student athletic ability spectrum" (Brittin 2015). While physical architecture must comply with ADA accessibility requirements, the use of VR within classrooms offers an accessible vantage for disabled students. While schools may host a large and diverse range of students, the physical architecture must be designed to support activity, regardless of VR integration considerations.

Steelcase is a company dedicated to providing industry-leading office equipment and furnishing and is also involved with researching student learning environments to improve their products. In 2014 Steelcase released a while paper highlighting new data found in contemporary classroom arrangements and how they compared to traditional row setups. With a lack of reliable post-occupancy evaluations, it is difficult to determine the success of the original design vision for an architectural project. To remedy this gap, Steelcase Education researchers collaborated with academic professionals from the United States and Canada to survey four U.S. universities. The survey developed focused on student engagement and classroom design and was titled the Active Learning Post Occupancy Evaluation (AL-POE) (Konyndyk, Magnusson, and Hiebert 2014). It has been shown that the built environment can affect retention, attention, motivation, and academic achievement; student engagement is highly correlated with student success making it the primary focus of this study. 12 Factors were analyzed in the survey: collaboration, focus, active involvement, opportunity to engage, multiple means, in-class feedback, real-life scenarios, ways of learning best, physical movement, stimulation, comfortable to participate, and enriching experience. Figure 25 below indicates different active learning classroom layouts used in the study than a traditional row setup.

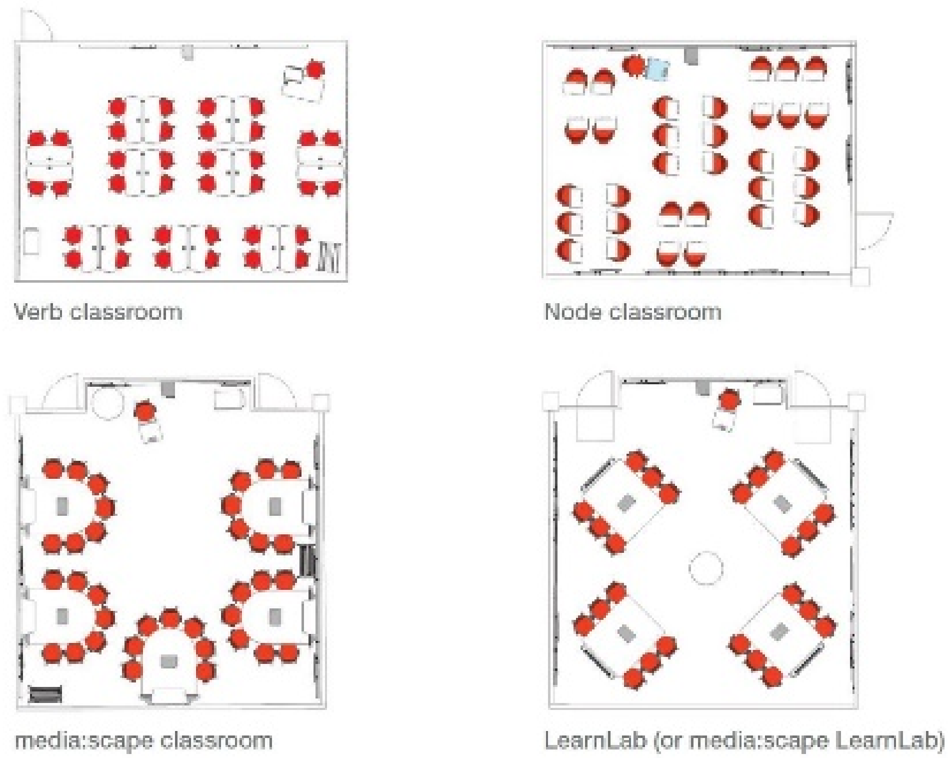

Figure 25: Four different scenarios for Steelcase Advanced Learning Environments used in the AL-POE study. Figure from source: (Konyndyk, Magnusson, and Hiebert 2014)

The results of the study found several primary findings. First, it was reported that participants in the new active classrooms were more engaged than students in traditional classrooms. Second, most students preferred the new classrooms and rated them as superior to traditional classroom setups in all 12 measured categories, as seen in Figure 26. Third, active learning practices and the impact of the physical space were more significant for both students and faculty in the new classrooms. Lastly, the active classrooms proposed greater engagement, more motivation, the expectation of better grades, and more creativity (Konyndyk, Magnusson, and Hiebert 2014). Overall the results of the study concluded that if classroom environments are intentionally designed to support active learning arrangements, students will overall engage more with their environment and have a better experience and improved performance.

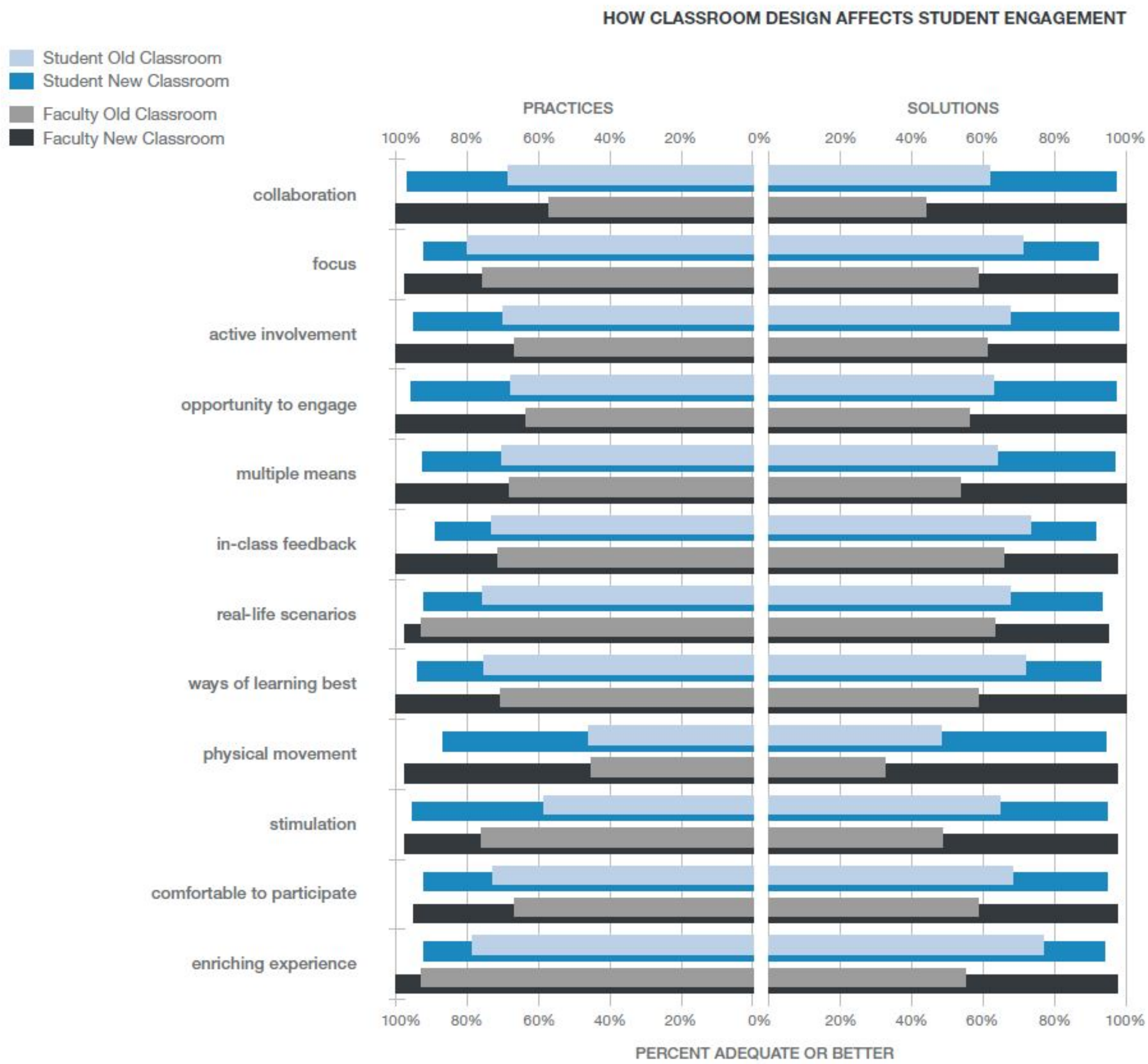

Figure 26: The results of the Individual Survey Items for 386 students and 42 Faculty in the Steelcase Advanced Learning Environments: AL-POE study. Figure from source: (Konyndyk, Magnusson, and Hiebert 2014)

CHAPTER 5

PHYSICAL PRECEDENT STUDIES

Physical precedent studies are a standard process at the beginning of architectural design to determine what projects are successful and how professionals creatively approach projects with different initial conditions and problems. Because the ultimate product for this thesis will feature a virtual environment based on physical design properties, performing both a physical and virtual precedent analysis is necessary for two reasons. First, it is essential to understand how physical architecture responds to the needs of students and educators to create cutting-edge facilities that promote education. Second, because different barriers and freedoms are involved when approaching virtual design, it is essential to identify successful virtual projects and understand how designers approach the virtual. The following section will begin with physical precedents analysis, followed by virtual in the next section.

5.1 Roy and Diana Vagelos Education Center

The Roy and Diana Vagelos Education Center of New York City is located in the Washington Height neighborhood and supports the training of medical professionals within the Columbia University's Medical Center. Design studio Scofidio + Renfro collaborated with Gensler as an executive architect to design the project. Multiple partners were involved in the design team, including Ricardo Scofidio, Charles Renfro, and Benjamin Gilmartin, with Elizabeth Diller, who operated as Partner-In-Charge. Construction began in September 2013 and was the center opened to students on August 15th, 2016, for the fall semester. The structure features 110,000 gross square feet of space contained in 14 stories. Dr. P. Roy Vagelos and Diana Vagelos, his wife, were distinguished members within both medical and education communities and were the primary patrons and raised funds through many friends, faculty, and alumni donors. Hence the building was named in their honor for their contributions. The primary constraint for the project was to create an elaborate design solution within a minimal site footprint, hence the elongated rectilinear form of the building as it towers 14 stories. The building base responded to the local communities' needs with a connecting bridge to the Washington Height area along with green spaces around the complex to break up the urban setting. Dr. Lee Goldman, the Executive Vice President and Dean of the Faculties of Health Sciences and Medicine at Columbia University, stated the building is a “state-of-the-art facility that reflects our commitment to providing world-class instruction and a superb learning environment for students” (“Roy and Diana Vagelos Education Center / Diller Scofidio + Renfro” 2016). With the advances in medical technology, research, and educational practices, the building also attempts to reflect these sentiments in the structure's design.

The Vagelos Education Center was shaped by the needs of contemporary educational demands to embrace non-conventional education methods departing from the traditional framework of lecture-based approaches to new team-based problem-solving.

> “In contrast to the traditional, institutional nature of medical education buildings—characterized by low-slung ceilings, densely-packed programs, and double-loaded corridors— the 14-story glass tower’s ‘Study Cascade’ extends campus activity along the south elevation of the building with a diverse network of social and study spaces for informal learning and collaboration” (“Roy and Diana Vagelos Education Center” 2016).

The philosophy of the Vagelos Education Center departs from many traditional norms by creating many non-uniform spaces that include individual study spaces, stepped lounge, exterior terraces, and a 275-seat auditorium with custom features. The north elevation is populated with learning spaces, including classrooms, class labs, and a simulation center, and includes cadaver and simulation-based examination rooms (“Roy and Diana Vagelos Education Center” 2016). The spaces allow students to work individually or collaboratively, in public or private, in light or shadow, and working day and night to accommodate night owls and early birds alike. The Vagelos

Center has also integrated virtual reality simulators as an educational tool among other "cutting edge" technologies "to service a wide variety of learners through innovative curriculum offerings" (Advincula 2018). Overall, the project integrates heterogeneous formal aspects to create nuance and character while creating a highly functional space that considers the needs of its students in the present and future.

The Vagelos is a physical architectural project and may not appear to offer direct utility to the goals of this document; however, there are many design philosophies embedded in the Vagelos Center that can be allocated to virtual architecture. Aside from the common theme that VR is increasingly utilized to aid medical professionals with their educational tasks and skill development, the center reflects many spatial sentiments applied a VR setting may apply. As a general observation from firsthand accounts, most virtual worlds operate within single-story planes enclosed by partitions or feature a relatively low number of stories. A hypothesis for this trend could be a byproduct of teleportation mechanisms to transfer one's avatar from one space to another space, making virtual worlds that feature multiple stories appear to lack utility. This may also be perpetuated with the accessibility to create VEs compared to immense effort to create a finalized physical space often bounded by site conditions.

The Vagelos Education Center demonstrates an elegance vertically and a shift from traditional grid arrangements to a more dynamic dialogue between spaces and layers. The non-homogeneity between the center spaces creates new potentials for collaboration and exploration while maintaining distinct programmatic elements. Not all learning needs to take place precisely in a "classroom" setting. Relationships between students are a pivotal aspect of learning, thus meeting and discussing in non-formal places often supports education beyond the classroom. The Vagelos Education Center clearly expresses this idea through its formal arrangements. This precedent invites its users to continue to climb up and through its different unique spaces, representing the non-uniform patterns of an individual's education journey with all its roadblocks and stagnations symbolically. To learn is never linear. Thus, the structure reflects its function. The architectural language of the Vagelos Center is a prime president in its synthesis of design philosophy with the final product, making it a profound influence on both physical and virtual architecture.

5.2 Smart Innovation Learning Center

The Smart Innovation Learning Center was a renovation to the Ganquan Foreign Languages Middle School located in the Putuo District of Shanghai, China. The school's roof was modified into advanced learning spaces designed to accommodate students with colorful and open modular classrooms. The primary designers for the project were NEILI Lab, their first official project with architects Jiaqing Wu and Jia Lin in command. The total gross square footage for the renovation featured approximately 800 square meters and was completed for student use in 2017. The Foreign Languages Middle School Shanghai is located in a primarily urban setting with rows of vegetation that flank the site's boundaries and run along alternating urban strips. The school organization itself was established in 1954 and had a reputation for being experimental as it is one of the first Chinese schools to integrate Japanese into the standard curriculum ("School Introduction" 2017).

The original roof of the school was a traditional flat roof; however, with this renovation, the roof was modified to sloped and opened the space directly below to create an ample space with the heightened ceiling and exposed structure and utilities. This choice to strip the space required additional structural requirements but created new issues for partitioning. The design concept for this renovation began with creating a new experiential and innovative space for students. With restrictions in the placement and density of structure members, the idea of "Innovation Cubes in the Forest" was created to turn this disadvantage into a pivotal element (Hu 2018). With the many dense columns representing the trees of a forest, modular partitions were embedded off-grid to create the "cubes." The traditional arrangement of partitions with the structural grid provided to be too inefficient. The project's focus was on students and their experience of the space through the concept of “hidden education,” which involves psychology, behavior, and cognitive sciences (Hu 2018). The challenge was to integrate these philosophies with the initial conditions of the space. The cubes specifically are the highlight of the design, for they each represent a different space with different utility and ultimately a most colorful interior.

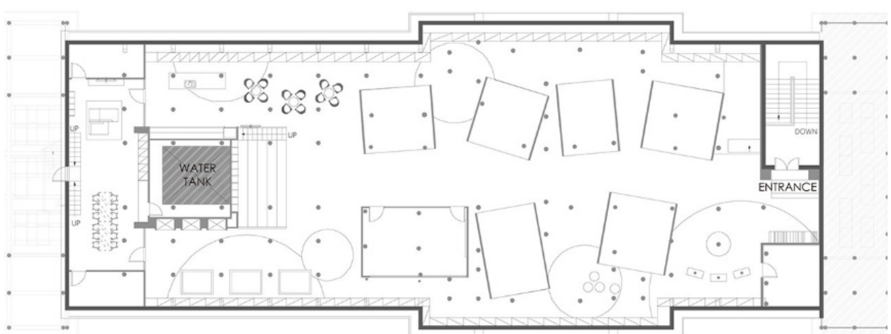

Figure 27, 28, & 29: Smart Innovation Learning Center Assorted Images of the interior, floor plan, and sample cube interior. Image by architects from source: (Hu 2018)

> “Each Cube is marked with a different fresh color, in which the students could experience a different inspirational space. The spaces are equipped with functional devices and furniture with different geometric elements, thus forming a multi-dimensional environment with multi-color & multi-shape co-combination, which serve better for inspiring students' creativity and enthusiasm of exploring the space” (Hu 2018).

All cubes within the interior are different in arrangement and function, featuring several tables and work surfaces, others with cubbies and landings. The flexibility of the space allows students to independently pick an environment that suits their needs on a day-to-day basis, adding an individualization element.

As a precedent for virtual learning, the cube clusters of the Smart Innovation Center renovation evoke privacy, diversity, and freedom for students to choose an environment, a sentiment that future educational VEs should consider. The non-linearity of the cubes encapsulates the potential of virtual environments to default from traditional structural rectilinear bays. While columns prove to be an archetypal element of architecture and rectilinear column grids prove highly efficient, structural necessity is often in conflict with formal architectural visions, the union of both resulting in successful physical architecture. For this precedent, the structure disadvantage becomes the basis for innovation and ultimately thematic towards to overall concept. In a virtual setting, the significance of the perceived structural integrity of a space or architecture has yet to be explored in-depth. However, virtual architecture is not bound by structural necessity. Thus, partitions and space framing elements are of primary importance to create successful virtual spaces. The cube model echoes successfully within a virtual setting for its intended educational use. Student agency is the critical factor for empowering students to venture and explore intellectual material and physical space to their liking. This sentiment is echoed through the non-uniformity of cubes via spatial juxtaposition and appearance. Virtual environments can significantly benefit from this approach to design philosophy, for it will make VEs more immersive and create a holistic sense of place.

5.3 Integrative Learning Center

The Integrative Learning Center is a focal point for the University of Massachusetts Amherst campus as a hub for team-based learning and highly functional tiered lecture spaces. The building is located on 650 North Pleasant Street, was designed by Stantec Inc., and was constructed by the Barr & Barr construction company. Construction occurred between March of 2012 and August 2014, and the project was estimated to have cost $93 million for the gross square footage of 173,000 sqft. The Integrative Learning Center (ILC) offers:

> "state-of-the-art education and technology facilities for the Communication, Journalism, Linguistics, and Film Studies departments. Located adjacent to the Lincoln Campus Center and Student Union, the facility houses offices, film broadcasting and production studios, editing and screening rooms, auditoriums, technology-enabled active learning (TEAL) classrooms, lounges, and language laboratories" (Rendano 2020).

The ILC is also a noteworthy building for its sustainable design. Over 90 percent of stormwater is processed with natural filtration mechanisms embedded in its green roof and lawns adjacent to the building. High-efficiency internal plumping allows a 39 percent reduction in overall potable water use. Compared to baseline buildings of the same size, the ILC uses approximately 34 percent less energy overall (Rendano 2020). The ILC has been a crucial asset for the university due to the public health response of the university during the 2020 COVID pandemic with its high-quality indoor ventilation and large teaching spaces that could host a large number of students for in-person teaching despite the reduction in overall occupancy from social distancing precautions. The embedded technology within most rooms allows for simple, hybrid-style teaching where someone may broadcast lessons through modern video communication technology.

The strengths of the ILC as a precedent for educational VEs can be derived from the variety of its educational spaces. The educational program of the ILC features a gradient of space types, including a large capacity auditorium, several tiered lecture spaces, multiple TBL classrooms, and many lower occupancy classrooms with high tech integration and non-fixed furnishings. The high occupancy lecture spaces feature dual screens for a full view of presentation slides, surround sound speakers to better broadcast a teacher's lecture, and whiteboards/chalkboards for more traditional note-taking utility. Although students concerning their professor range in the distance, the technology of the space accommodates the needs of all students to make for accessible lesson delivery. On an intermediary scale, TBL classrooms offer a highly interactive learning experience through group learning. In conjunction with easy access to screens for individual or group projection, socialization streamlines communication from one team to another, regardless of their spatial orientation. While TBL classrooms feature fixed furnishings, the last category of spaces within the ILC, the small classrooms, offer moveable 5’ by 1.5’ tables that can be arranged into many different arrangements. The tables allow adaption to the needs of individual classes. In terms of virtual application, a common theme from these spaces is the static focusing of student attention within larger spaces transitioning to more intimate and dynamic arrangements for smaller education setups. ILC classrooms make for an excellent foundation for the beginning of virtual design spaces.

The ILC is an excellent precedent for virtual class typology but will also serve as the site for the physical design intervention for this document. Section 7 of this document will discuss designing a platform embedded within the ILC that can support educators to teach within virtual environments. Section 8 will document the virtual design that mimics the University of Massachusetts campus with a solid connection to the ILC.

Figure 30: Integrative Learning Center – West Elevation Perspective from Campus Central Pathway. Image Copyright the University of Massachusetts Amherst from source: (Rendano 2020)

Figure 31: Integrative Learning Center – Site Map with Surrounding Context. Image copyright the University of Massachusetts Amherst from source: (Rendano 2020)

CHAPTER 6

VIRTUAL PRECEDENT STUDIES

6.1 Labster

Among the many utilities that virtual worlds may provide, a core theme based on previous research is their potential to deliver quality STEM educational setups. Labster is an organization that captures this sentiment with their virtual environments that simulate physical experiments one may find within a physical laboratory. Labster offers simulations and courses in Biology, Microbiology, Chemistry, Physiology, and Physics to over 1,000 universities and 3,000 schools; Labster advertises that 3 million students use Labster's virtual science labs ("About Us | Labster" 2020). Michael Bodekaer, the founder of Labster and serial entrepreneur, created the company to create a new tool for educators to convey information aside from digitized texts and lectures. Michael provided a TED talk about the potential of Labster in October of 2015, where he states that the addition of Labster in conjunction with the traditional educational approach nearly doubled the student retention of material (Bodekaer 2015). An article published in EdSurge from 2019 documents a surge of recent investments by several venture capital firms to support content development and further expansion into the US market. In all, 21 million dollars was estimated to be raised (Millward 2019). As schools transitioned to online learning during the 2020 COVID-19 pandemic, California Community Colleges incorporated Labster simulations to promote education while students remained at home.

The virtual architecture of Labster spaces features environments that attempt to recreate the aesthetics of physical science laboratories and facilities. While there are rumors that practicing architects designed the virtual spaces, no conclusive evidence suggests this notion. Regardless, the interiors within Labster are well designed regarding creating a controlled environment that aids in the narrative of scientific exploration. The interiors are reminiscent of physical lab setups with adequately modeled equipment that corresponds to a physical counterpart. This can be seen with the common materiality of furnishings and futuristic ceiling overlays. Interiors differentiate between modules; however, instead of formal continuity, the material, color, and shape languages of the spaces relate them together. An asset creator for Labster, Dirga Setyawan, uploaded images of different furnishings within Labster spaces seen in Figure 34. These furnishings highlight a unified aesthetic between architectural elements. Labster demonstrates that without continuity of space through formal juxtaposition, VEs can create a sense of place by appearance.

Figure 32: Signal Transduction: How Cells Communicate Virtual Lab Interior Perspective. Image copyright by Labster: ("Signal Transduction: How Cells Communicate Virtual Lab | Labster" 2018)

Figure 33: Sample Labster Interior Perspective. Image copyright Labster from source: (Labster 2020)

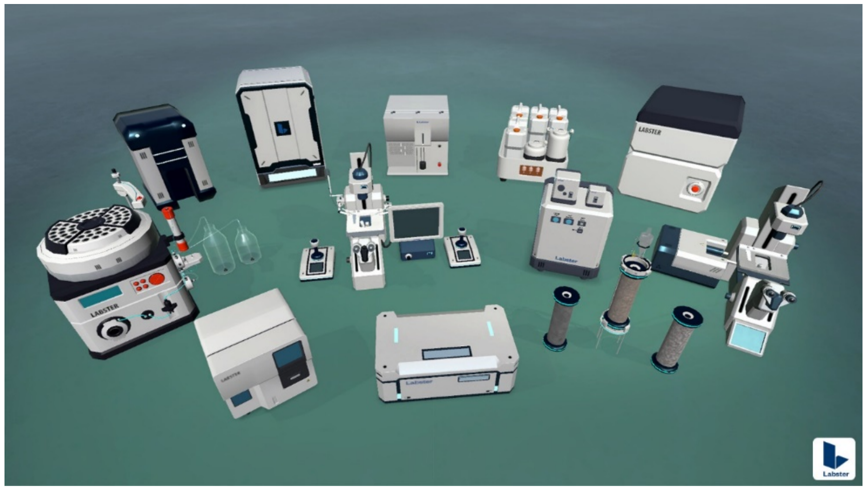

Figure 34: Assorted Labster 3D assets by artist Dirga Setyawan. Image copyright Labster. Image by artist from source: (Setaywan 2020)

6.2 Victory XR Academy

Another business venture similar to Labster is VictoryXR Academy, an online virtual environment platform for educational purposes. VictoryXR features over 240 different VR and AR experiences with more than 50 different learning units ("About Us | Victory XR" 2020). The company was founded by Steve Grubbs, Rene Gadelha, Wendy Martin, and Gus Halwani, all with rich backgrounds in education and learning research. VictoryXR operates within the larger VR educational platform ENGAGE: an education and corporate training platform for virtual reality technologies. ENGAGE "empowers educators and companies to host meetings, presentations, classes and events with people across the world." ("Home | ENGAGE" 2020). ENGAGE functions as a hub for students and teachers to access different VEs or simulations, VictoryXR modules included. In the near future, it may be possible to see courses on ENGAGE fully accredited. Through this platform, the mission of VictoryXR is to create intimate VR classrooms and spaces that are highly accessible and offer high-quality educational value.

Figure 35: Sample Victory XR Interior Perspective. Image by Steve Grubbs (Grubbs 2020)

Figure 36: Sample Victory XR Interior Perspective 2. Image by Steve Grubbs (Grubbs 2020)

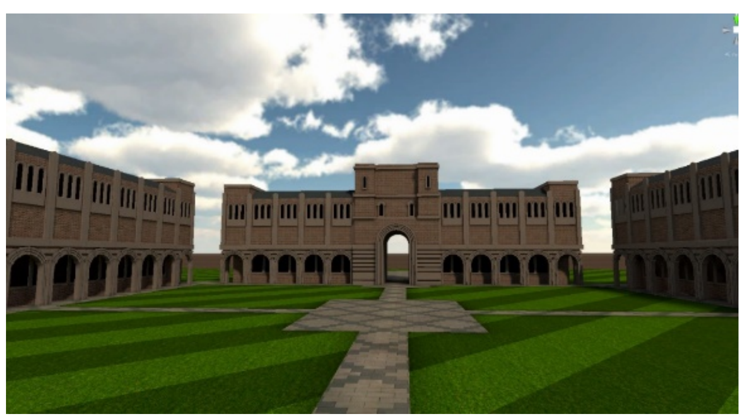

Figure 37: The VictoryXR Quad, intended for students to gather for studying and debate. Image by Steve Grubbs. (Grubbs 2020)

Before students can access the classrooms with VictoryXR, they are prompted to design an avatar that features a likeness to their physical selves. This is achieved by uploading a photo of an individual, and the avatar is procedurally created from that reference. A student or teacher may then select an environment to be transported to, depending needs of the class. The environments of VictoryXR were partly created by 3D modeler Aaron Hagens, the principal artist, and implemented by Daniel Coyle, the lead software engineer. The environments are highly optimized to encompass the range of VR technology currently on the market and allow compliance with various HMDs. Environments within VictoryXR feature a low number of total polygons, averaging 150,000 for a single classroom, a relatively low number for environments. The curriculum of VictoryXR differs from Labster, featuring experiences in space science, engineering, and life science. The environments for these courses provide contextual spaces and a variety of assets, animations, and tools for the educator hosting students. Like video meeting software, educators would feature a full range of commands to control the class environment. Among all the features that VictoryXR environments host, they also feature interactive media screens to broadcast 2D video and other media within the virtual environment. Avatars are also equipped with tablets that operate as a user interface to perform file searches or web browsing. The environments allow for digital interfacing with cloud storage to allow downloading of documents to share in class.

While VictoryXR environments are designed to capitalize on accessibility and ease of use for students and educators, there are elements to these environments that an architect may criticize. As a general observation, the architecture of VictoryXR attempts to replicate traditional classroom layouts without noticeable innovation to capture virtual opportunities. While the programming and software infrastructure is highly developed to focus on user experience, the environments are plain and ordinary with few elements that suggest embedded functionality. Designated seating appears to be the only element in a classroom that has a purpose, for it allows a student a tethered element for their avatar to be situated for lessons. VictoryXR features high-quality asset animations for display and interaction, but there is little consideration in terms of representation within the environment. For example, the display of pterodactyl models with flying animations spawn outside a classroom and follow a path through exterior walls, into the interior, and out again. If immersion is a critical aspect for educational utility, dinosaurs should be displayed in an environment and sequence as one would find if they were physically present unless approached in a diagrammatic fashion. This plays more into the narrative of delivered context, but the environment should facilitate the narrative if that is the goal.

Although the 2020 pandemic has forced many students to study remotely, VictoryXR cofounder Steve Grubbs states that the COVID-19 has promoted the use of more virtual education tools. He also stated that the idea of the "digital twin campus" has become more popular (Grubbs 2020). Digital twins are virtual reproductions of physical devices or technologies that are often intended to be used as prototypes and iterated before produced physically. 3D printing a prototype before complex manufacturing is an excellent example of digital twin usage. However, digital twins have moved beyond uses in manufacturing and into applications within the Internet of Things (IoT) (Fruhlinger 2019). The term became more integrated into popular culture after the term was featured in Garter, an IT service management company, commenting on future technology trends. This article defines a digital twin as "a dynamic software model of a physical thing or system that relies on sensor data to understand its state, respond to changes, improve operations and add value" (Cooney 2016). The same article reflects on VR and AR technologies' growth: "Rooms and spaces will become active with things, and their connection through the mesh will appear and work in conjunction with immersive virtual worlds."

6.3 Community Projects

Precedent studies within an architectural context are a tool for design investigation and are more normalized to feature successful commercial or private projects. However, because virtual environments for educational use are still within their infancy, there may be advantages to analyze how online communities and the current culture adapt virtual space for their own grassroots applications. It is also important to highlight these examples since community-driven projects are the most accessible form of virtual environment available to the public and inform public view. Online community hubs such as *Second Life* or *VRChat* are free for users to use and create virtual spaces. While architects have designed virtual spaces on these platforms, most users do not have architectural backgrounds and do not approach their design process with a refined architectural lens. Thus, for the benefits of a referential analysis, the following community projects analyzed will focus on the advantages and disadvantages these projects offer towards the goal of functional but holistic educational virtual spaces.

The first space, *Inter-action on the Math* by user Phi16, is a space dedicated to the visualization of complex mathematical concepts. The space features several display zones embedded in a circle fashion, with each display representing a different mathematical principle. After an interview with the creator, the motivation behind the space was to introduce to everyday users of VR complex mathematical representations to engender interest and respect for mathematical principles. Individual apparatus present in the virtual environment may become a staple element for virtual classrooms as importable assets. While spaces, such as in Labster, feature assets that replicate physical equipment, the setups with *Inter-action on the Math* are more abstract and appear more museum-esque with different stations users can freely interact and visualize. The space surrounding these modules is a contentious design choice. From one perspective, featuring the different modules within an endless dark space may create a sense of emptiness for users. However, the contrast between the dark spaces and the module frames highlights them as distinct elements within the space. Many of the modules feature colorful displays as well, thus having a dark neutral background creates further contrast for the displays, making their presentation clear and straightforward. Virtual worlds such as this ask a critical question: would students benefit more from environments that attempt to capture a narrative through space making (architectural or otherwise) or from more abstract environments designed to create a contrast to highlight displays and streamline content? The answer may lie with a gradient of both perspectives and dependent on the educational context. An architectural intervention that may benefit this virtual world could be a hovering ceiling. This ceiling would make users feel more contained within a space without sacrificing contrast between the limits and displays of the environment.

Figure 38: *Inter-action on the Math* by user phi16. Image by author

A second community project examined for its architectural solution was the Helping Hands community, developed to support users in VR with learning sign language. By using specific HMD controllers, it is possible to replicate hand movements to one's avatar. Thus the Helping Hands community created a space to support users with this technology. Unlike *Inter-action on the Math*, the Help Hands community has created a space that conveys a narrative through its architecture. The flooring, ceiling, color, lighting, and threshold forms in this virtual environment suggest that users are within a futuristic spaceship. The Helping Hands community environment demonstrates a common practice for virtual environments: establishing a narrative through the surrounding space. A narrative is a powerful device to create immersion and is helpful to get students engaged with the content. However, in the case of the Helping Hands community environment, does the narrative of a spaceship interior translate to sign language? If the environment was dedicated to science education or astronomy, the theme of a spaceship interior makes thematic sense. This approach was used for Labster's interior environments that use visual motifs to suggest a scientific exploration occurs within the environment. The Helping Hands community project illustrates the importance of abstract architectural intervention. If one were to develop a traditional classroom environment, the abstract nature does not feature a bias in the narrative of educational content. If one were to create a specific environment with a specific narrative, space should use motifs to fit the intended exploration theme.

Aside from its formal dissonance, the Helping Hands environment illustrates the desired functionality for virtual space. The Helping Hands environment features several pocket spaces that each use different media interfaces. Wayfinding elements were introduced to guide users that may be lost in a labyrinth of industrial corridors. However, in one of the pocket spaces, shown in Figure 39, one can see geographic maps used as reference material. These maps form partitions within the space and move users through to the next pocket space. The relative size between the geographic map partitions suggests that users prefer a more open experience to allow multiple users to inhabit the space. This can also be inferred from the height of the ceilings.

Interestingly, the map partitions clash with the environment itself, raising the need to have educational assets and the environment match in theme. Again, Labster, with its asset creation, signifies a narrative of scientific exploration to match the surrounding environment. Lastly, the placement of assets within the Helping Hands community environment suggests that users explore the environment in the manner of a guided tour in a museum. Virtual museums are a typical application for virtual environments; thus, it is no surprise that parts of museum DNA are featured in other virtual environments. A linear exploration from space to space adds to the narrative and acts as a signifier for progress and development, a potentially helpful motif for educational spaces to adapt to motivate students.

Figure 39: Helping Hands community sign language virtual environment. Image by author.

Although there are flaws to community projects compared to professionally created environments, they clearly illustrate how users desire virtual space to manifest. Interactive content is a staple between professional and community projects, although the relation between asset and environment differs. Contained space compared to open exploration space, although contextually relevant, describes a difference in educational approach between community and professional interventions. Based on the explored precedents, professional-driven projects tend to create a more guided experience with the limited agency to explore. In contrast, community projects are much more expansive and encourage exploration at the cost of less refined assets and embedded functionality. Both approaches are valid based on educational philosophy, and it is essential to establish that VEs can support different approaches as spatial interventions.

CHAPTER 7

PHYSICAL DESIGN

7.1 Project Background and Design Requirements

By its nature, virtual architecture is dependent on physical architecture to house the necessary technology and provide a safe, dedicated space for occupants. Given the current standard of virtual reality technology, the mobility of setups has been steadily increasing. HMDs allow for highly mobile setups compared to other VR interfaces such as the CAVE. Google Cardboard allows smartphones to be augmented into a portable VR interface. The invisible fabric of data that occupies space is also not limited to conditioned walls. However, when someone is immersed within a VR setup, and their senses are adapted to the new medium, the fact they are also present in physical reality does not change. Regardless, if a user occupies a virtual space, one must consider their physical surroundings. Even if someone can enter virtual space outside of conditioned walls, it is not always practical (especially for an institutional setup). Thus, the following section will explore the design of a physical space for educators (specifically professors or teaching assistants) to provide lessons within a virtual space.

The University of Massachusetts Amherst is a public research university that features diverse, high-quality educational facilities. The Integrated Learning Center, located in the center of campus juxtaposed to North Pleasant Street, contains several TBL class labs, case study rooms, seminar rooms, and a 366 occupant lecture hall. The building is a shining facility for the university and is a focal point for many students. Room N140 is a double high student lounge/entrance circulation/informal learning space that features a café on the first floor. The west wall of the space features views via a double-height curtain wall towards a central courtyard framed by the Student Union and Campus Center buildings. The second floor features a pathway to the lecture hall (room N151 via N299G), a second-floor lounge, and additional classrooms to the south. While N140 features 3,775 sqft of space, the double-height area occupied roughly 900 sqft. Based on the nature of the double-height space, this room was chosen as the site for a teaching platform for instructors to deliver lessons while immersed in VR. Figure 40 below shows the ILC's first-floor plan with a green hatch to indicate the exposed double-height space between N140 and the second floor. The yellow hatch illustrates the footprint proposal for the physical design. The proposed sqft began from 156 sqft and was increased to 170 sqft for the final design to prevent claustrophobic reactions. Because the first floor is a highly dense circulation space, it was decided that the platform will hover above the first floor, suspended from the second-floor ceiling, adjacent to the northern stairs. This will allow the continued functions of the first floor while providing additional functionality to the second floor unused open space.

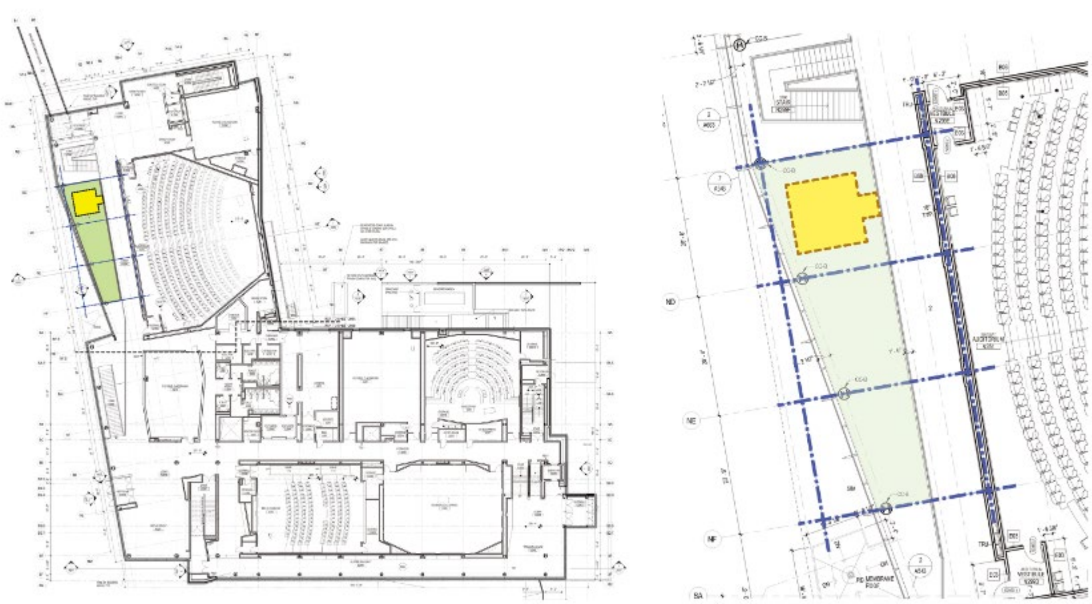

Figure 40: ILC Room N140 Floor Plan in context of the Physical Design Intervention. Green shading indicating the area available for design, and yellow indicating the design footprint. Figure by author.

In terms of constraints for physical design, there are several factors to consider. The first factor is the required space for people using HMD technology. VR arcades and dedicated VR spaces follow loose guidelines in terms of spatial setups, most commonly defining a dedicated square block of space to allow a full range of dynamic movement. Depending on the user's activity, one may use a full range of body movement, little or no movement. For more subtle activities, such as talking, people usually behave in a standing position, possibly shifting their weight to remain comfortable. HMDs can also be used sitting, to which the ergonomic constraints become adapted to that position. Some VR arcades and research experiments feature additional equipment that people may use to interact with virtual space. While hand controllers are the most common, they are not the only technology for this purpose. Because there are many possible outcomes when interfacing with VR, spaces are open and flexible. While the ergonomics of current VR spaces are relatively straightforward, technological advances are also significant.

The operational spatial requirements of contemporary HMD setups reflect the range of movement people need within virtual space. There are several brands of HMDs, each with a distinct range. Some HMDs feature self-contained sensors that react to how a person moves; other HMDs require base stations to relay movement signals and extend the detection range. Base stations often need to be placed in areas high and above, angled down, and pointed towards users. Base stations feature approximately 120 degrees of Field of View (FOV). These numerics change between brands (Lang 2016). Figure 41 demonstrates the different sizes of floor space recommended for an assorted array of HMD setups. Some brands such as the Oculus 2 feature a recommended area of 5 square feet, while other setups such as Steam VR can be operated with 16 sqft. The height requirements for base stations also depend on the brand but often feature a recommended range between 2 to 3 meters. Most base stations are mounted to ceilings; thus, ceiling height becomes the maximum possible installation height.

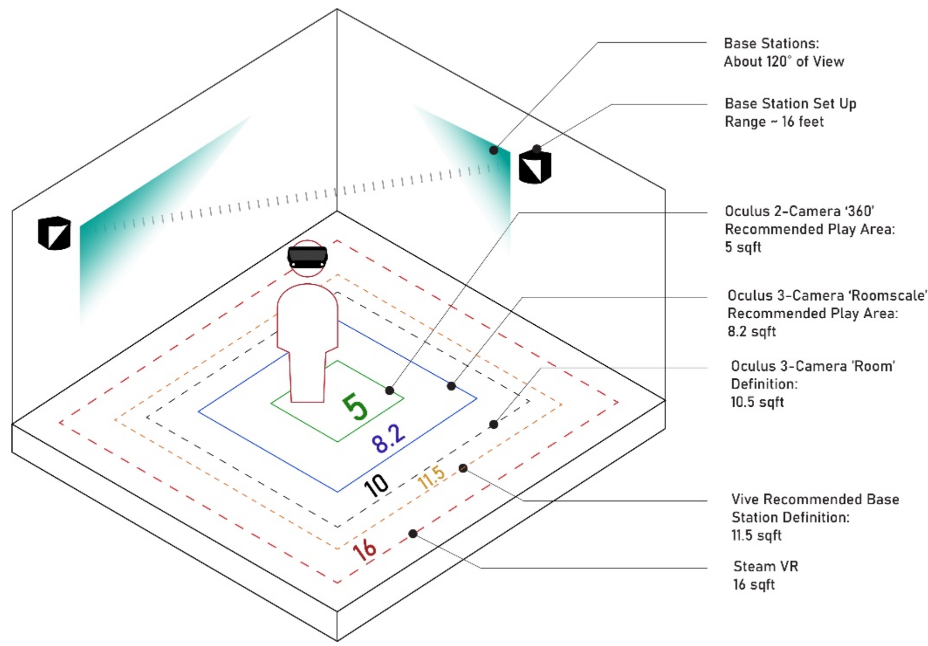

Figure 41: Typical Room Dimension for Different VR Setups. Figure adapted by author from photos by Ben Lang. (Lang 2016)

Lastly, although not a spatial requirement, there have been several adverse health effects that have resulted from the use of current HMD technology. "The VR Book: Human-Centered Design for Virtual Reality" by Jason Jerald, referenced again, describes several of the adverse health effects possible during VR use. However, Jerald's list features several effects, not all directly apply to the physical environment. Thus effects under an architect's control will be featured. The list of adverse health effects includes motion sickness, eye strain, seizures, aftereffects, physical fatigue, and hygiene (Jerald 2016). Thus the design of the physical environment should address these possible contingencies. Temperature controls and active ventilation are necessary interventions, along with access to fresh water and sunlight.

7.2 The Virtual Teaching Platform

With an established site for the physical design intervention and formal constraints (both technological and human-centered), the next step in design progression emerged from the structural requirements for a suspended platform. A structural analysis was performed to determine the required structural elements and feasibility of the concept. The structural concept for the VTP features eight linear rod columns interfacing with 43 intersecting joists (23 joists for the bottom plate and 20 joists for the top plate), intersecting at junctions to form a structural cage. The three additional joists on the bottom plate form to connect the N299G pathway and the platform. A renovation of the existing structural system in this area is required for the installation, most notably with supporting beams that run perpendicular to the main girders and interest with the rod columns axis. This would allow cables mounted to the rod columns to attached to the beams and be plumb, reducing their required diameter and increasing their efficiency. The force transfer works as follows: deck to joist, joist to rod column, rod columns to the cables, to the beams, to the girders, and then to the structural columns. Additional reinforcement may be required for the existing girders and structural columns since their original placement was scoped for the third-floor loads; this was not determined in this analysis. Based on the spans for the joists, 2 inches of structural steel decking were required. Lastly, connecting rods will be attached between rod columns between the top and bottom plate and between the top of the rods to the crossing beams. This is to provide resistance to possible torsional loads and overall improve the stability of the platform. Figure 42 provides a view of the assembled structure within Visual Analysis along with member information.

Although the relative number of occupants within the Virtual Teaching Platform will remain small (5 max), it is paramount that the VTP is code compliant. The International Building Code was used as the baseline for structural code requirements. Referencing the 2018 IBC, Table 1607.1, the minimum uniformly distributed live loads under category 34 structures (Walkways and elevated platforms) is 60 pounds per square foot. With a square footage of 170, effectively, the platform is required to sustain 10,200 lbs. With the effective linear length of the joists being 56 feet, this load is transformed into a 182 lbs./ft linear load. Within Visual Analysis, this load was then applied to the joists, rounded to 200 lbs./ft. With this information, the final results on the axial stress, bending stress, and deflection were calculated. Different profiles for the structural elements were iterated upon until the finals were chosen. This again can be seen in Figure 42. The calculation results for the final profiles can be seen in Figure 43.

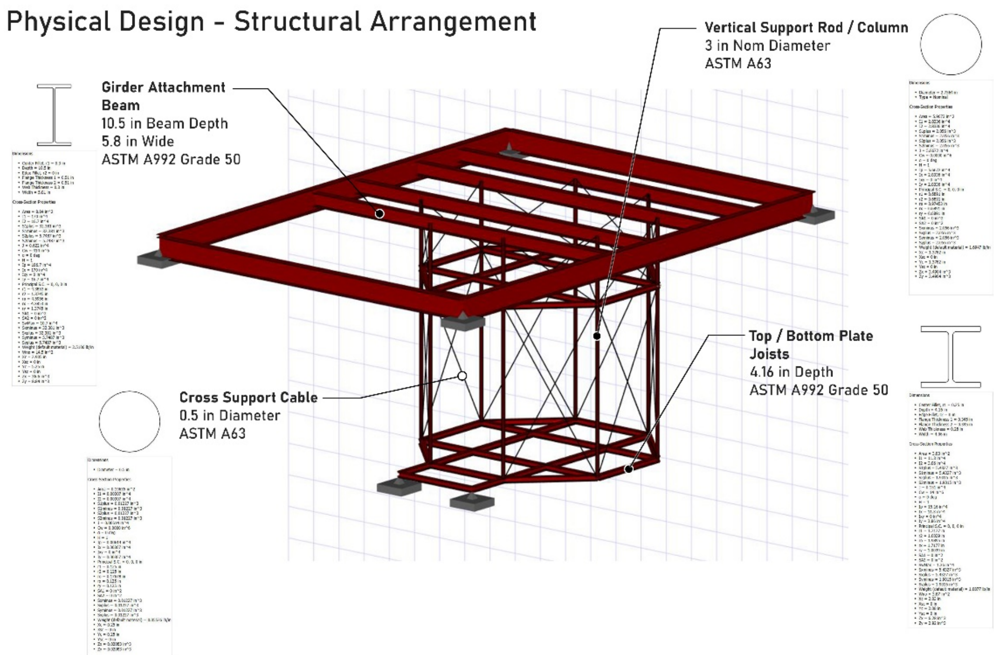

Figure 42: Structural grid arrangement for the Virtual Teaching Platform (VTP) using Visual Analysis. Figure by author.

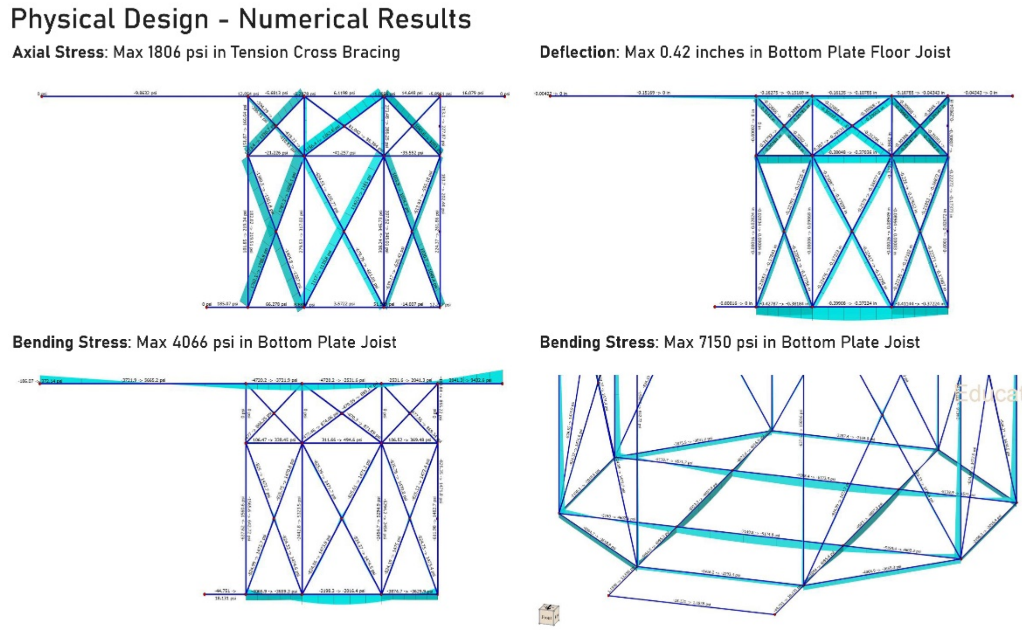

Figure 43: Structural analysis results for the Virtual Teaching Platform (VPT). Figure by author.

In terms of embedded functionality, the Virtual Teaching Platform will feature a plethora of different design elements. First, to mediate privacy between the external public walking across the adjacent hallway and the user within the platform, the glass panels installed will feature electrochromic glass that can change transparency as the user's will. Because the platform will be contained in a conditioned space, there is no need for insulation or additional shaders. The Student Union to the West provides sufficient shading over the ILC first floor in the evening when sun angles are low. Second, the floor surface of the platform will feature three different materials. The first material chosen was linoleum, which will occupy a 6-foot diameter circle originating from the center of the platform. This circle will denote the proper area of acceptable movement for the user within the space when immersed in VR. The second material will consist of a rubber-based texture that will ring around the inner circle and extend to an 8-foot diameter. This ring will provide haptic feedback to the user to indicate leaving the acceptable operational range.

Air quality, ventilation, and temperature are design variables that cannot transfer to a virtual context but are paramount for physical designs. A fan coil unit mounted to the ceiling will provide proper heating and cooling when needed. A casing around the fan coil will be installed to mediate noise pollution. The fan coil unit is also essential as an orientation mechanism for occupants. With air blowing in a linear direction, haptic feedback from the air will allow users immersed in VR to understand the directionality of their physical surroundings properly. People, when engaged within a virtual environment, may feel hot due to increased cognitive processing. The fan coil unit can act as a cooling element to ensure user comfort. Proper lighting, security cameras, and base stations will be mounted to the ceiling. Also, for visual feedback and software usage, two TVs connected to the embedded computer will be ceiling mounted. Lighting fixtures placed on the bottom plate would allow proper lighting for first-floor occupants for students studying in the lounge during dusk hours. For additional security, the front entrance will feature an aluminum panel to prevent break-ins.

Overall, the final design of the teaching platform was intended to capture the form of the surrounding chandeliers within the double-height space while also maintaining a distinct presence. The glazing of the platform reflects the adjacent curtain wall and allows views inside and out. The VTP can be seen from the outside of the ILC. If virtual learning environments in the future gain public acceptance, this platform may become an icon for the institution of UMass in its efforts to promote diverse learning approaches. While this singular platform can only allow one teacher a time to deliver a lesson, the abilities of VR technology do not prevent other educators from using the same virtual space. Additional dedicated teaching rooms may follow if demands increase. However, adding additional platforms in the same space would hamper the double-height space experience. The VTP should stand on its own and represent the self-contained, personal, and immersive transportation to the virtual UMass campus.

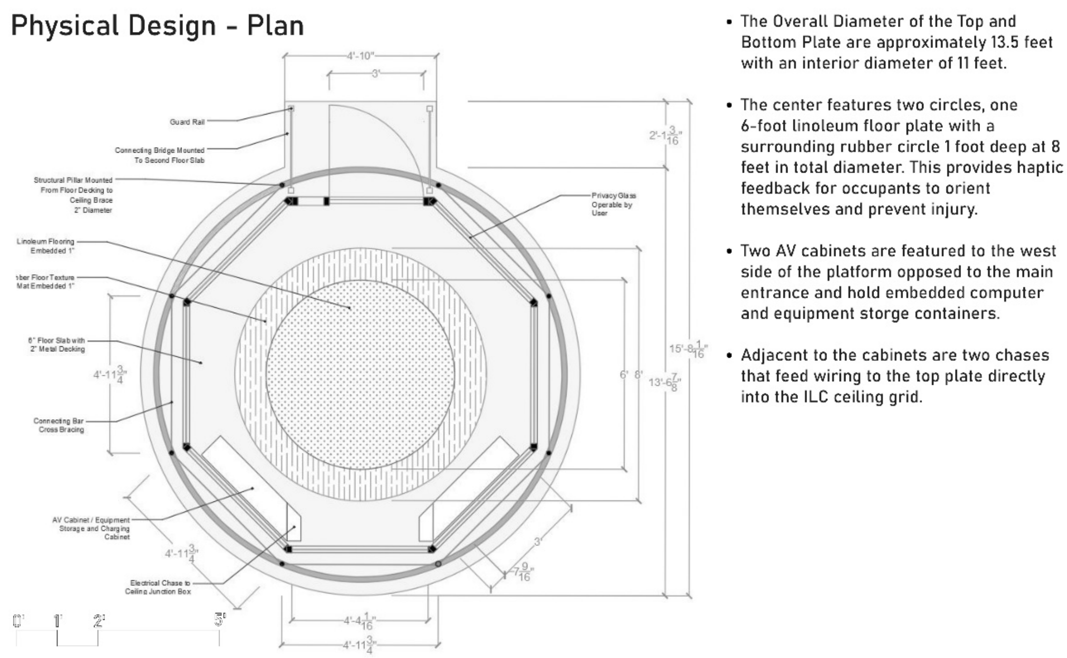

Figure 44: Plan Diagram with notes for the Virtual Teaching Platform (VPT). Figure by author.

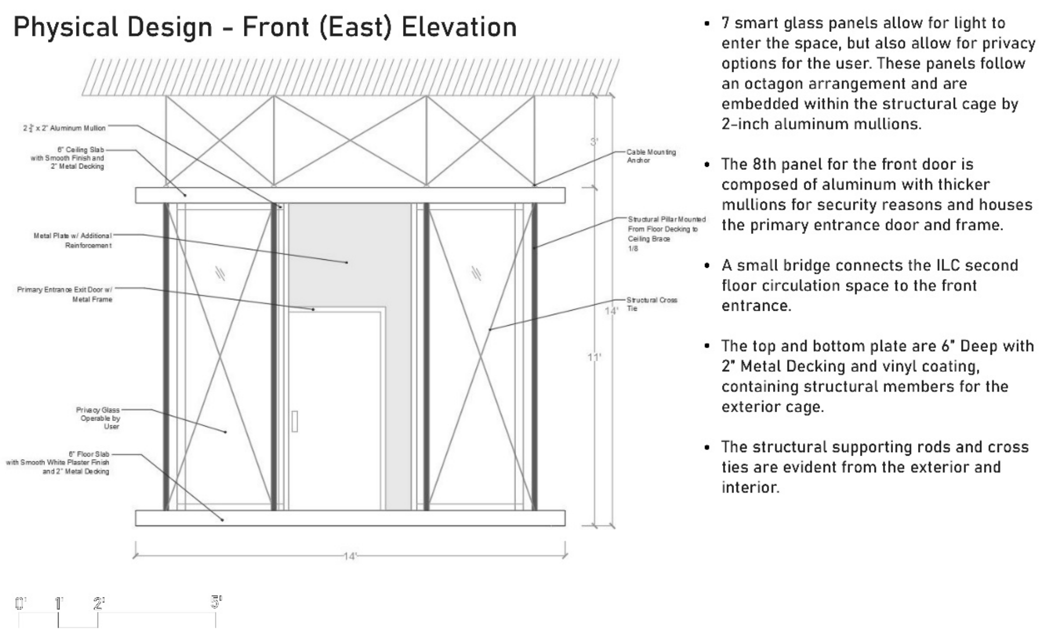

Figure 45: East Elevation Diagram with notes for the Virtual Teaching Platform (VPT). Figure by author.

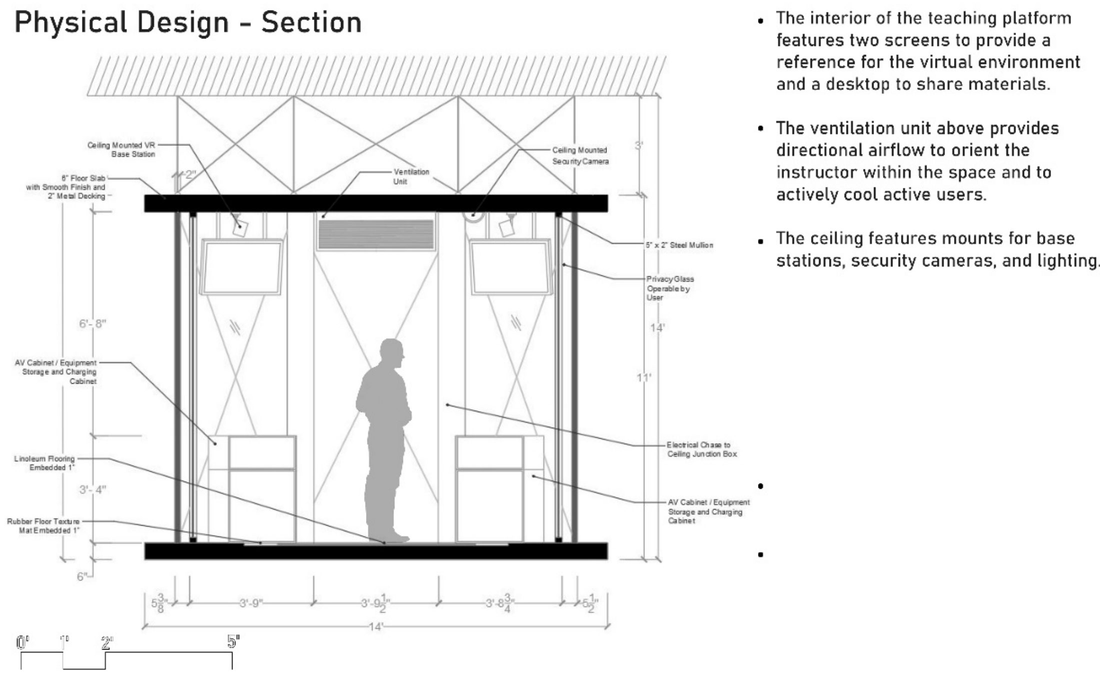

Figure 46: Section Diagram with notes for the Virtual Teaching Platform (VPT). Figure by author.

Figure 47: Perspective Render from 2nd-floor circulation space N299G looking south of the VTP. Figure by author.

Figure 48: Perspective Render looking up from 1st floor Room N140 looking north. Figure by author.

CHAPTER 8

VIRTUAL DESIGN

The virtual design for the University of Massachusetts Amherst campus began with standard site analysis. Although this portion of the project was purely digital, it was approached through a standard architectural design methodology. Because physical reality, as stated before, is infinitely complex, it was paramount to isolate a specific site for virtual construction. If a virtual designer were to create a more accurate representation of a physical location, one might include high levels of the surrounding context, creating additional complexity. This context is necessary to facilitate the location's identity but can become exponentially more complex with the degree of freedom occupants can dwell. Although a virtual space is not its physical counterpart, the memory of a virtual place crystalizes its identity. The memory of the physical space will also interact with the experience of the virtual space. Referring to Figure 49, the red dash line represents the established visibility boundary of the external context an occupant may view while within the virtual site boundary. The virtual site boundary represents the site's limits regarding where an occupant is provided agency to explore.

The UMass Campus Center compliments the design for a virtual counterpart due to the surrounding architectural context acting as a buffer for external views. This buffer creates a contained site. However, the spaces between buildings leak into the further surrounding context. Within Figure 49, the orange gradients with photos indicate the views between buildings, leading to the surrounding context. After referencing a historic photo of the university from 1934, seen in Figure 50, it was discovered that the east and west edge site axes were previously filled with vegetation. It was decided that the virtual campus will feature a reintroduction of this vegetation to act as a buffer and containment mechanism. Based on previous research, nature views are an essential element to promote health in educational spaces. While it is unknown if this principle applies within a virtual context, there may be benefits to having virtual vegetation embedded within and around the site. An overabundance of vegetation signifies that this is a different site than the physical UMass Campus Center that has changed with introducing a representative temporal element. One may interpret this as a dreamlike intervention; however, it was done primarily to create a functionally enclosed space. The UMass Campus Center also works well for virtual design for additional reasons, including relatively flat topography, existing circulation structure, and open spaces without present infrastructure.

Figure 49: Context Map of the University of Massachusetts Campus with project boundaries and assorted details. Figure by author.

The center of the UMass campus features a small but steady gradient that begins from low elevation at the campus pond up to peaks at the borders of the external site axes. The total change in elevation between the lowest and highest points is approximately 32 feet. However, most of this change occurs towards the edges. The site is relatively flat. The topography of the site can be seen in Figure 51. While more organic in the past, the campus axes have become rectilinear after the completion of several buildings: The Student Union, the Campus Center, the Fine Arts Center, and Morrill Science Center Complex. Smaller buildings filled the western axis: The Old Chapel, the Du Bois Library, and Memorial Hall.

Figure 50: The University of Massachusetts, Amherst campus ariel from 1934. Image copyright The University of Massachusetts.

All the buildings surrounding the center of campus all feature historical values and contribute a sense of place for the UMass Campus. Because the center of the campus is historical, the gesture to surround but not occupy provides another advantage for a virtual intervention.

While historically vegetation was abundant on the east and west site axes, currently, there are portions of the site interior that feature spotted vegetation. Figure 52 illustrates the existing placement of trees on the site. The east side of the campus pond is relatively barren aside from a few trees around the sites' edges. However, the southwest portion of the site features a plethora of vegetation sprinkled between green pockets between circulation pathways. The external portion of the site abides by the central campus axes; these axes return to a more organic origin closer towards the campus pond.

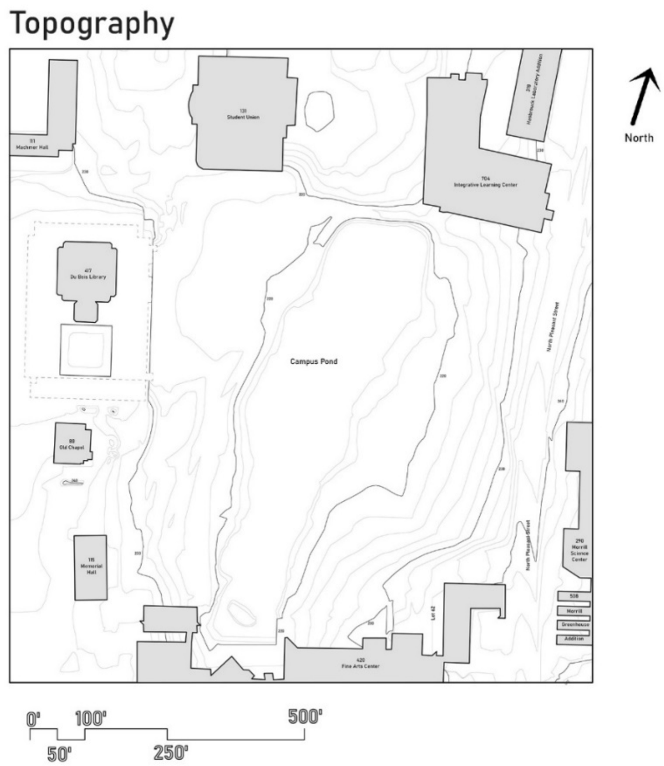

Figure 51: University of Massachusetts, Amherst campus center topography diagram. Figure by author.

The circulation of the campus center can be seen in Figure 53, where the main pathways occupy the primary axes and along the campus pond. From these primary pathways, secondary pathways diverge. The campus center features high congestion between class time blocks, often with students traversing from the north portion of the campus to the south, east to west, and vice versa. Thus the existing pathways help to guide students to their desired location without disturbing the natural landscape. From these pathways, students often veer off the path to sit within certain pockets of green space. The pathways are an essential element for how students experience the center of campus through a guided gesture.

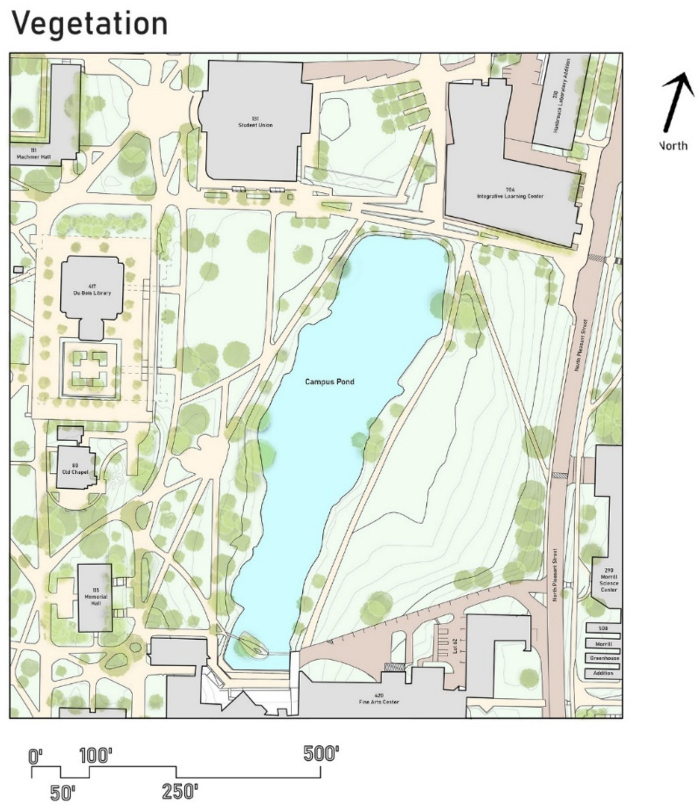

Figure 52: University of Massachusetts, Amherst campus center vegetation diagram. Figure by author.

These pockets can be seen in Figure 53 as yellow patches. Students tend to settle by the edge of the pond or towards the eastern site edge. Students perform reactional activities within the ample green space to the east; the other more oversized pockets are not as popular for student gatherings. The exact figure also features orange dots to represent building entrances to clarify potential final destinations. While this does not apply within the virtual campus since these buildings are not inhabitable, understanding the current campus culture is essential. Overall the campus center at UMass makes for a dynamic but stable site as a host for virtual architecture.

The existing topography of the site was recreated as terrain data within unity. Different textures were painted on this terrain to recreate the different soil layers present on site. Using the external plugin Enviro – Sky and Weather, real-time lighting of the environment was produced based on the latitude and longitude of the existing UMass campus along with the 2021 sun orientation calculation. The plugin Vegetation Studio was also used to populate the existing and introduced vegetative context and animate grass. While there was available wind data for the UMass campus, it was not implemented as a wind map to animate the vegetation. External tree assets were used to create the vegetation.

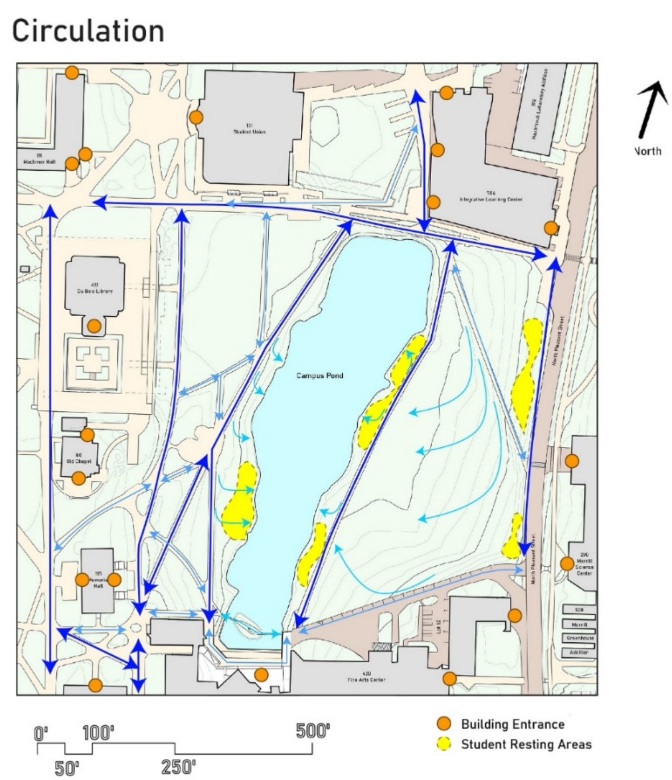

Figure 53: University of Massachusetts, Amherst campus center circulation diagram. Figure by author.

The virtual architectural proposal of this document features five distinct architectural entities: The Workshop Building, the Experiment Building, the Amphitheater Park, Individual Learning Cubes, and the Central Transportation Platform. These five entities all serve a different purpose to help educators with the delivery of virtual lessons. Figure 54 demonstrates the different aspects of the virtual campus and its subcomponents, such as spawn points and site edges. Figure 55 illustrates the site from an orthographic aerial plan perspective. From this view, one can see how the site is populated and follows the established circulation structure. All virtual assets for this project were modeled and textured in Blender and then imported as FBX files into Unity. The following section will describe the design intent for each architectural entity.

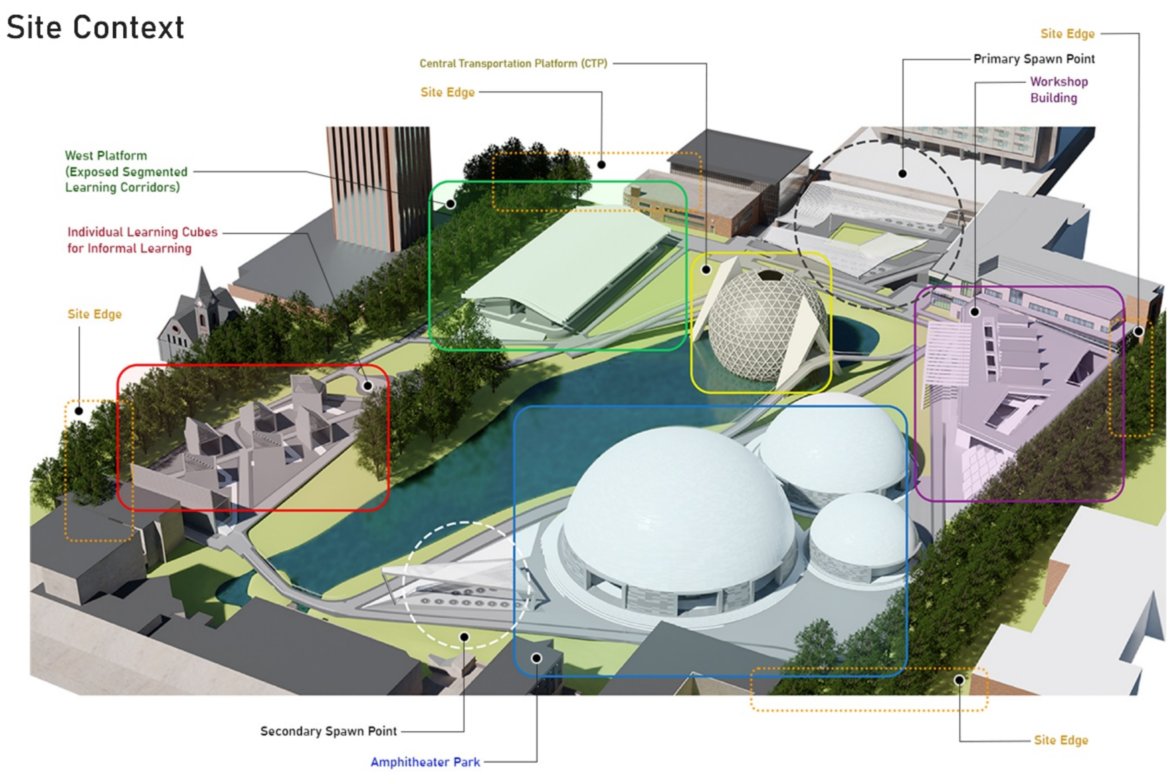

Figure 54: Perspective of the UMass virtual campus with the five different virtual architecture interventions and external context. Figure by author.

Figure 55: Bird's eye orthographic plan projection of the UMass virtual campus with all virtual architectural entities. Figure by author.

Before a detailed explanation for each virtual entity can commence, it is important to establish general design assumptions for the general virtual campus. Based on the current state of technology, this campus was designed for occupants to use HMD technology as immersive VR equipment. As a result, there are only two active senses that an occupant may use to experience the space: vision and hearing. Because vision is the primary sense in terms of the architectural experience, the design of virtual architecture features a focus on lighting and views as primary design drivers. While an essential element for auditory learning, audio was not a critical design element for architectural consideration: it was intended that external programming would calibrate the auditory experience. The following are a set of principles of design for the virtual campus:

- Gravity is an active force on the users within the virtual environment.
- Avatars may run, jump, or lie down, or sit down when exploring the main campus.
- If one has full body trackers in addition to an HMD, a full range of movement is allowed.
- Avatars will only be able to walk and sit down while within a virtual building but can move dynamically if they have full-body trackers.
- Via the Unity engine, the virtual environment will be lit through real-time lighting.
- Students will not be permitted to walk on or in the campus pond.
- Wind zones will be active within the virtual environment to animate grass and vegetation.
- Mesh colliders are required on all import asset static geometry, including single face geometries with flipped normals.

Because virtual architecture uses data as the fundamental construction material for all structures, although texturing options were available, the virtual structures were all composed without external texture data and given a color value between white, grey, or black. This was to create contrast between structural surfaces and highlight the nonrepresentative elements of virtual materials and speed asset production. While future virtual architecture projects may explore more options and adapt texture data to create representative architecture, this project determined this approach.

Architecture as a medium features a systematic approach to experience that derives from our day-to-day experience. Although the physics of a virtual environment can be manipulated based on the creator's intent, an architect should strive for a pleasant experience of the environment, meaning any non-typical experiences were not considered for this intervention. Because users will be exploring this virtual environment in an upright position with their HMD, in the VTP or otherwise, one’s avatar should reflect the user's physical reality. Different architectural elements that can be considered archetypical are also included in the design as a motif for the intended function. For example, people inherently understand that stairs take one from a lower elevation to a higher elevation without deep contemplation of the function of stairs. Thus stairs, ramps, railings, roofs, and thresholds were all used to support the user's experience within the virtual environment without creating confusion.

While it can be debated that ramps are more ideal as a form of transportation for virtual users than stairs, this discussion is ultimately fruitless since both perform the same functions. The virtual campus features stairs with low risers, essentially becoming a ramp. While disabled users may experience ramps as a mode of transportation within physical space, stairs are still standard. Thus the virtual design includes both with the intended use as more formal than functional. Invisible walls are a common element in video games that prevent users from exploring unintended areas. The use of guard rails was used instead of an invisible wall to act as a visual element to indicate the barriers of the crafted experience.

8.1 The Workshop Building

From its initial conception, the Workshop Building was thought of as a recreation of a zoom call or other video conferencing software into a spatial configuration. The space features a seating platform for class use and an array of meeting rooms as breakout spaces. The southern tip is exposed to allow informal gathering before reconvening to the inside. The western pathway hugs the west façade with a gesture towards the southern tip. The partitions inside the external shell mold space up and through the roof. Louvers around the façade act as a break in the outer shell to allow views to the outside. While the roof is inhabitable, Boolean cuts were made to feed light into the space. Floating guard rails were introduced to prevent users from falling off of high elevation points as it is a disorienting sensation within VR and is not a behavior an architect should promote.

The internal circulation of the Workshop Building features the main stair that carries occupants to the second and roof levels. The second-floor circulation features a loop configuration with ascending ramps to allow users to walk to the smaller meeting rooms along the west façade. This pathway then features a landing above the northwest front entrance before looping around to the internal partitions of the larger conference breakout space rooms. Another pathway breaks from the loop to carry users to the roof informal learning spaces. The roof also provides views of the UMass virtual campus. On the first floor, next to the west façade, a column structure is planted to encase a seating area along the pathway reminiscent of ancient stoas. This creates a distinct shading pattern and acts as a framing device pointed to the amphitheater park. This area is also intended for informal gatherings before users reach the southern tip.

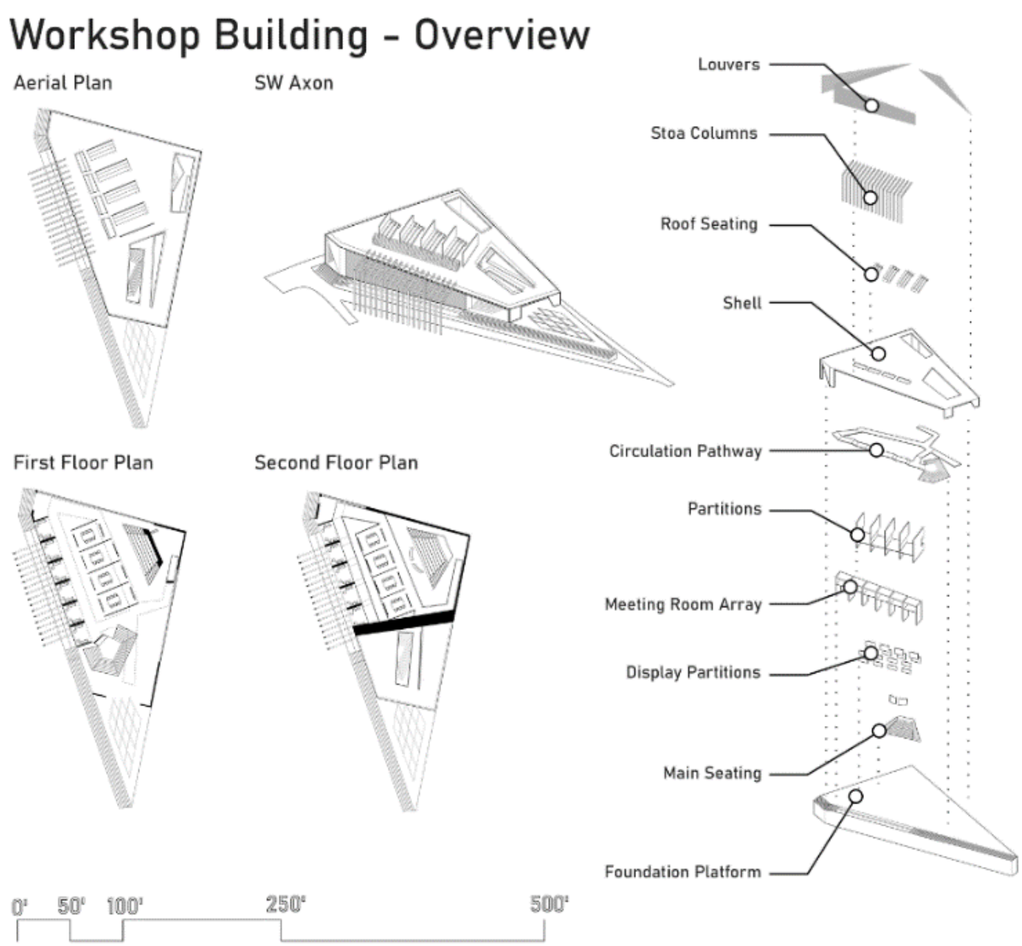

Figure 56: Exploded Axonometric Drawing of The Workshop Building. Figure by Author.

Workshop Building - Section

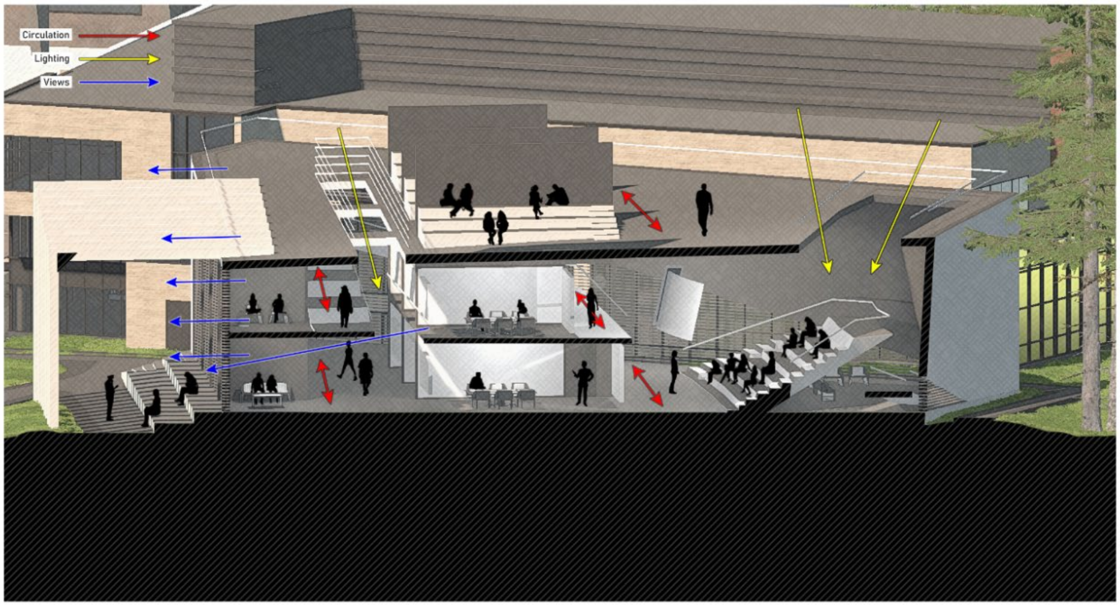

Figure 57: Sectional Diagram of The Workshop Building. Figure by author.

8.2 The Amphitheater Park

The Amphitheater Park features three different size large gathering spaces for professors to lecture students. The park features a small, medium, and large amphitheater that can hold approximately 30, 125, and 300 students, respectively. Each Amphitheater has two screens to display external media and are large and curved to help students easily view no matter where they are seated. Each amphitheater also features a spherical shading device that, with the principle of flipped normals, shades the internal area of the amphitheater while allowing for external views. The amphitheaters feature a stage as the teaching podium to allow the loading of external assets for display purposes with a theatrical flair. The base of the shader is perforated to allow views inside and out. Thresholds were introduced to provide wayfinding inside and out of the amphitheater. An urban plate is situated to the southeast to allow informal gathering and prevent congestion.

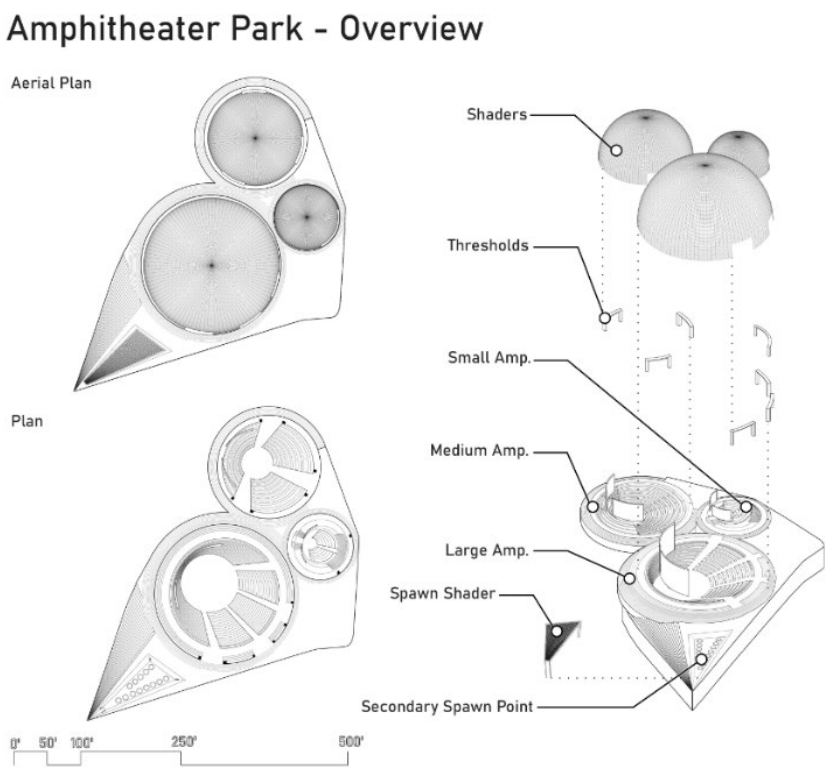

Figure 58: Exploded Axonometric Drawing of the Amphitheater Park. Figure by author.

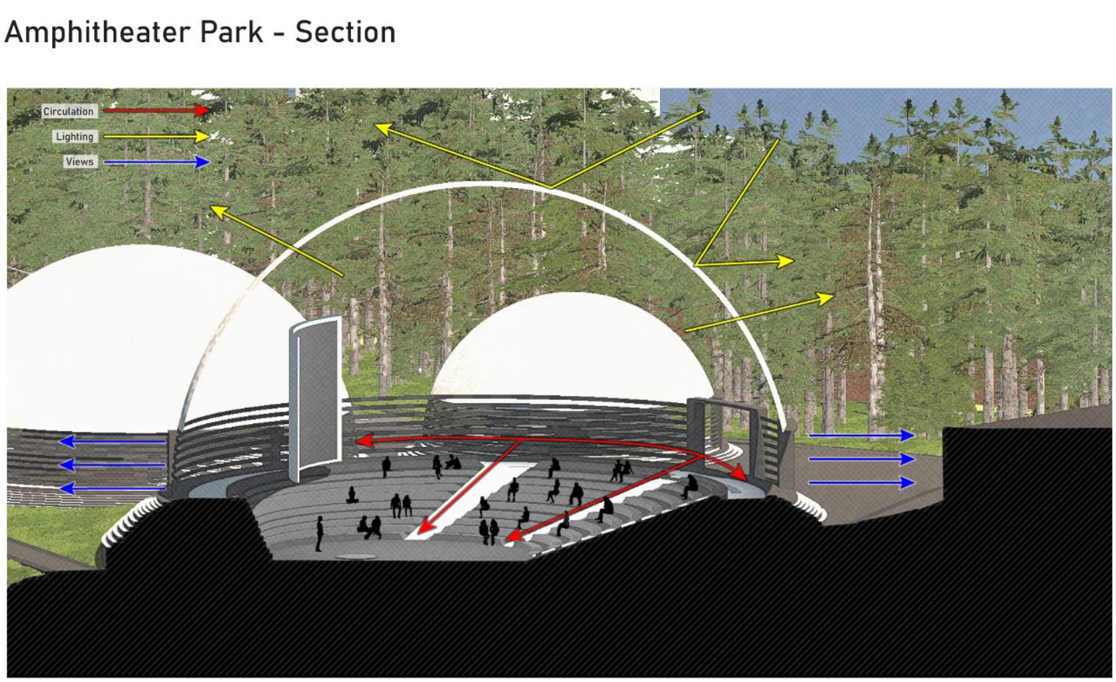

Figure 59: Sectional Diagram of the Amphitheater Park. Figure by author.

8.3 The Experiment Building

The Experiment Building ties directly to virtual spaces for scientific education after referencing the precedent studies. The internal arrangement mimics the layout of contemporary lab space with additional pocket spaces between benches to allow for interactive displays. The bench spaces are intended for external assets with preprogrammed content to be imported into space. The exterior façade comprises small panels intended for occupants to move and modify to their liking as a mix-use display/study tool (referencing the memory palace study). Similar to the Amphitheater Park shaders, the concept of flipped normals is used for one-way viewing on this façade to create privacy. The open space between rafters is intended for bounced light to enter the space through real-time simulation to create a diffused light effect while featuring an archetypical architectural design element.

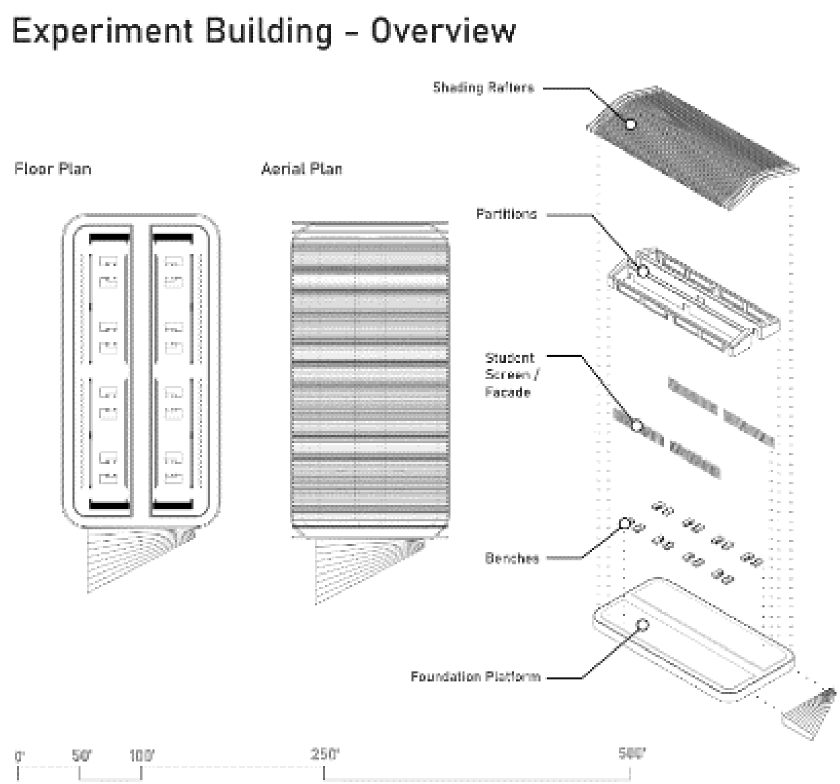

Figure 60: Exploded Axonometric Drawing of The Experiment Building. Figure by author.

Experiment Building - Section

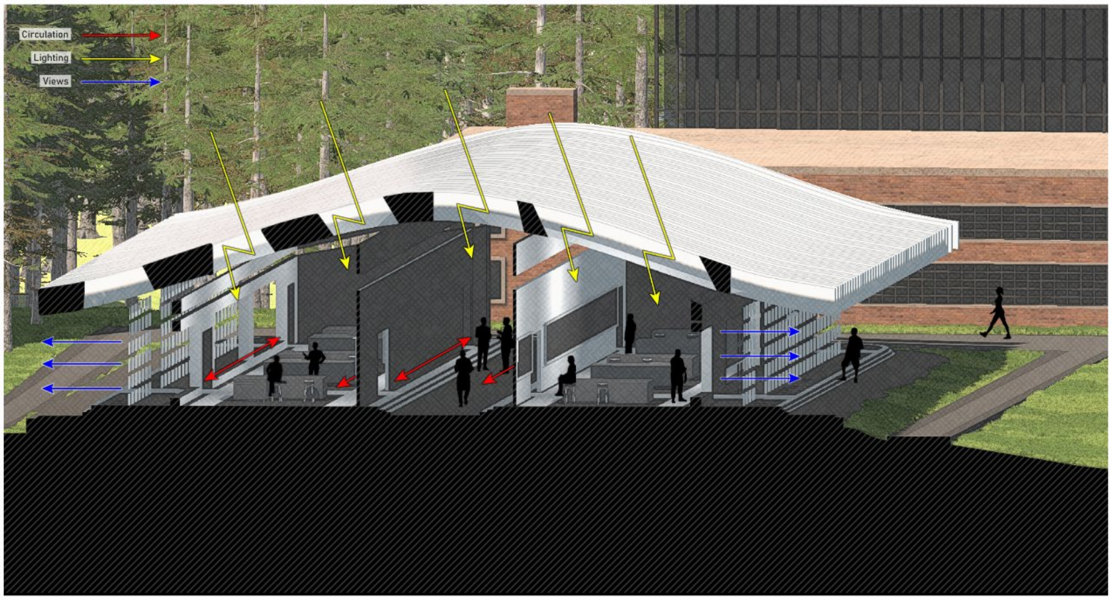

Figure 61: Sectional Diagram of The Experiment Building. Figure by author.

8.4 Individual Learning Cubes

The Individual Learning Cubes were based on the patterns sampled from current grassroots communities. They are intended for informal, individualistic learning and social gathering. With an open virtual campus, the cubes themselves can be reserved for a single student or up to a group of four. Each cube features an interactive display, but assets can be transferred onto the urban plate for more complex visualizations. While a Cube is a self-contained space, the side openings are intended for more dynamic collaborations between students in different cubes. Similar to the Experiment Building, the roof louvers are intended to feed bounced light into each cube via southern orientation. If the institution of UMass permits student customization of the virtual campus, this area will allow students to modify the exterior of cubes to their liking and save them for later use. Each student may develop their cube profile tailored to their preferences for virtual study spaces.

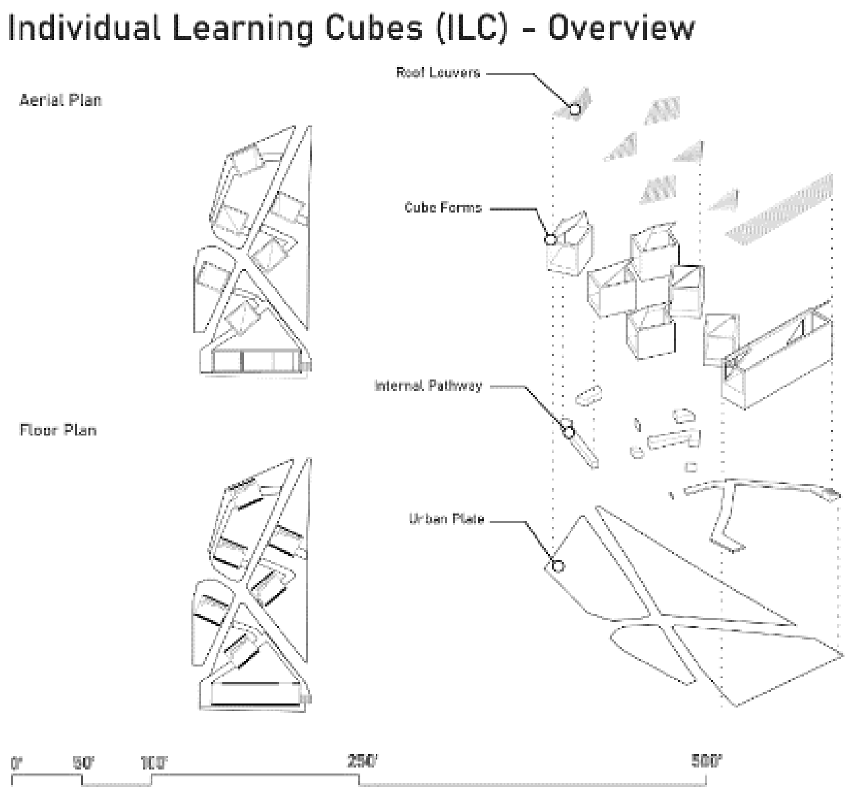

Figure 62: Exploded Axonometric Drawing of the Individual Learning Cubes. Figure by author.

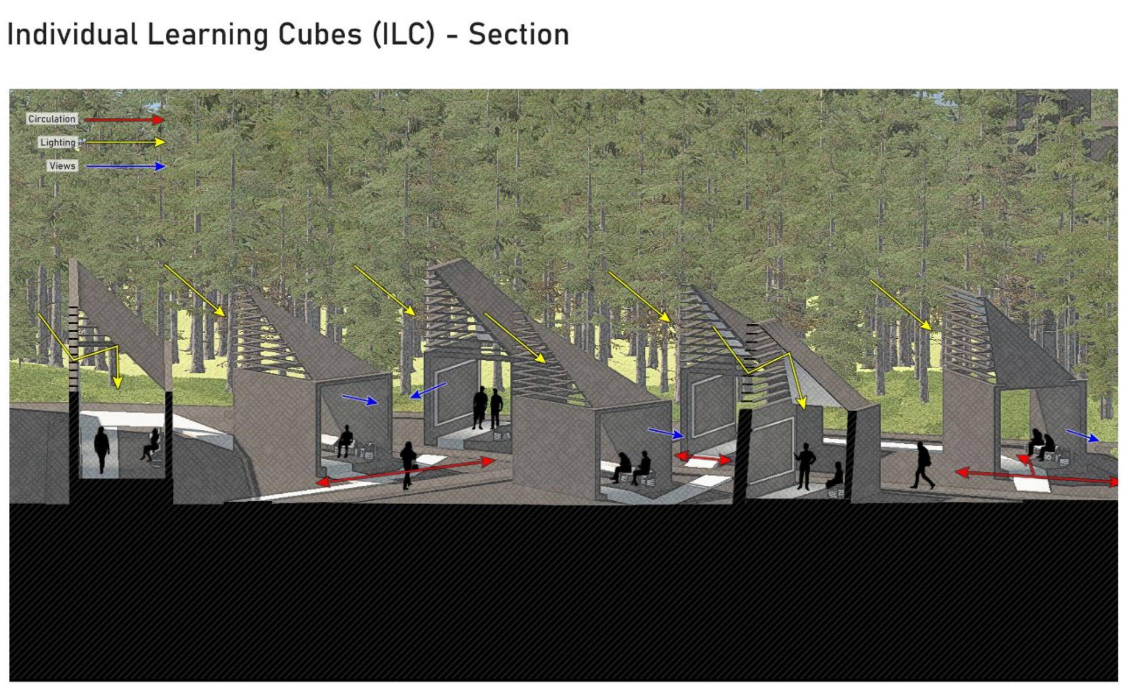

Figure 63: Sectional Diagram of the Individual Learning Cubes. Figure by author.

8.5 The Central Transportation Platform

The Central Transportation Platform is a space intended for group gatherings before mass transportation to different virtual worlds. The form of the CTP follows a simple geodesic sphere pattern with openings at the top and sides. The CTP features two spheres; students circulate to the inside by following a ring path between both spheres. The CTP has a maximum occupancy of 50 students; higher occupancies would not be managed well in external virtual content and reflected in this occupancy cap. The interior flooring at the center of the CTP features perforated rings to allow views of the campus pond from below unhindered by the principle of flipped normals. The CTP is a place of short-term dwelling and is intended to represent the infinite number of virtual worlds a user can be transported.

The design was influence by Disney's Epcot sphere but is more representative of the alchemical symbol of prima materia, a symbolic unification of information and matter. The prima materia is representative of the infinite potential that physical materials manifest. The pathways leading to the CTP and the threshold frames are representative of the wings of the round chaos, another ancient symbol of potential made of the prima materia. The round chaos has associations with the Roman god Mercury, the messenger god and controller of information. Mercury is associated with attention, interest, information, and education. The virtual UMass campus features representations of the existing physical campus surroundings composed of monumental brutalist architectures. The CTP was featured not as an explicitly high functional space but as a definitive element in contrast to the surrounding architectural styles. The space of the CTP is intended to incite student reflection before embarking on new immersive experiences.

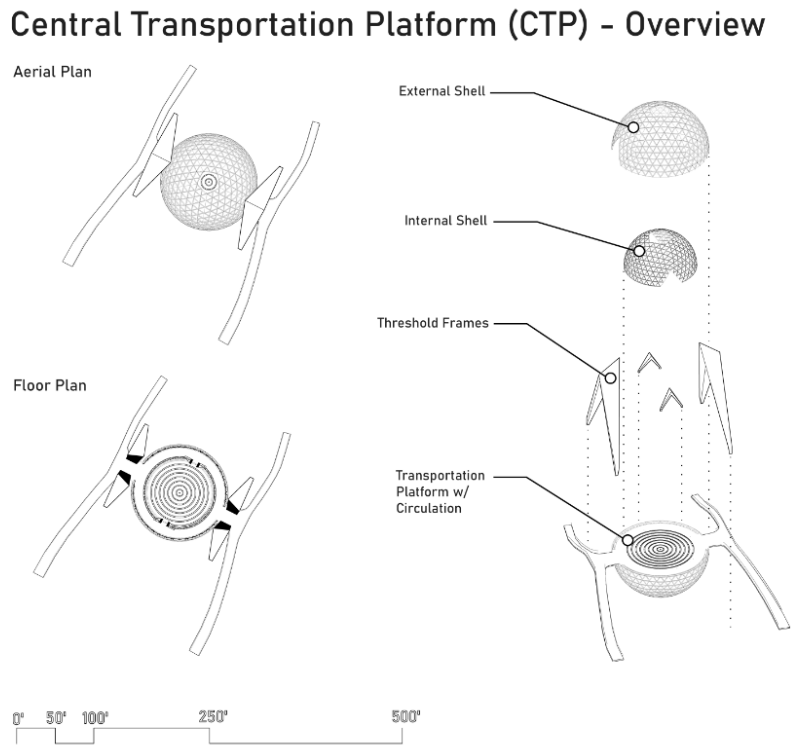

Figure 64: Exploded Axonometric Drawing of the Central Transportation Platform. Figure by author.

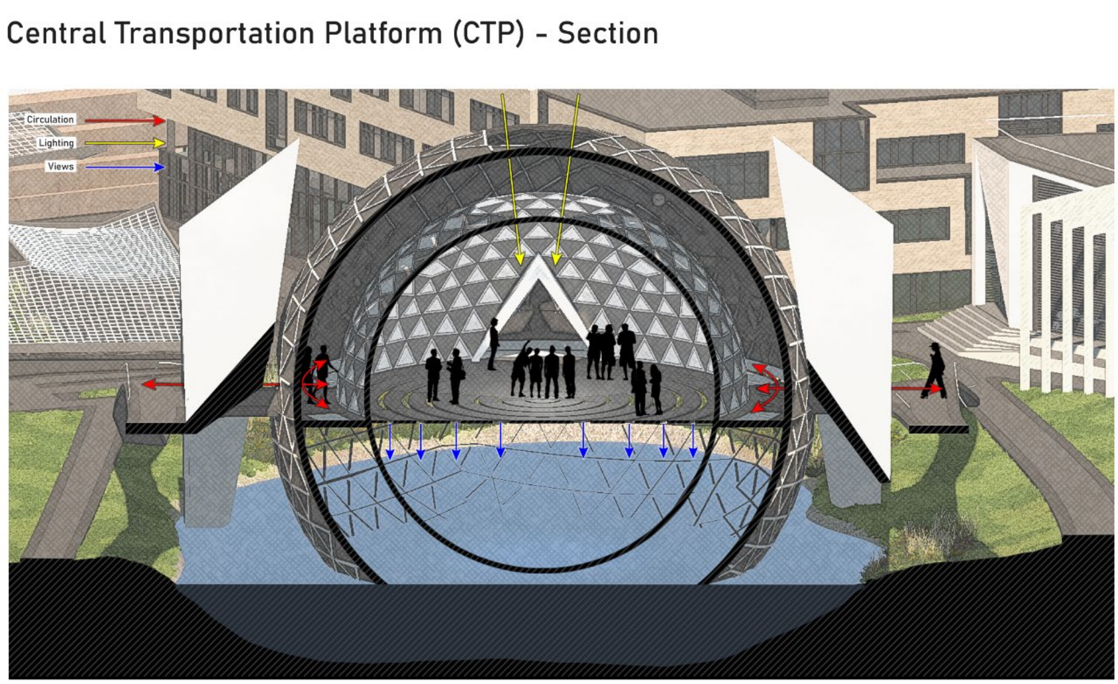

Figure 65: Sectional Diagram of the Central Transportation Platform. Figure by author.

CHAPTER 9

CONCLUSION

Design as a discipline is involved with the creation of functional objects executed with an aesthetic awareness. Different mediums such as text, image, video, and video games that attempt to represent space usually facilitate a narrative or represent a physical space. However, we must not forget that physical space is as well as a representation of a far more complex universe. Virtual spaces are design creations with embedded functionality; however, we commonly view virtual space through 2D interfaces. With the introduction of immersive VR technology, we can now explore virtual space as we do physical space, justifying the involvement of architects. 3D artists, programmers, and software engineers may be competent virtual designers; however, architects are the experts in creating user-friendly environments and add a needed additional perspective to this phenomenon. An architect's training is not purely limited to construction expertise but the meaningful creation of space designed for human use. Not all virtual environments need to be designed by architects, but architects would be the most knowledgeable as design experts.

Because of the complexity of topics such as virtual space, education, environmental psychology, philosophy, and physical architecture, this thesis attempts to tie multiple fields together at a high level to approach the problem of virtual architecture. The primary goal of this thesis was to provide the right questions through example, not necessarily the correct answers. Since there is little research on architectural design trends implemented within a virtual context, this thesis project was intended to provide a precedent for future designers to iterate. However, the primary goal was the introduction of physical design data integrated into the virtual context.

A survey on the virtual design intervention was distributed to an architectural graduate studio IV, class 601, from the University of Massachusetts Amherst to understand how contemporary graduate students understand virtual architecture and to document their opinions. A pre-evaluation survey was distributed first to understand how well students were informed about

VR technology and gain a census of virtual architecture understanding. A post-evaluation survey was distributed after presenting the virtual design and a virtual walkthrough using video conferencing software. These results can be seen in the appendix, figures 68 and 69. From this survey, it can be determined that students have mixed opinions on virtual architecture and its future applications. Current technology acts as a barrier to entry for most students, although the presentation sparked interest.

It is challenging to design virtual architecture in the present, for virtual architecture will inevitably respond to technological growth and development of applications to be used within a virtual context. Within our physical environments, there are a plethora of objects and tools that we may interact. Thus the virtualization of physical space use is easier to comprehend compared to virtual space. The true utility of virtual spaces will be to bridge user experience with technology. Without technology, tools, or objects to interact with, virtual space appears more void and empty than rich with life. However, it is the potential for these tools that makes virtual spaces promising and enjoyable to contemporary users. The tool potential combined with the social experience of virtual worlds further extends the potentials of the space.

A specific aspect of virtual architecture that has yet to be addressed is how the realism of a virtual world affects user experience over the long term as well. While some may embrace the virtual world as a separate entity from reality, others find themselves disoriented when using the technology. Another issue is technological fatigue. Although contemporary technology makes society more efficient and complex tasks simple, the constant use of technology creates a strain on users over time. Traditional architecture responds to technology fatigue by creating environments rich with dynamic light, healthy air, and a reflection of nature with natural material use or views to an external environment. While users may engage with technology to perform tasks at work or home, their surrounding environment helps to facilitate healthy living. Thus, how should a virtual environment be designed to avoid the overstimulation of users? This document only touches the surface concerning the rabbit hole of this conundrum. The introduction of physical design variables is the first step to a better understanding. Virtual environments are also inherently involved with issues of ethics, culture, inclusiveness, and sustainability. While these questions may have complex answers, with more time and exposure to VEs, more data may be developed with future studies.

Virtual reality will not replace traditional physical learning environments. Physical classrooms are here to remain; virtual classrooms are secondary tools to primary learning environments. Thus virtual designs need to parallel physical learning environments; otherwise, virtual environments risk alienating students. The design language and archetypical themes of classrooms should be preserved no matter the medium. Regardless, virtual environments are here to remain as long as the internet and current technologies continue to function. Architectural firms may benefit from adopting virtual environment design as secondary work during economic dry spells. Construction is usually one of the first industries hit by recession activity. Thus the design of virtual environments may supplement physical design work during rough patches (if there is demand for such services).

In the not-so-distant future, when technology has progressed to capture more of our physical reality within a virtual context, the call for architects to participate in virtual design with echo louder. It is currently unknown if virtual reality will become a mainstream technology and if current projections are overly optimistic. Regardless, the impact of VR on education will ultimately be beneficial. Architects may or may not participate in this development. However, virtual spaces will be less impactful without an architectural perspective. After all, everyone would benefit from the creation of memorable and highly functional virtual spaces.

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APPENDIX

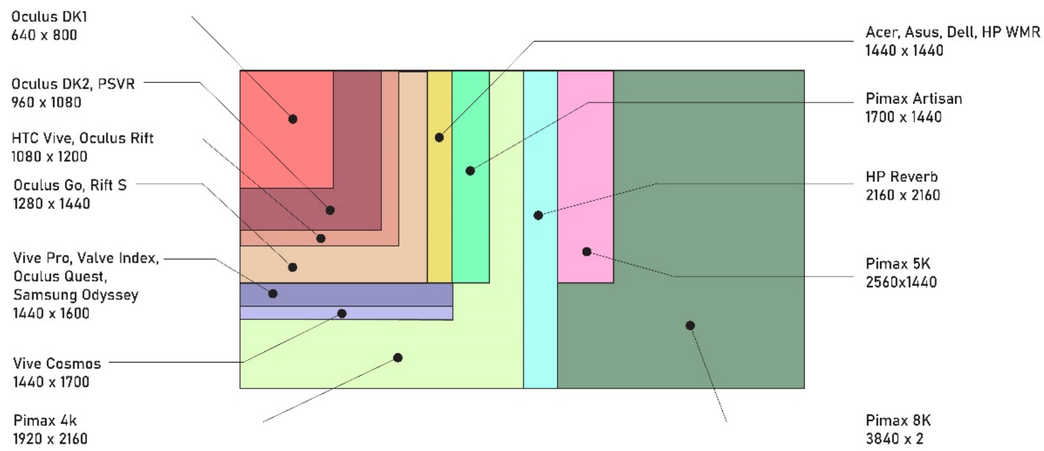


Figure 66: Array of Different VR Headset Resolutions. Figure adapted from creator Night1, Copyright SA 4.0 (Niqht1 2020)

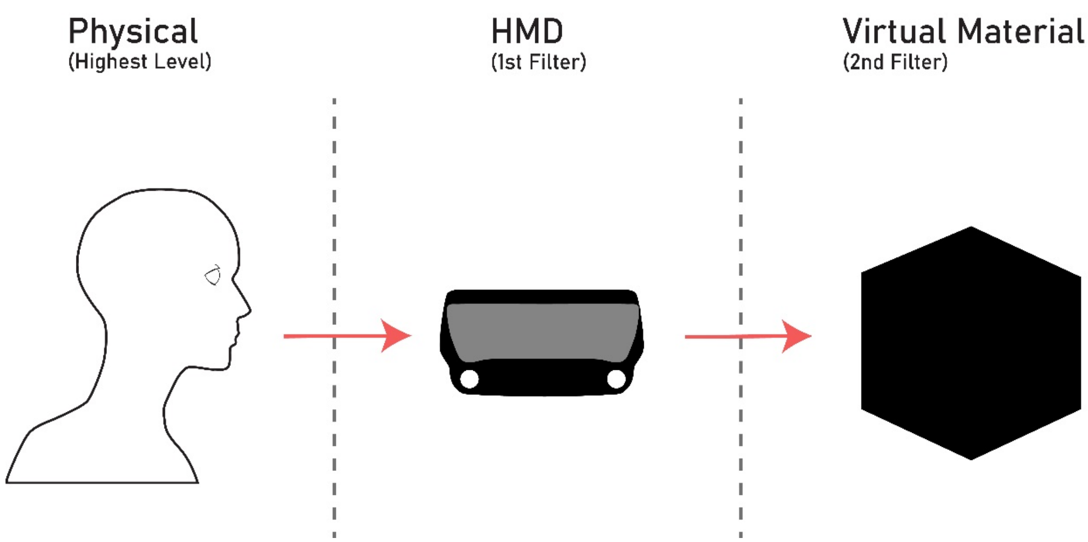
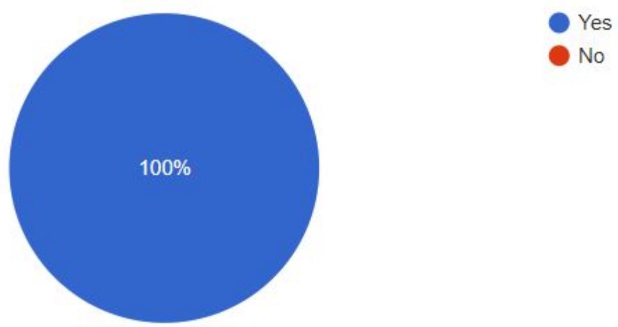


Figure 67: Resolution thresholds from standard human perception to virtual materiality. Figure by author.

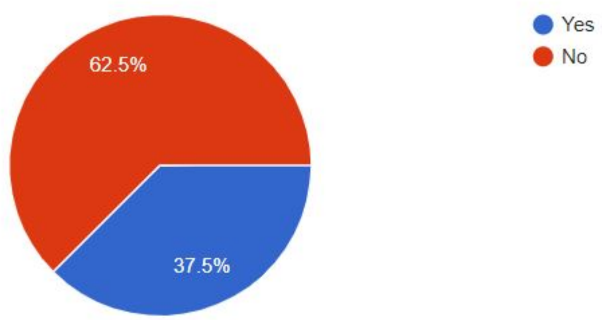
Have you heard of VR (Virtual Reality), AR (Augmented Reality), or HMD (Head Mounted Display) technology before?

8 responses



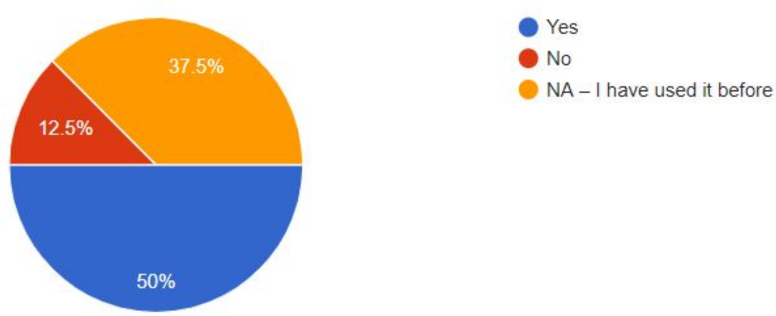
Have you ever used a VR (Virtual Reality) headset, AR (Augmented Reality) headset, or HMD (Head Mounted Display) to experience virtual space?

8 responses



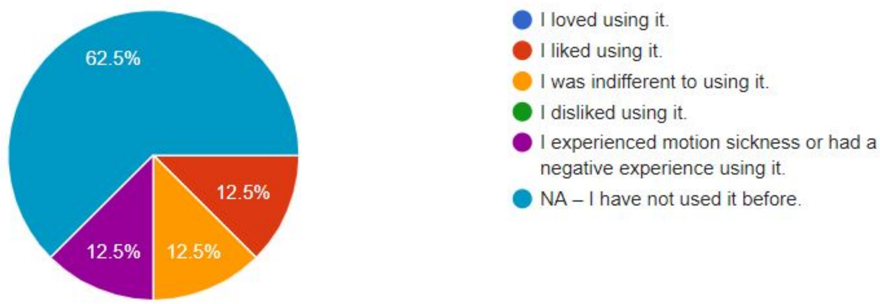
If you have answered no to question 2, would you be open to experiencing VR (Virtual Reality) if given the chance?

8 responses



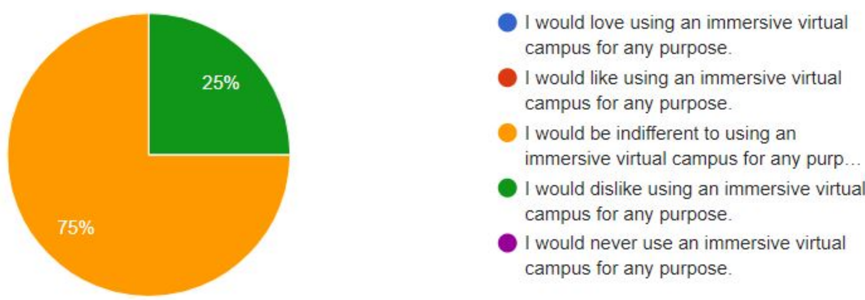
If you have answered yes to question 2, was your previous experience with VR (Virtual Reality) enjoyable?

8 responses



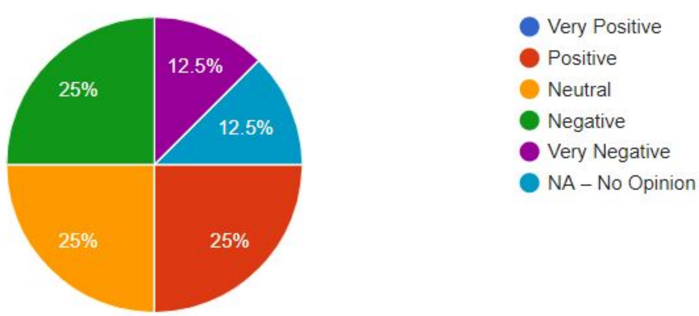
If UMass created a virtual campus that one could inhabit with VR (Virtual Reality) technology, either provided from the school or personal equipment, would you be interest in using it as formal / informal learning space?

8 responses



If you have an opinion on virtual architecture (architecture experienced in virtual space with immersive VR equipment), what is your current opinion?

8 responses

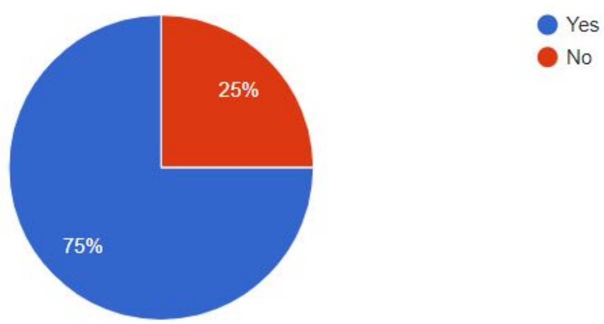


The pre-evaluation open-ended survey questions revealed that many students are curious but skeptical of virtual reality technologies. As architecture students, the individuals were interested in VR's potential to visualized and express physical designs. Students were indifferent or had no basis of understanding the significance of virtual architecture as a deliverable in itself. Some have had negative experiences with the technology causing nausea and motion sickness, leaving a poor impression of the technology.

<u>Figure 68:</u> Pre-Evaluation Survey Results. Survey conducted to University of Massachusetts Graduate Studio IV Arch 601 students. Eight submitted results. Figure by author.

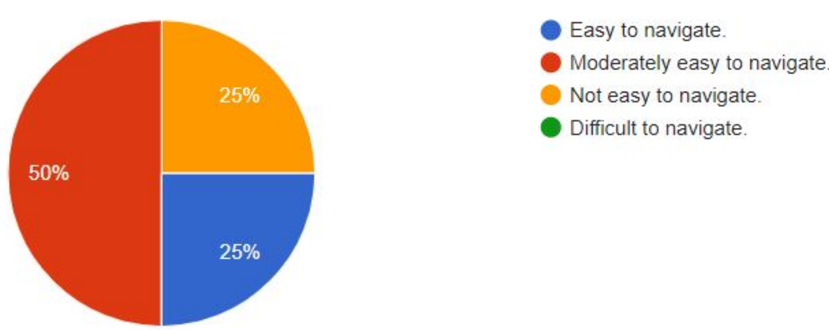
If given the chance, would you attempt the same walkthrough experience with a VR setup?

4 responses



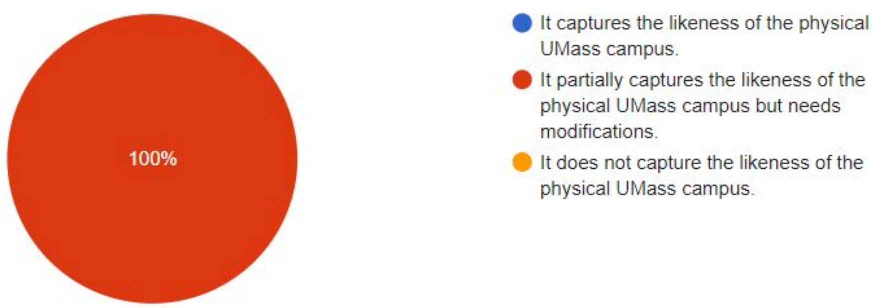
Based on the walkthrough, would you say the Virtual UMass campus is easy to navigate?

4 responses



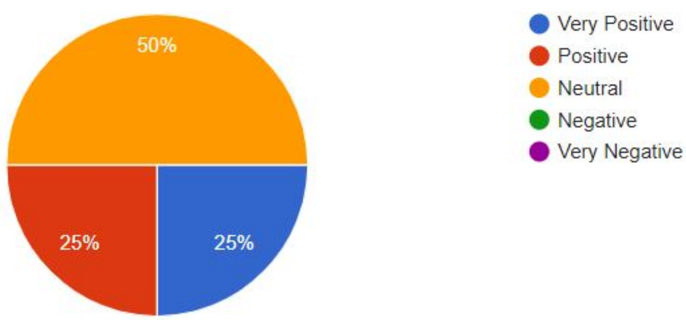
Do you think the virtual campus captures the likeness of the physical UMass campus?

4 responses



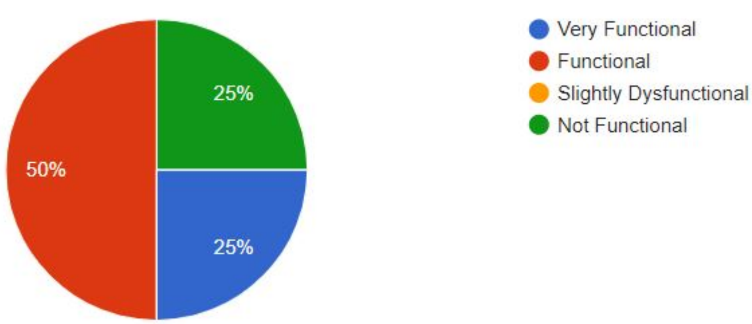
What is your opinion on the aesthetic design of virtual architecture within the virtual UMass campus?

4 responses



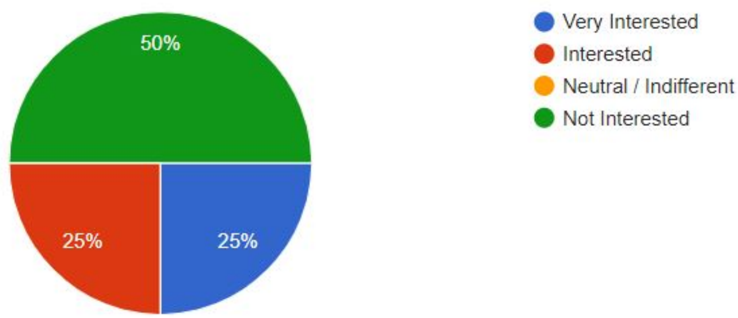
What is your opinion on the functionality of the virtual architecture within the virtual UMass campus for your purposes as a student?

4 responses



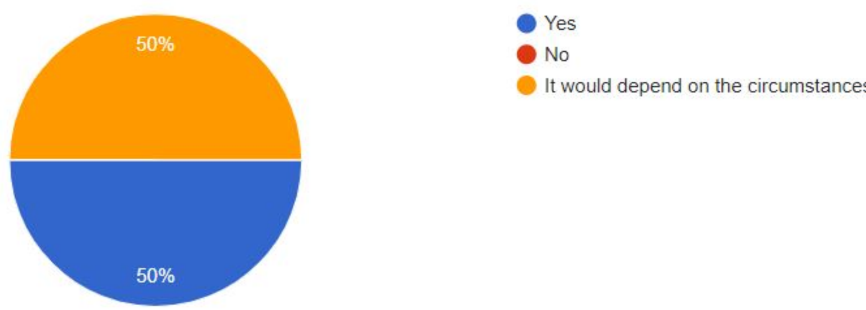
If UMass offered classes within the virtual campus, would you be interested experiencing class in one of the virtual structures using or not using VR (Virtual Reality)?

4 responses



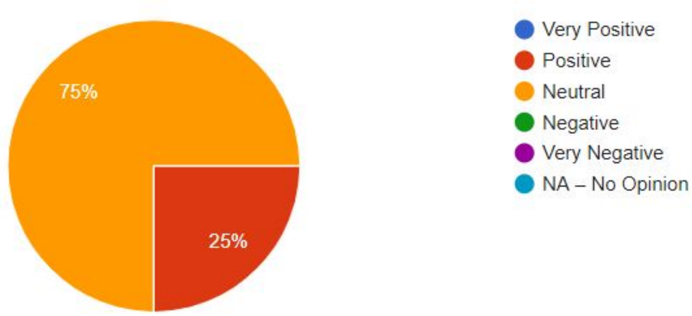
Would you prefer a class being held within the virtual campus instead of a zoom, Microsoft teams, skype, discord, or any other video communications software.

4 responses



After experiencing the walkthrough, have your opinions on virtual architecture (architecture experienced in virtual space with immersive VR equipment), changed? Please rate your updated opinion on virtual architecture.

4 responses



The post-evaluation open-ended survey questions demonstrated that students enjoyed the virtual space walkthrough but were conflicted if they wished to use the space for virtual instruction. Students highlighted that they would prefer the virtual environment slightly over video conferencing. Students thought well of the design intervention but were overall indifferent to the uses of virtual architecture. Students disliked modifications to the current UMass infrastructure that was supplemented or modified in the virtual design, for they believed the quirks in the current infrastructure supports the narrative of UMass as a location. The tour sparked further curiosity about the potentials of VR technologies.

Figure 69: Post-Evaluation Survey Results. Survey conducted to University of Massachusetts Graduate Studio IV Arch 601 students. 4 submitted results. Figure by author.

Table 4: Design Parameters that Impact Student Achievement with Findings from the Study.

Table adopted by author from source: (Barrett et al. 2017, 428–30)

Naturalness

Design Parameter	*Indicators*	*Factors*	*Measurement criteria making up high rating*
Light	A) The quality and quantity of natural light the classroom can receive B) The degree to which the lighting level can be controlled	1) Glazing orientation 2) Glazing area/floor area 3) Quality of the electrical Lighting 4) Shading covering control	Larger windows from orientations with no direct sun (glare) Both more and better quality Blinds with good functionality/quality
Sound	C) The frequency of the noise disturbance D) The degree to which the pupils can hear clearly what the teachers say	5) Noise from the school outside 6) Noise from the school inside 7) Length/width 8) Carpet area of the room	Large distance from traffic noise or presence of buffer zone Large distance from playground or busy Areas Higher L/W ratio More Coverage is Better
Temperature	E) The quality and quantity of sun heat the classroom receives. F) The degree to which the central heating system can be controlled	9) Orientation and shading control 10) Central heating control	Rooms with little sun heat, whether by orientation or shading Thermostat and radiators in classrooms give better control
Air quality	G) The degree of respiration that affects the CO2 level in a fully occupied classroom. H) The degree to which air changes can be adjusted manually	11) Room volume 12) Opening window size and position 13) MV	Greater volume is better. More opening choices and bigger opening area MV present

Links to nature	I) The degree to which the pupils can get access to natural elements J) The degree to which views of nature are available through the window	14) Access to nature 15) View out	Door directly to outside. Plants and wooden chairs/desks in the room. Windowsills below child's eye level and interesting or green near and far views

Individualization

Design Parameter	*Indicators*	*Factors*	*Measurement criteria making up high rating*
Ownership	K) The degree to which distinct characteristics of the classroom allow a sense of ownership L) The degree to which the FF&E are comfortable, supporting the learning and teaching	16) Distinct design features 17) Nature of the display 18) Quality of the FF&E 19) Quality of the chairs and desks	Originality or novelty character to room. Personalized lockers or coat hooks. Child made display. Ergonomic and good quality furniture appropriate for age group Ergonomic and good quality desks and chairs appropriate for age group
Flexibility	M) The degree to which the pupils have an appropriate provision of space N) The degree to which the classroom and wall area allows varied	20) Classroom floor area and shape: Key Stage appropriate 21) Breakout and storage space attached to the classroom. 22) Learning zones: number of zones key stage appropriate	Larger rooms with simpler shapes for older pupils, but more varied plan shapes for younger pupils An attached and dedicated room for breakout and widened corridor for storage A greater number of well-defined zones for play-based learning, fewer

	learning methods and activities	23) Wall area for display opportunities	zones, and more formal zones for older pupils Larger is better.
Connection	O) The presence of a wide pathway and orienting objects with identifiable destinations	24) Corridor width 25) Orienting corridor	Wider is better. Displays, landmarks, and daylight with views toward the outside along the pathway

Stimulation

Design Parameter	*Indicators*	*Factors*	*Measurement criteria making up high rating*
Complexity	P) The degree to which the classroom provides appropriate visual diversity. Q) The degree to which the display provides appropriate visual diversity	26) Visual diversity of layout and ceiling 27) Visual diversity of display	Curvilinear effect: Overall visual complexity including room layout and displays should be balanced; not too high nor too sterile
Color	R) The degree to which the "color mood" is appropriate for the learning and teaching	28) Wall color and area 29) Colors of blinds, carpet, chairs, and desks 30) Display color	Light/white walls with bright highlights or feature wall Bright color works better. Bright color works better.

Table 5: The University of Georgia's School Design and Planning Laboratory List of Significant Design Patterns for School Architecture. Table adopted by author from source: (C. Kenneth Tanner 2000, 6–9)

Number	**Design Pattern**	**Descriptor** (Ref Table X)	**Description**
1	Promenade	f	Walkways linking main outside areas, ideally placing major activity centers at the extremes.
2	Green Areas	q	Outside spaces, close to the school building, where trees, grass or gardens may be seen (but no cars or roads).
3	Quiet Areas	q	Solitary places where students may go to pause and refresh themselves in a quiet setting.
4	Play Areas	f	Special locations where children are given the opportunity to be together, use their bodies, build muscles, and test new skills. Using imagination and releasing energy are two important activities seen in these areas.
5	Campus Plan	f	Several natural and built structures that may be connected by walkways (sometimes covered), pathways, and/or promenades that complement the delivery of the educational program.
6	Entrance Area	f	A friendly space connecting the outside world to the inside world. This age appropriate space should be inviting and highly visible for students and visitors. It should evoke a "welcome" feeling.
7	Private Spaces for Children	f	Social places where a small group of children may go to be alone (i.e. reading areas, quiet places, reflection areas, listening areas, etc.)
8	Instructional Neighborhoods.	f	Places (perhaps wing(s) of the building) that include teacher planning spaces, flex. zones (places for multiple use), small and large group areas, wet areas for science and art, hearth areas, and restrooms. The hearth area is a place used for reading and quiet time.
9	Outdoor Rooms.	f	Defined outdoor learning environments - enough like a classroom, but with the added beauties. of nature.
10	Circulation Patterns	f	Indoor spaces for circulation should be broad and well-lit allowing for freedom of movement.
11	Reference	f	Main building has an obvious point of reference among the school's buildings. It is a focal point. where paths and buildings connect. This design feature heightens the sense of community. It stimulates students' imagination.
12	Building on Student's Scale	f	place designed and built to the scale of children (e.g. door handles or handrails low enough for children to reach to accommodate their heights).

13	Administration Centralized	f	Administrative offices are grouped together in a centralized area allowing for connection and convenience. If there are schools within a school or a campus plan, the person in charge should be. readily accessible (at least for the safety of the children).
14	Acoustics	q	Control of internal and external noises levels.
15	Windows	a	Spaces bringing natural light into the learning environment. Windows may have some form of glare control but should be in use (when glare is not a problem) and be without painted obstructions and other devices that restrict views. Windows should invite the outdoors inside
16	Intimacy Gradients	q	A sequence from larger to smaller-public to private spaces, giving the effect of drawing people into the area. These are usually found in main entrances but may be used throughout the learning environment.
17	Technology for Students	a	Spaces with computers, compact disks, learning packages, Internet connections, television, and video.
18	Technology for Teachers	a	Computers (including laptops), multimedia and Internet connections are easily accessible. Teachers have access to technology (outside the media center) for use in research and planning lessons.
19	Pathways	f	Clearly defined areas that allow freedom of movement among structures. These play a vital role in the way people interact with buildings. Pathways may also connect buildings to one another so that a person can walk under the cover of arcades.
20	Context	q	The school and grounds are compatible with the surroundings and sufficient to facilitate the curriculum and programs.
21	Learning Zones	a	variety of indoor / outdoor spaces developed to meet individual learning styles.
22	Climate Control	a	A quiet system designed to maintain a comfortable temperature in the classroom learning environment.
23	Safe Location	s	The site and learning environments are free of excessive non-pedestrian traffic and noise. Natural or built barriers may protect these areas.
24	Storage	a	Secured spaces for teachers and students to store their personal belongings, tools, and supplies.
25	Ceiling Heights	a	A variation of ceiling heights allows individual comfort and intimacy within the school.
26	Background Detail	q	Spaces for colorful displays on walls and doors (e.g. light switches, wall outlets, louvers, and surface raceways) that might be unnoticed by adults.
27	Visual Stimulation	q	Walls and finishes should effectively display color and vivid patterns.
28	Personal Artifacts	a	Places designed for items of a personal nature that relate to each student.
29	Natural Light/Full Spectrum	a	Artificial light plus natural light from the outside, preferably on two sides of every room.
30	Living Views	q	Views of indoor and outdoor spaces (gardens, animals, fountains, mountains, people, etc.). These allow minds and eyes to take a break.

31	Paths with Goals.	f	Places designed to provide focal points when walking to particular locations. (e.g. displays of students, work, meaningful posters, benches, or plants).
32	Personal Space	a	Places for children to participate in activities and tasks without being jammed (crowded).
33	Activity Pockets	a	Spaces designed for small group work.
34	Outdoor Spaces	f	Places which are defined; may be surrounded by wings of buildings, trees, hedges, fences, fields, arcades, or walkways.
35	Learning Signature	q	The school's focus and passion. If, after touring the school, you have to ask if the school has a learning signature, the school probably does not have one.
36	Animal Life	q	Places in a school or on the school grounds for animals to live (includes butterfly houses, bird houses, trees, etc.). Caring for animals helps teach the students a sense of responsibility and respect (values).
37	Bathrooms in Classrooms	s	Bathrooms contribute to the comfort, safety, and convenience of the students and teachers.
38	Lunchroom Atmosphere	q	An inviting setting, including ample lighting and space, allowing students to eat comfortably. A positive atmosphere gives students a sense of worth and value.
39	Overall Impression	a, f, s, q	Judged on whether the learning environments are student friendly and teacher friendly and meet the educational program's needs.

Table 6: The University of Georgia's School Design and Planning Laboratory List of Design Patter Descriptors. Table adopted by author from source: (C. Kenneth Tanner 2000, 6)

Pattern Descriptor	**Description**
f	Functionality of the pattern
a	Adequacy of the pattern
s	Safety associated with the pattern
q	Quality of the pattern