Analyzing Color and Human Behavior through a Built Environment

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Abstract

Recent studies suggest that human psychology and cognition can be affected by the habitual elements and built environment of a space, specifically the color, light, sound, shape, and space of a room. These factors can affect the perception of information within the brain and therefore influence behaviors such as productivity and attentiveness. In this project, we studied the impact of color on the human perspective and looked at how it can best be implemented in an academic space on the Worcester Polytechnic Institute campus. In conjunction with our findings, we designed a structure that will provide a space for students and faculty to work on projects and other related coursework.

Capstone Design Statement

All team members are Architectural Engineering (AREN) majors; Marco, Steven, and Allison have a structural concentration while Angely has a mechanical concentration. However, since she was pursuing her M.S. in Fire Protection Engineering, that was Angely's focus for this MQP. In regards to the structural component, we performed structural analysis on the existing Project Center as well as our redesign. Our main focus was on sizing the columns, beams, and new cantilever beams based on the building loads. For the fire protection aspect, we performed a fire safety analysis. We focused on calculating the occupant load and egress capacity of the building to ensure the Project Center was code compliant with the building codes in accordance with the state of Massachusetts.

We all acted as designers on this project. The design tasks were split up among team members in such a way that we had to communicate with one another to understand our results and utilize them in various parts of the project. The main software that we used was Revit with an Enscape plugin; however, AutoCAD and Excel were also used to aid in some structural calculations. We referenced multiple codebooks as part of this project, including the 2009 International Building Code (IBC) and 2012 NFPA 101 Life Safety Code. We considered sustainability by working with an existing building and making as few changes to it as possible, therefore minimizing the need for new materials.

Executive Summary

Introduction

Recent studies suggest that human psychology and cognition can be affected by the habitual elements and built environment of a space. This research demonstrates how different elements of design can impact cognition. Elements such as color, light, sound, shape, and space of a room can affect the dynamics of the brain and therefore, behaviors such as productivity. We specifically focused on the impact that color has on human attention, and its potential role in improving attentiveness and productivity in a study space. In conjunction with our findings, we designed a renovation of the Project Center to better house its new occupants. After completing our redesign of the Project Center, we created the building in virtual reality and tested people's attentiveness through a simple task.

Color has been found to affect human cognition and influence one’s “attentional level and arousal” (Dzulkifli & Mustafar, 2013). Through years of studies, researchers have discovered just how important the role of color is in the built environment. Certain colors can be implemented to affect the emotions and psychological perceptions of those within the room, and experiments focusing on attentiveness and productivity have found that certain colors consistently impact specific parts of the brain that relate to these topics.

Methods

At the start of our MQP, we developed a Proposed Immersive Space Methodology, where we planned to test participants’ attentiveness and productivity in the immersive space in Kaven Hall. However, due to an increase in COVID-19 cases and heightened restrictions that were put in place at WPI, these initial intentions were replicated in a VR setting instead. The VR setup situated participants in a virtual room within the building designed by the team. This room was a “tech suite,” a room with monitors and chairs where students can privately collaborate and study. The procedures were similar to those of the immersive space methodology, but the tasks were different during this new phase of experimentation as to conform to the restrictions of virtual reality. We planned to gather the same data on productivity and attentiveness as we would have done in the immersive space experimentation.

To investigate the effect of color, we randomly but equally assigned a different color sequence including red, green, and blue to the participants. In the VR space, the color of the walls transitioned from a natural color through the assigned color sequence, and back to natural. While this happened, the participants wore a VR headset on top of an EEG headset that recorded their brain activity throughout the testing. As the walls changed colors, the participants performed a task where a series of numbers appeared on the screen, one by one, and the subject was asked to click a button for each number that appeared except for numbers containing the digit “3.”

Subjects had two seconds to react to each number and their response was recorded. The whole experimentation and setup of equipment took about 30 minutes per person. Before and after experimentation, we had the subject relax and close their eyes as needed to help them reach a baseline that could be used for data analysis. We also administered a post-experimentation questionnaire to better gauge their reactions to the experiment.

Building Design

Our building design was a renovation of WPI's existing Global Project Center. Currently, this space houses both the school's Interdisciplinary and Global Studies Division (IGSD) as well as their Career Development Center (CDC). The interior of the existing building was gutted and replaced with a new floor layout. The building will remain structurally supported by the existing structural steel columns and brick walls, and any additional beams or columns that are needed as a consequence of the redesign were determined. Once the new Boynton Street Building is completed, the CDC will move into that space, allowing the IGSD to fully utilize the Project Center.

To begin our research, we looked at several case studies to determine what we wanted to incorporate or improve upon in our redesign of the Project Center. Mostly, we focused on researching academic buildings that encouraged group work and included open collaboration spaces. From the Foisie Innovation Studio at WPI and the Harvard Campus Center, we took their ideas of project-based learning spaces and curtain walls, allowing for a connection with the outdoors. We also liked their implementation of a main staircase that can also be used as seating. The design review of the University of Pennsylvania campus taught us that we should provide public spaces for working that are ideally visible from the outside of the building. In regards to the facade, we really liked the look of the Crystal Houses' glass brick design and the circular cutout from WPI's Boynton Hall. All of these elements were adapted to be included in our building.

The design of our building was mainly influenced by the analysis of the current Project Center. Our team spoke to several faculty members in order to determine the suitable approach to renovate the building to better fit its new future occupants - the Project Center faculty. We performed a site visit and made observations of the current building as well as researched case studies on recently renovated campus buildings for inspiration. We also analyzed the condition of the current building to evaluate possible changes for inclusion in the structural and mechanical analyses.

Our team added tech suites, a conference room, and more offices for meeting spaces. We created an open meeting area by the main entrance on the first floor for students to collaborate with others and added a break room on the second floor. To improve accessibility, we added another staircase within the building that connects the two floors, an elevator, and a hallway that loops around providing access to all rooms. This centralized hallway is on both floors to create a better flow of users, minimize distractions, and allow for easier navigation. In addition, offices will no longer need to be shared since enough will be added to the building to house the faculty comfortably and allow for a growing staff. This will also minimize commotion and maintain privacy for the faculty utilizing these offices. We also focused on structural and fire protection elements to make sure that the renovation to the building would be code compliant.

Findings, Recommendations & Conclusion

We were able to test eight subjects and overall, our experimentation went as planned. We ran into some issues with the EEG, since it was sitting under the VR headset and sometimes had trouble with all of its sensors making contact, especially for people who had longer hair. After administering the post-experimentation questionnaire, we learned that participants found the task simple but repetitive over a very long period of time. Some of the participants lost focus during experimentation, and others felt very distracted by the colors of the wall changing. The majority of the participants were distracted five to 10 times due to the colors changing in the background, and some felt the color red was very intense while performing their task.

After completing our experimentation, we developed several recommendations that would be helpful to a future MQP group or someone who wanted to improve upon our research:

- Different types of attention can be further studied such as selective attention, divided attention, alternating attention, and sustained attention.
- Data collected from the immersive space could be used to create the VR space and implement the VR data into the design of the Project Center.
- It should be determined whether the change in color has a noticeable effect on cognition rather than just the effect of each color.
- A larger sample size would be ideal as it would increase the validity of the results and the scope of the data.
- Online brain games such as Lumosity could be used for experimentation as the tasks are more complex and the website generates its own data. Each subject would have to create their own Lumosity account. On the downside, Lumosity games are more challenging to replicate in VR so that additional time would have to be planned for.
- Look into the issues created by wearing both the EEG as well as the VR headset and find a solution.
- Test different tasks with ranging amounts of difficulty, the effects of other colors that were not assessed in this study, and the effects of color strictly on productivity as was originally intended.
- Take into consideration the fatigue factor since participants felt tired throughout experimentation. We recommend determining whether the duration of time for experimentation was appropriate - perhaps testing for a shorter or longer period of time would have been better.

We hypothesized that blue light would improve productivity, green light would improve attentiveness, and red light would be distracting to participants based on the research that we completed prior to experimentation. Although we were unable to have our data analyzed due to our time constraints, the participants' responses to our questionnaire suggested that people tended to feel very strongly opposed to the color red. We also learned that most participants were reacting more to the fact that the wall was changing colors rather than the feeling imbued by the individual wall colors, making all of the colors distracting as a whole.

Acknowledgements

We would like to thank our advisors, Professor Leonard Albano and Professor Soroush Farzin, and all of the WPI faculty members who helped us develop our project - Professor Ali Yousefi for helping us with our experiment design, Professor Kent Rissmiller for informing us about the current and future function of the Project Center, Professor Milosh T. Puchovsky for providing us with guidance on the fire protection aspect of our project and Professors Ingrid Shockey and Sarah Strauss for giving us insight into the perspectives of working in the Project Center and other buildings on campus. Thanks to Laurie Mazza for helping us with the virtual reality aspect of our project and Kensuke Arai for analyzing the EEG data. And last of all, thank you to all of the WPI students who took the time to participate in our project!

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Authorship

All team members contributed to the MQP equally. The team was all present during the virtual reality experimentation. Marco, Steven, and Allison worked on the structural aspects, and Anyely worked on the fire protection elements in alignment with their concentrations.

Anyely worked on the writing sections of the VR Methodology, the Architectural Building Design, and the Recommendations. She researched case studies for the new building design, completed the fire protection component of the project and created recommendations for future MQP teams. She also worked on the documents in the Appendices regarding forms and questionnaires for potential participants.

Marco worked largely on the design and execution of the experiments which became more complicated as the methodology changed several times. Other than general writing and editing, he worked on the majority of the precedent studies as well as the research and analysis of the existing Project Center and its pros and cons. He also worked on calculations pertaining to tributary area and beam sizing for the cantilevered beams in the new building.

Steven worked on the floor plans in Revit as well as the calculations for the loads on the existing columns in order to determine whether an upgrade in column sizing is needed for the redesign of the building. In terms of content, he worked on the Productivity and Attentiveness sections of the Background, the Methodology, the Site Plan, Site Visit, Floor Plans, and Structural, sections of the Architecture Building Design, and the Recommendations section.

Allison worked on organizing, formatting, and editing the paper. In terms of content, she worked on the Productivity and Attentiveness sections of the Background, the Methodology, facade case studies, floor plans and renderings using Revit and Enscape, some structural calculations and decisions, and compiling documents for the IRB such as the VR Screening and COVID-19 protocols.

Chapter 1: Introduction

Recent studies suggest that human psychology and cognition can be affected by the habitual elements and built environment of a space (Proulx et al., 2016). This research demonstrates how different elements of design can impact cognition. Elements such as color, light, sound, shape, and space of a room can affect the dynamics of the brain and therefore behaviors such as productivity. In this study, we specifically focused on the impact that color has on human attention.

Scientific studies have been conducted to show the influence color has on emotions, productivity, and learning (Elliot, 2015). The colors of the spaces around us can affect our attention spans, motivation levels, and emotions. Calmness, comfort, and happiness are typically associated with colors such as blue, green, and yellow, while anger, pain, and power are linked with colors like red and orange (Cherry & Gans, 2020). These colors stimulate a user's attention for a long period of time, whereas dull colors such as white and grey can distract the user and reduce their attention and concentration. Similar to color, light can also have an impact on human cognition (Kaplan & Kaplan, 1995). The implementation of artificial light versus natural light affects how a user is feeling in a specific space (Edwards & Torcellini, 2002). Artificial light tends to cause physical and mental stress, while the purity of natural light can promote more soothing and tranquil feelings. The user's attention, stress, and mood can also be impacted by the angle, color, intensity, and quality of the light (Küller, Mikellides, & Janssens, 2009). These elements all work together to affect human cognition and productivity in any given space.

To further examine the impacts of architectural elements on the human brain, the WPI Neuro-Arch lab, whose research focuses on adaptive architecture to understand and regulate human emotional states, has developed a configurable immersive space that integrates a brain computer interface (BCI) platform. The BCI systematically studies the associations that could potentially link the brain activities, behavior and architectural elements. Our Major Qualifying Project focused on redesigning the WPI Project Center, which provides a space for students and faculty to work on projects and other related coursework, using adaptive kinetic architectural design to regulate the human's cognitive state. Our team focused on color's effect on architecture to study the cognitive domain of attentiveness and productivity in a study space. We designed an experiment within the immersive space to investigate the role of colored walls on the cognitive attentiveness of the user. This understanding of color will help with the redesign of the Project Center. Throughout this experiment, we designed and analyzed the structural and fire protection systems of the Project Center. After the redesign of the Project Center, we created the building in virtual reality and tested people's attentiveness through a simple task.

Chapter 2: Background

2.1 Introduction

Color has been found to affect human cognition and influence one's "attentional level and arousal" (Dzulkifli & Mustafar, 2013). Through years of studies, researchers have discovered just how important the role of color is in the built environment (The Perception of Color in Architecture, 2017). Certain colors can be implemented to affect the emotions and psychological perceptions of those within the room, and experiments focusing on attentiveness and productivity have found that certain colors consistently impact specific parts of the brain that relate to these topics (Kurt & Osueke, 2014). The psychology of color within architecture is complex, but in this paper, we will discuss several case studies that provide an overview of the topic. We will also cover research on methods and techniques we took into consideration as we redesign the WPI Project Center.

2.2 Productivity

Productivity refers to the amount of work accomplished "*over a particular period of time*" (Hanna, n.d.). Generally, the goal is for workers to have the highest productivity levels possible. In universities, students aim to increase their productivity as well in order to complete their schoolwork and research as efficiently as possible. This increased productivity can occur "*when people can perform tasks more accurately and quickly over a long period of time*" (Clements-Croome, 2000). However, some factors beyond control can have a large impact on people's efficiency, from mental disorders such as ADHD and ADD to their surrounding environment, including the layout and color of the room in which they are working, among other aspects.

Specifically, the color of one's surrounding environment can affect productivity and mood. Kwallek et al. (2007) studied the amount of errors made on a typing task along with mood when participants worked in a red versus a blue office environment. Participants filled out an eight-state questionnaire after the task was completed to provide a measurement of the important emotional states and moods that they experienced, and her team discovered that "*anxiety and stress scores were higher for the subjects who remained in the red office*" (Cattell & Curran, 2018). For productivity, the researchers found those who changed offices to work in multiple-colored environments made more mistakes on their typing task, so this study demonstrates that too much shifting of color in the built environment can cause a decrease in productivity. Kwallek's other studies in this area also generally reflect the conclusions that were found during this experiment, showing that color does play a major role in both people's productivity and their mood.

Küller et al. (2009) studied the brain's reactions to different colors. They ran three tests to compare the differences in subjects' reactions, arousal, mood, and productivity between colored and grey spaces to find which color causes participants to experience the highest levels of productivity. They also used an EKG (an electrocardiogram) to record their hearts' electrical signals and asked the subjects interview questions to gather additional data for each colored room. The experiments concluded that for participants, "*the perception of the room itself was affected, and the colors also had an impact on the emotions and physiology of those who stayed in the rooms*." In addition, vibrant colors such as red can create a more "*excited state*" within the brain, which can in extreme cases slow down one's heart rate.

One way to measure productivity is to measure subjects' speed of completion and correctness on a certain task. In an experiment conducted by Tsutsumi et al. (2007), they calculated the productivity of their subjects by assigning them mathematical addition problems. When two numbers popped up on a computer screen, the subject was instructed to provide the correct sum. The researchers measured the accuracy of their answers and the time it took them to answer the question. They found that while people who tested under the blue conditions did better on the test, it also resulted in a stronger arousal effect than other colors such as red.

There are several case studies that examine the effects of the color of a participant's environment on their productivity levels. In one such study performed by Kwallek et al. (2007), subjects were asked to "*perform nine tasks consisting of fine motor tasks, psychophysical judgments, and gross motor tasks" to analyze "the effects of three office color interiors ... on worker productivity*." Each subject was assigned a differently colored space - either white (a neutral color), red (a warm color which stimulates excitement), or blue-green (a cool color which is generally soothing) - and instructed to work there for four consecutive days. The researchers measured their accuracy and performance on the tasks, and after taking into account their subjects' individual differences in sensitivity in changing environments, their results suggested that "*interior color can ultimately affect a worker's overall productivity in the long run depending on the duration of exposure*."

2.3 Attentiveness

Attentiveness is when someone is paying close attention to something or someone, and similarly, an attention span is the time frame that someone is focusing on something or someone (Attentiveness and paying attention, n.d.). Just like productivity, researchers have found that color can also have an effect on the attentiveness of a subject (Kim, 2010). Most findings show that red usually elicits a negative response - a drop in attentiveness - while blue tends to increase attention spans, which in turn improves productivity (Elliot & Maier, 2007).

While some colors may impact someone positively, other colors can be distracting in a learning environment (Kwallek et al., 2007). Individuals are more productive in a blue environment. Shades of blue have been found to help improve reading comprehension and problem solving in challenging learning situations, and blue has also been found to be a calming color. However, if the shade of blue used is too dark, it can make an environment feel somber, while lighter shades of blue tend to seem more "welcoming" (Effect of Different Colors on Human Mind and Body, 2015). Studies have also shown that the color green improves people's efficiency and focus. Green not only increases concentration and clarity but also promotes feelings of tranquility and relaxation. In a working environment, shades of green can help students concentrate on an assignment for a longer period of time. Conversely, warm colors such as red or orange are stimulating. The color red draws a lot of attention, making it the color of choice for safety-related details. This can potentially distract a student from completing a task efficiently. Too much exposure to the color red can cause stress and even frustration. For a learning environment, it's important that colors were picked to encourage students to be productive and focus on their work.

In one study, Dr. Kate Lee (2015) examined 150 college students. They assigned the college students a boring task that pushed their attention span to its limit. This activity consisted of students reading off a computer screen, where they would press a series of numbers and were told not to press the number three when it appeared on the screen. Once it was time for a break, they viewed a "city rooftop scene," where half the students looked at a green roof while the other half viewed a bare concrete roof, as shown in Figure 1. The results showed that students who viewed a green roof made fewer errors and were able to concentrate better overall. This study proved the importance of an environment's colors and showed that a green space could provide a boost of energy for workers who are struggling to concentrate (Calligeros, 2015).

Figure 1. The Images Show to Students in Dr. Kate Lee's Study (Calligeros, 2015)

In a study by Elliot and Maier, they experimented with different colored anagrams as well as cover sheets to analogy and IQ tests. They concluded that "red evokes avoidance motivation and undermines intellectual performance, and that it has these effects without conscious awareness or intention." If someone wants to create a purposefully distracting environment, they can consider using the color red (Elliot & Maier, 2007).

Prior experiments have covered several different methods to measure subjects' attention during experimentation, but for our experimentation, we used an electroencephalogram (EEG), which is a test "*used to evaluate the electrical activity in the brain*" (Blocka, 2018). This is useful in measuring the productivity and attentiveness of a user during the tasks they complete. The device measures delta, theta, alpha, beta, and gamma waves, each corresponding to a certain way in which the brain fires neurons depending on the surrounding environment and task (Oken et al., n.d.). Numerous studies have been done using EEGs as a way to measure subjects' reactions to different colors; for example, Yoto et al. (n.d.) showed participants different-colored paper and recorded their brainwaves to analyze changes in perception and attention levels. They found that the EEG picked up larger values of the alpha and theta bands when subjects looked at the red sheet of paper as compared to the blue one; this "*indicated that red possibly elicited an anxiety state and therefore caused a higher level of brain activity in the areas of perception and attention than did the color blue*" (Yoto et al., n.d.).

In 2016, Xia et al. team compiled years of research on the color red versus blue and its effects on cognitive task performances. Through this, they found that red and blue are both favored, just at different times - for example, red is preferred for a simple detail-oriented task, blue for a difficult creative task, and red for a difficult detail-oriented task. This research shows that depending on the type of task assigned, one color might have more effect on a subject's motivation and arousal, so tasks must be carefully selected.

2.4 The Building: Precedent Studies and Relevant Research

Investigating case studies is a crucial step when designing or redesigning a structure that allows designers to learn from the past. The following case studies were chosen as they excel in covering a variety of aspects that affect the future WPI Project Center.

2.4.1 Seattle Public Library

The Seattle Public Library, a hub for the busy city, has stood out for its innovative design since its opening in 2004. The structure was designed by the Office for Metropolitan Architecture and architect Rem Koolhaas. The concept of the building was to reinvent it to efficiently contain the vast amount of information we now have available and make it easy to navigate. Before beginning on the design, Koolhaas met with several large technology companies to solicit their views on the potential future of information and found that they believed that books would probably not be a "thing of the past" (Seattle Public Library, 2020). With this in mind, they designed the "spiral," which is Shown in Figure 2. It is an inclined floor that spans five of the floors and hosts the vast majority of the books with the goal of making it harder to get lost in the building.

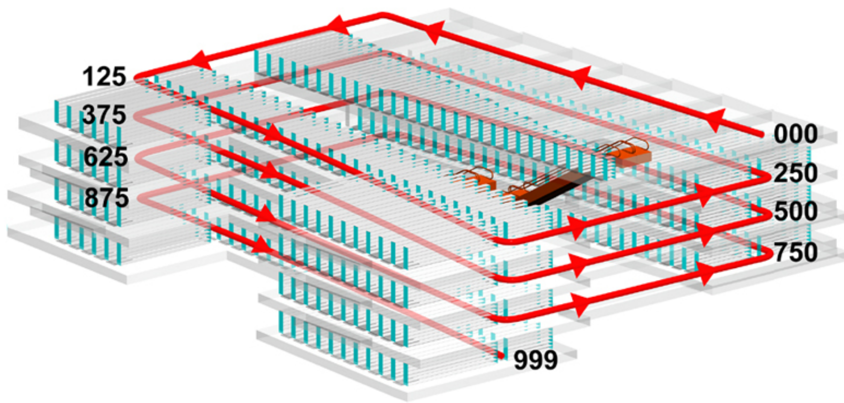


Figure 2. The Seattle Public Library's Book Spiral Flow Pattern (Diagram Book Spiral, n.d.)

One of the most striking features of the building is its corrugated metal and glass facade that wraps around the unevenly sized floors, shown in Figure 3. This facade hosts almost 10,000 different glass panels so that all levels can receive sunlight. Natural lighting has been shown to increase productivity, so designing buildings for a lot of natural light should be a goal for most academic settings, including the WPI Project Center.

Figure 3. Interior View of the Seattle Public Library's Glass Panels (Armianu, n.d.)

The Seattle Library also uses artificial lighting in conjunction with color to curate its indoor environment. One of the most obvious cases of color when entering the library is the illuminated, acid yellow stairs that demand attention to ensure that people do not miss them and cause injury to themselves. Koolhaas also uses color excessively on the fourth floor, where the walls, floor, and ceiling of the hallway are a deep red. This creates an uncomfortable space that leads to meeting rooms that are painted with neutral, more pleasing tones. This contrast makes the meeting rooms more comfortable in comparison. By analyzing these strategies and uses of color, we implemented similar strategies in our design of the Project Center.

2.4.2 COVID

With the rise of the novel coronavirus, we found that our buildings were not fully prepared to deal with a pandemic. While this virus may be eradicated in the near future, similar events will likely happen again, and we should be prepared. Although much of the burden is on the individual to promote healthy practices such as wearing a mask, many architects and designers are already looking to see how the next pandemic could be quelled by designing structures that can prevent the spread of disease. The CDC finds that activities with the highest risk in schools are ones where students are inside in close proximity as well as moving from classroom to classroom and causing cross contamination. By spreading students out and stopping them from visiting many rooms throughout the day, the number of infections can greatly be lowered. This also goes for almost any collaborative space (Operating schools during COVID-19: CDC's Considerations, 2021).

One of the most important things that we are still learning more about is how COVID-19 travels through the air and how infection is mainly due to this airborne contaminant. The firm Salon Alper Derinbogaz developed a design for a “pandemic-resistant” building that could combat this issue (Ecotone, n.d.). The building’s future location is between a textile academy and the offices of the teachers in Yıldız Technical University in Istanbul. It would be open to the air to lessen the risk of spreading COVID-19, since re-circulating air is a large risk factor (Roadmap to improve and ensure good indoor ventilation in the context of COVID-19, 2021). To deal with heating and cooling without an HVAC system, they decided to use geothermal methods instead. The academic building also includes several other innovative design and material choices, which makes it an inspiration - but a “far reach” in comparison to what the Project Center can become with all of its limitations (Block, 2020).

Chapter 3: Experimental Methodologies

3.1 Proposed Immersive Space Experiment

This chapter was previously designed with the expectation that we would be able to perform experimentation in-person and on campus much earlier in the MQP process. However, due to an increase in COVID-19 cases and heightened restrictions that were put in place at WPI, we were unable to complete our Immersive Space experiment. The previous methodology has been moved to Appendix A, and we have instead created an experimentation protocol using Virtual Reality in order to complete our goal which is further covered in Section 3.2.

3.2 Virtual Reality Experiment

3.2.1 Description

The methods stated in Appendix A were replicated in a virtual reality (VR) setting. The VR setup situated participants in a virtual room within the building designed by the team. For this study, we selected a "tech suite," a room with monitors and chairs where students collaborate and study. The experimental procedures were similar to those defined for the immersive space in Appendix A, but the tasks were different during this new phase of experimentation as to conform to the restrictions of virtual reality. We planned to gather the same data on productivity and attentiveness as we would have done in the immersive space experimentation. Later in this chapter, we will discuss the steps of the experiment in depth.

3.2.2 Basis of Experiment

To investigate the effect of color, we randomly assigned a color sequence to each participant that tested their productivity and attention, which are elaborated on in Table 1 below. All variables in virtual reality remained constant except for the color of the walls in the interior space. Each subject performed the same task, which allowed us to measure the subject's ability to focus on this specific task over a long period of time.

Table 1: *Objective, Method, Analysis, and Anticipated Results for VR*

Objective	Method	Analysis	Anticipated Result
Determining how color affects subject productivity and attentiveness	Field study	Phase A: If qualified for the study, measure baseline vitals (heart rate, blood pressure, skin temperature, and brainwaves).	Blue light improves productivity, green light improves attentiveness, and red light is distracting.
	N: 30 people	Phase B: Complete task while collecting EEG data	
	Stimuli: Color (red #CC0605, green #57A639, blue #3B83BD)		
	Dependent variables: heart rate, blood pressure, skin temperature, task completed, number of errors, EEG	Phase C: Measure until return to baseline vitals. Have participants take off gear, do a questionnaire, sanitize, and leave the office.	

The timeline of our VR experimentation methods is shown below to better understand the project's process.

Table 2: *VR Testing Timeline Before, During and After Experimentation*

Prior to Testing					
EVENT	Subject Enters and Sanitizes	Informed Consent and VR Screening	Study Procedure Instructions	VR and EEG Measurement Device Placement	Task Instructions and Tutorial
TIME	-	1 min	2 min	4 min	1 min

Experiment											
EVENT	Measure Baseline	Natural	Transition from Natural to A	Color A:	Transition from A to B	Color B:	Transition from B to C	Color C:	Transition from C to Natural	Natural	Measure Baseline
COLOR		*Natural*	-		-		-		-	*Natural*	*Natural*
TIME	2 min	2 min 30 sec	30 sec	2 min 30 sec	30 sec	2 min 30 sec	30 sec	2 min 30 sec	30 sec	2 min 30 sec	2 min

Post-Experiment, return to baseline and questionnaire				
EVENT	Remove Equipment	Post-Experiment Questionnaire	Participant Sanitizes	Sanitize Equipment and Participant Exits
TIME	1 min	2 min	1 min	5 min

3.2.3 Data Collection

3.2.3.1 EEG Data Collection

We utilized the DSI-24, a Dry Electrode EEG Headset, shown in Figure 4, to collect basic EEG data, or the brain's electrical activity. An EEG reads five different waves: delta, theta, alpha, beta, and gamma, all summarized in Table 3; each corresponds to a different way in which the brain is firing neurons. Depending on both the task and environment, the rates of each wave type are constantly changing.

Figure 4. DSI-24 Headset (DSI 24, n.d.)

Table 3
Brain Wave Types and Levels

Normal Levels		Irregular Levels	
Type	Association	High	Low
Delta	Deep Sleep, Subconscious tasks	Learning difficulties	Poor Sleep
Theta	Imagination, reflection and sleep	Depressive and attention disorders	Anxiety and stress
Alpha	Relaxation	Prevents focus, meditation	Anxiety, stress, insomnia
Beta	Attention-based tasks	Anxiety and Stress	Apathetic and depressive moods
Gamma	High-level cognitive processing	Happiness	Mental and learning disorders

3.2.3.2 Other Data

The VR headset also collected data while the participant was completing their task. This will be further discussed in later sections.

3.2.4 COVID-19 Safety Protocols

Due to the current circumstances of COVID-19, this experiment followed local and institutional recommended guidelines to promote health and safety practices. Student investigators and participants were asked to follow the COVID-19 protocols that are further described in Appendix B.

3.2.5 Prior to Experimentation

The basis of this study was to better understand whether different colors alter human productivity and attentiveness while subjects complete tasks with a virtual reality headset. The study originally contained 30 participants, but at the time of testing, only eight students were able to participate. The subjects were assigned one task to complete, and this task was performed under all three colors (red, green, and blue). Subjects also performed a baseline test before and after testing which was done under neutral color room. The test subjects were enrolled in the study via email distribution (located in Appendix C) to WPI students. The message sent out contained a brief description of the project and a prescreening through the Google Form located in Appendix D. Once the volunteer was selected to participate in our study, they were required to read and sign the Informed Consent Agreement located in Appendix E.

The prescreening made the data more consistent by controlling external factors. In addition, gathering the participants' emails allowed our team to contact them if necessary in the future. The email sent out to potential participants asked subjects to refrain from volunteering for the study if they have been diagnosed with ADD or ADHD, have a color deficiency, or were currently using any stimulant or depressant medications.

A person's attention span has a major impact on their performance at work, school, and during regular everyday tasks. Subjects who have ADHD (attention-deficit/hyperactivity disorder), ADD (attention deficit disorder), or are visually impaired (have color vision deficiency, color blindness, achromatopsia, or other similar conditions) were not selected for testing. Subjects with a color vision deficiency or visually impaired were not tested because we were measuring the relation of color and attentiveness. Subjects must have been able to see the colors around them in order to participate in the experiments. Subjects with color deficiencies, who have been diagnosed with conditions such as ADHD or ADD that may affect their focus, or were taking stimulants or depressants at the time were asked to refrain from the experiments because their conditions may alter the results in a negative way.

3.2.6 Experimentation

The Virtual Reality equipment was set up prior to the subject's arrival in the lab (Figure 5). Our team introduced the DSI-24 and VR headset and explained their function before the participant placed the equipment on themselves. A short overview was also given to the participant on how to use the VR controls. To determine baseline, we asked the subject to remain relaxed and leave the equipment on for two minutes as we measured the deviation throughout the test. Our team was able to inform the subject about the tasks they were going to perform and the order in which they will be completed. We gave participants the opportunity to ask questions as they joined us for about 30 minutes, 15 of which were active.

Figure 5. Study Area for VR Experimentation

Once the baseline data was collected, participants began experimentation in virtual reality. The subjects were tested in all three of the colors while performing one task. The order of the colors was randomly assigned for each subject. We used a random number generator to decide which color goes first and which colors proceed, with each of the three colors being shown once to ensure guaranteed randomness. There was a 30-second-long transition between colors to not surprise the subject and draw attention to the walls. Apart from the walls changing colors, the interior spaces in virtual reality remained constant for each subject. For the task, a series of numbers appeared on the screen, one by one, and the subject was asked to click a button for each number that appeared except for numbers containing 3. Each number was shown briefly, then a circle with an X in it would appear shortly after. Subjects were given two seconds to react to each number. If the correct response was inputted, the task would continue, but if the incorrect response was inputted, the phrase “Press when a number does not contain 3” would appear. After the participant experienced all three colors, they were done with this phase of experimentation.

For the virtual reality experiments, we chose to place participants in a tech suite (Figure 6), where students typically want to maximize their attentiveness and productivity while they participate in group work. These rooms are more secluded as they aim to minimize noise and maximize privacy. This space creates a perfect working environment for students. The model we created to test participants includes a small conference table and five chairs. In addition, we mounted a computer monitor on one end of the table and placed whiteboards on the walls to encourage group work. The experiments were conducted with the participant remaining seated for the duration of their testing. The task was displayed on the monitor located at the end of the table. The numbers appeared in black font on a white background.

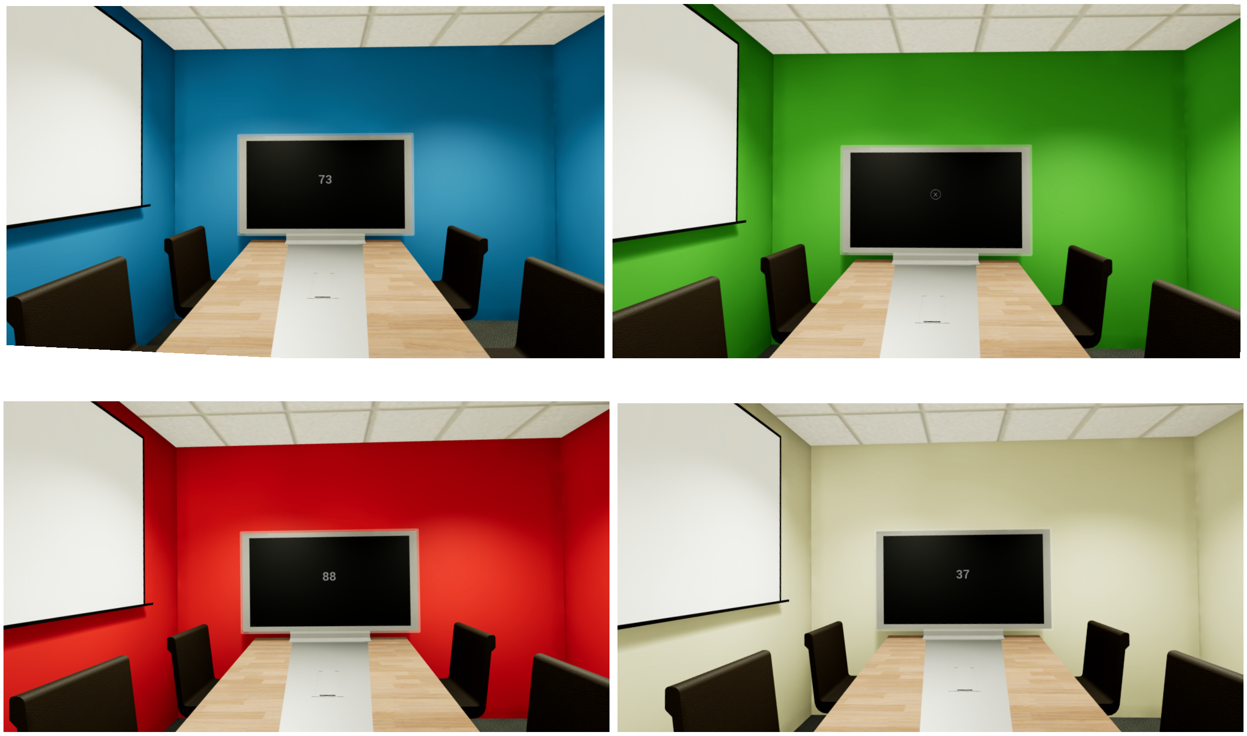


Figure 6. Different Color Walls in Tech Suite within Virtual Reality

3.2.7 Post-Experimentation

Upon completion of the tasks, participants left the DSI-24 and VR equipment on until they returned to or close to baseline state. The data from the device can be used to indicate the intensity of any discomfort that the subject may feel as well as the length of time it takes them to feel comfortable again. If this process took longer than anticipated, the subject was asked to slowly open and close their eyes to help them return to baseline.

When they reached baseline, our team administered a questionnaire that provided us with additional information for post-experimentation analysis. It covered how the subject felt during the experiment in regards to the colors utilized as well as any other pertinent questions. The full set of questions are included in Appendix G.

While the subject completed the post-experiment questionnaire, they used hand sanitizer before leaving the test site as we reset the experimental equipment and returned all instruments to their original positions. This ensured that any data inconsistencies did not result from the equipment setup. After they left, we sanitized all of the equipment and any surfaces that the participant may have come in contact with and then prepared for the next experiment.

Chapter 4: Architectural Building Design

4.1 Introduction

Our building design was a renovation of WPI's existing Project Center. Currently, this space houses both the school's Interdisciplinary and Global Studies Division (IGSD) as well as their Career Development Center (CDC). The interior of the existing building was gutted and replaced with a new floor layout. The building will remain structurally supported by the existing structural steel columns and brick walls, and any additional beams or columns that are needed as a consequence of the redesign were included. Once the new Boynton Street Building is completed, the CDC will move into that space, allowing the IGSD to fully utilize the Project Center.

4.2 The Existing Project Center

The Project Center is a two-story building that was built in 1902. This building was known as the Foundry, which originally served as a commercial and educational space where students learned to cast machine parts from molten metal. The original design of the Foundry when it was first built can be seen in Figure 7. The Foundry was then renovated to restructure the Institute's undergraduate education program (The WPI Campus, n.d.). Today, the lower level of the Project Center houses WPI's CDC and the top level houses the IGSD (Project Center, n.d.).

Figure 7. Interior Space of the Foundry (The WPI Campus, n.d.)

Since the original purpose of the building was an iron foundry, the general design and much of the materials used are not ideal for the typical office building. The bricks that make up the exterior walls are fire-resistant and are one of the larger elements that has caused issues for the building's renovations. While it was used as a forge, the Foundry was one large room with no second floor as this best suited WPI's needs at the time. The Foundry was renovated into the current Project Center in the 1970s. This created a more challenging space to renovate. Once the CDC center moves into the Boynton Street Building, the IGSD will have more room to expand their office space.

Currently, the IGSD has had difficulty collaborating with students because of a lack of space combined with insufficiently sized offices. Some faculty offices have an area of 100 square feet that is only comfortable for about one other person to be present in. Because most ID2050 and IQP teams are composed of 4-5 students, it's important that the faculty have sufficient space to meet with their entire team in a comfortable working area.

As the Global School becomes more popular for students at WPI, a necessary increase in their staff size is anticipated (Rissmiller, 2020). Due to this, WPI will need to create additional offices in the Project Center while minimizing the number of staff that are sent to other academic buildings such as the Foisie Innovation Studio.

The sizes of the offices in the Project Center vary drastically from one to another and the floor layout has a poor configuration where some advisors must walk through other advisors' offices in order to get to their own office. The building does not have enough meeting spaces, which sometimes limits professors and advisors from meeting with their students often. Some designs have been previously proposed for the Project Center's building renovation. One design proposed that cubicles could function as the professors' offices, but the design was quickly vetoed since cubicles would not give enough privacy to professors who sometimes must have confidential conversations with students.

4.3 Site Visit and Goals for Our Project Center

4.3.1 Site Visit of the Current Project Center

Before beginning our design process for the renovation of the building, we toured the current building and examined floor plans of the existing space along with floor plans of a proposed, new second-floor layout. The Project Center was renovated to have two floors instead of its original one-story building, which led to some issues with the current layout that we worked on fixing in our redesign. One issue is the lack of adequate, accessible egress in the main area of the second floor. There is one staircase on the east side of the building that leads to the Global School, and one main hallway that does not reach all of the offices on the floor. In addition, office sizes are not ideal, especially for project team meetings, and some are shared or even act as pathways to offices that cannot be accessed from the main hallway seen in Figure 10. This created an unintentional maze-like path for some faculty to travel to the opposite side of the building to reach their office.

Figure 8. The Old Foundry (The WPI Campus, n.d.)

In addition to touring the building, we met with three of the building's faculty - Professors Kent Rissmiller, Ingrid Shockey, and Sarah Strauss - to gather their feedback and any suggestions for a potential redesign. Professor Rissmiller stressed "*the need for a better utilization of the space since they only had access to the second floor*" (Rissmiller, 2020). This included a better design of the office spaces as well as improving the connection between the two floors. Also, there were some faculty who had to work in other buildings on campus, and he noted that collaboration would be easier if the Project Center team had the space to work together in the same building. In addition, he recommended the addition of more workspaces so that it can accommodate the increasing population of students. Professors Shockey and Strauss have experience working in Foisie and wanted the redesigned Project Center to have some similarities to and differences from their current situation. Foisie's offices do not have much privacy and the windows do not open, so they recommended that the new offices have operable windows so that the temperature and outside airflow can be controlled. They agreed with Professor Rissmiller's statements that there should be enough space for faculty as well as enough collaboration space for students, whether that be in offices or common areas (Shockey & Strauss, 2020).

Figure 9. Hallway in the Project Center *Figure 10.* Desk Setup in the Project Center

4.3.2 Evaluation of the Current Building

Based on our investigation on the building, we created our objectives for the redesign of the Project Center based on the pros and cons of the current building:

Table 4: *Pros and Cons of the Current Project Center Building*

Pros	Cons
• Good central location • Offices are private and distraction free • Windows can be opened, unlike Foisie • Majority of faculty is located there	• Offices are not equal sizes • Not wheelchair accessible • Lack of space for meetings, collaboration areas, and interactive activities

The Project Center is located in the center of campus next to the fountain. This makes it one of the more accessible buildings for students and faculty to visit. With the majority of the IGSD faculty located in the Project Center, advisors are readily available to meet. While the faculty offices are oftentimes not large enough for professors to work with their students, their offices are rather private and free of distractions, which is not always the case with other academic buildings. Another non-standard feature of the Project Center offices are windows that are able to be opened for fresh air.

While having positives, faculty have several gripes about the design of the Project Center. Due to the building not being originally designed to house offices, the current layout has several flaws. One of the biggest of these flaws is the maze-like feel of the building and differently-sized offices leading some faculty to have worse offices than others, and in some cases, advisors must even share their office with others. One of the biggest issues we found is the lack of collaborative spaces. While common in other buildings in the form of tech suites or open common areas, the Project Center only has one conference room which is used for faculty meetings. Since the Project Center was remodeled so long ago it also does not conform to modern ADA standards and is not wheelchair accessible. Overall the IGSD is difficult to navigate from one space to another.

4.4 Case Studies

Several case studies were researched in order to generate new designs for the Project Center. We looked into academic buildings that encouraged project-based learning and comfortable spaces that were ideal for group meetings and open collaboration.

4.4.1 Harvard University: Richard A. And Susan F. Smith Campus Center

Harvard University's new Campus Center is located in Cambridge, Massachusetts. The building went through a two-year renovation and reopened in September 2018. It was transformed into a hub as a way to encourage interactions between students, faculty, and staff. This building allows the Harvard community to come together in many different ways. The Smith Campus Center includes spaces for relaxation, studying, group gathering, programs, and events. It offers a wide range of gathering areas for Harvard students, faculty, academic personnel, staff, and visitors and contains restaurants as common spaces for social and meeting purposes (Common Space, n.d.). The building has unique indoor landscape elements, comfortable furniture, and newly designed outdoor spaces.

Similar to the Smith Campus Center, the WPI Project Center will include common spaces for students to collaborate with their peers and faculty advisors on projects such as IQP and MQP (The WPI Campus, n.d.). This building will focus on project-based learning where the space will be optimized for group work.

A unique element to the Smith Campus Center is its interior stairs that not only serve as a form of egress but also function as an area to work and collaborate with others (Luthra, 2018). A design similar to this will be incorporated to the Project Center's renovation. This renovation will contain a set of stairs that provides a pathway from the common space to the faculty offices and also functions as a study space for students to work with their peers or advisors.

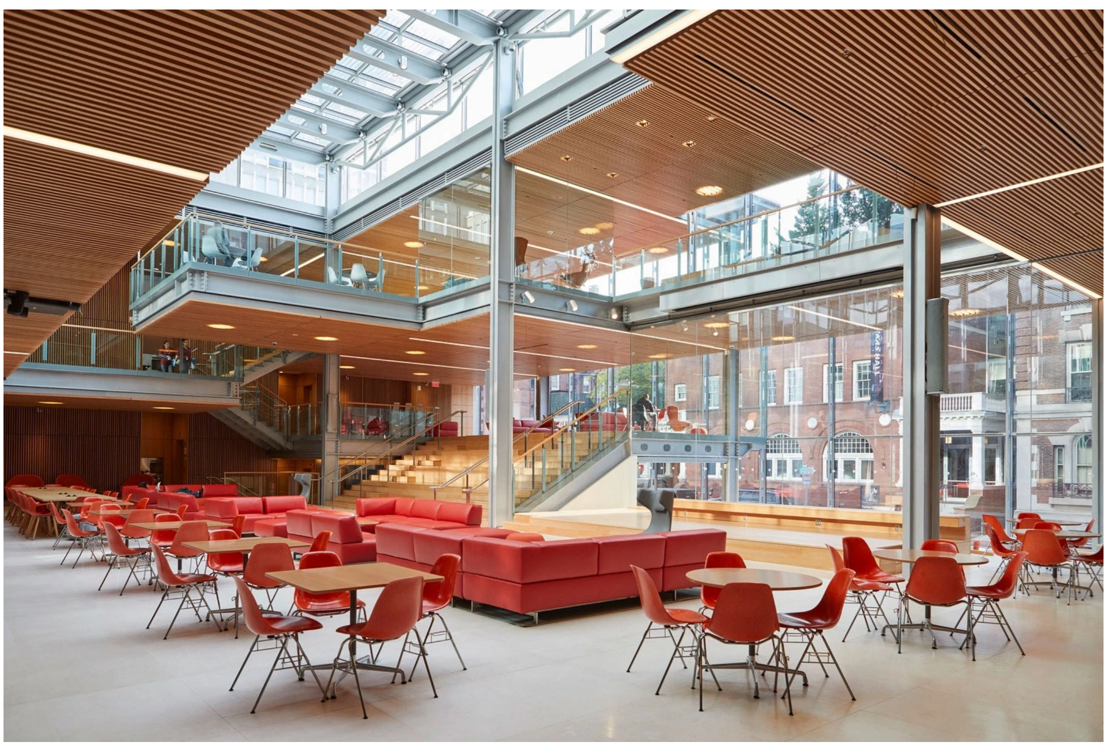


Figure 11. Harvard Campus Center (Common Space, n.d.)

4.4.2 Worcester Polytechnic Institute: Foisie Innovation Studio

WPI's Foisie Innovation Studio is a residential and classroom facility that promotes integrated living and learning. This building includes a robotics lab, a makerspace, high-tech classrooms, and a welcoming café. With WPI's distinctive project-based approach, Foisie "*encourages open minds through open spaces*" (Foisie Innovation Studio, n.d.).

Similar to Harvard's campus center, Foisie also has a set of stairs that serves more than one purpose. The open stairs in Foise are not only a form of egress, but a stadium-like seating space for students to spend time together and do work or watch new content on the large display screen composed of forty large screens (Foisie Innovation Studio, n.d.).

Figure 12. Foisie Innovation Studio (Foisie Innovation Studio, n.d.)

4.4.3 Design Guidance and Review of UPenn Campus Projects

Campus buildings are unique when compared to other commercial buildings. A review of the University of Pennsylvania campus buildings (Design Guidelines and Review of Campus Projects, n.d.) looks into the qualities that many of the buildings have and which missing qualities they should aim to include in future projects. This review covers topics like promoting intellectual and social exchange, predominant materials, orientation, architectural style, and the design process. Some of these sections point to certain design choices that should be made as an academic building and others require noting specific design choices on a given campus so as to maintain cohesion between buildings. For example, the review states that "*individual buildings should ... be designed to maximize the opportunities for social and intellectual exchange.*" This is done by providing ample public space for work or conversations. This public space should also be visible from the outside to passersby to entice them to use the building. This review gives some concrete design choices that can be followed to maintain the campus aesthetic as well as promote collaboration and functionality.

4.4.4 Case Studies on the Facade

Our facade was inspired by Harvard's Campus Center and WPI's Foisie School, shown in Figures 13 and 14 below. We liked the use of curtain walls in both buildings and adapted them to work in ours, especially since the faculty that we interviewed stressed the importance of a connection with the outdoors while working in an office within a building.

Figure 13. Harvard Campus Center Facade (Lehoux, n.d.)

Figure 14. WPI Foisie Business School Facade (Construction in Foisie, n.d.)

We also took inspiration from Crystal Houses in Amsterdam's facade design, which integrates glass bricks into regular ones in a randomized design such as in the photograph shown in Figure 15. We did this heavily along the west side of the new Project Center to transition from the curtain walls into the currently existing, traditionally brick facade of the building.

Figure 15. Brick Pattern on the Exterior of Amserdam's Crystal Houses (Scagliola & Brakkee, n.d.)

We wanted to design something for the exterior that would symbolize the Global School, so we took the idea of a circular cutout from WPI's Boynton Hall as in the image shown in Figure 16 and adapted it to represent the new occupants of the building.

Figure 16. The WPI Seal on a Circular Window in Boynton Hall (A, 2011)

4.4.5 Summary of Case Studies

We looked at several case studies to determine important features to incorporate or improve upon in our redesign of the Project Center. Mostly, we focused on researching academic buildings that encouraged group work and included open collaboration spaces. From Foisie and the Harvard Campus Center, we took their ideas of project-based learning spaces and curtain walls, allowing for a connection with the outdoors. We also liked their implementation of a main staircase that can also be used as seating. The UPenn review taught us that we should provide public spaces for working that are ideally visible from the outside of the building. In regards to the facade, we really liked the look of the Crystal Houses' glass brick design and the circular cutout from WPI's Boynton Hall. All of these elements were adapted to be included in our building.

4.5 Building Design

4.5.1 Introduction

The design of our building was mainly influenced by the analysis of the current Project Center. Our team spoke to several advisors and professors in order to determine the suitable approach to renovate the building to better fit for its new future occupants - the Project Center faculty. We made observations of the current building and researched case studies on recently renovated campus buildings for inspiration. We analyzed the condition of the current building to evaluate possible changes and included them in the structural and fire protection analyses. This section will go over the process and components of our building in more detail.

4.5.2 Site Plans & Location

After evaluating the possible locations of the new Project Center, our team decided to keep the building in its current location. We believed keeping the Project Center at the center of campus will be more accessible for students and faculty. The Project Center is next to Freeman and Reunion Plazas where students will spend time relaxing. It also stands between the Campus

Center and the Gordon Library, two of the most commonly visited buildings on campus. This puts it in a very central location that is easily accessible to students and faculty, as displayed in Figure 17 below.

Figure 17. WPI Map Centered on the Project Center (Worcester Polytechnic Institute, n.d.)

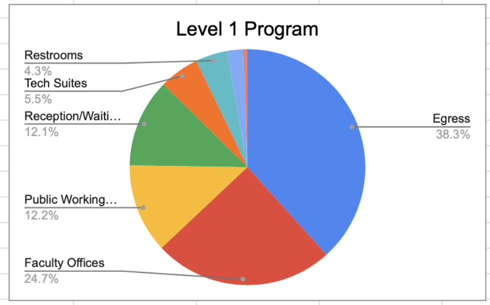
4.5.3 Floor Plans

In terms of the program, after further analysis, our team added tech suites, a conference room and more offices for meeting spaces. We created an open meeting area by the main entrance on the first floor for students to collaborate with others and added a break room on the second floor. To improve accessibility, we added another staircase within the building that connects the two floors, an elevator, and a hallway that loops around providing access to all rooms. This centralized hallway is on both floors to create a better flow of users, minimize distractions, and allow for easier navigation In addition, offices will no longer need to be shared since enough will be added to the building to house the faculty comfortably and allow for a growing staff. This will also minimize commotion and maintain privacy for the faculty utilizing these offices. The proposed program (Table 5) allows for better visualization of the space division. In addition, all drawings and renderings for this MQP were developed in Revit (Figures 18 and 19).

Table 5. Programs for Level 1 and 2

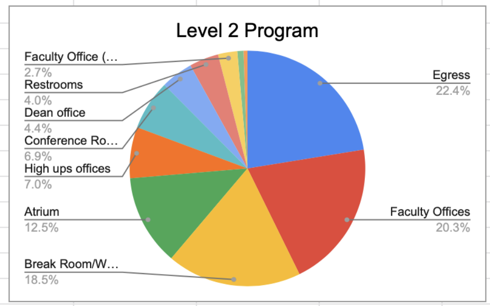
LEVEL 1

Type	Size (sqft)	Quantity	Total Area	% of Level Area
Egress	1816.28	1	1816.28	37.64%
Faculty Offices	130	9	1170	24.25%
Public Working Area	580.36	1	580.36	12.03%
Reception/Waiting Area	574.18	1	574.18	11.90%
Tech Suites	130	2	260	5.39%
Restrooms	103	2	206	4.27%
Mechanical Room	106	1	106	2.20%
Janitorial Closet	28	1	28	0.58%
		total area of rooms	*2896.54*	
		Total Area of Level	**4824.86**	



LEVEL 2

Type	Size (sqft)	Quantity	Total Area	% of Level Area
Egress	1150.74	1	1150.74	28.93%
Faculty Offices	130	8	1040	26.15%
Break Room/Work Space	947.01	1	947.01	23.81%
Atrium	639.05	1	639.05	16.07%
High ups offices	180	2	360	9.05%
Conference Room	352	1	352	8.85%
Dean office	226	1	226	5.68%
Restrooms	103	2	206	5.18%
Faculty Office (Next to Bigger Offices)	136	1	136	3.42%
Large Storage Closet	43	1	43	1.08%
Storage Closet	28	1	28	0.70%
		total area of rooms	*3977.06*	
		Total Area of Level	**5381.88**	



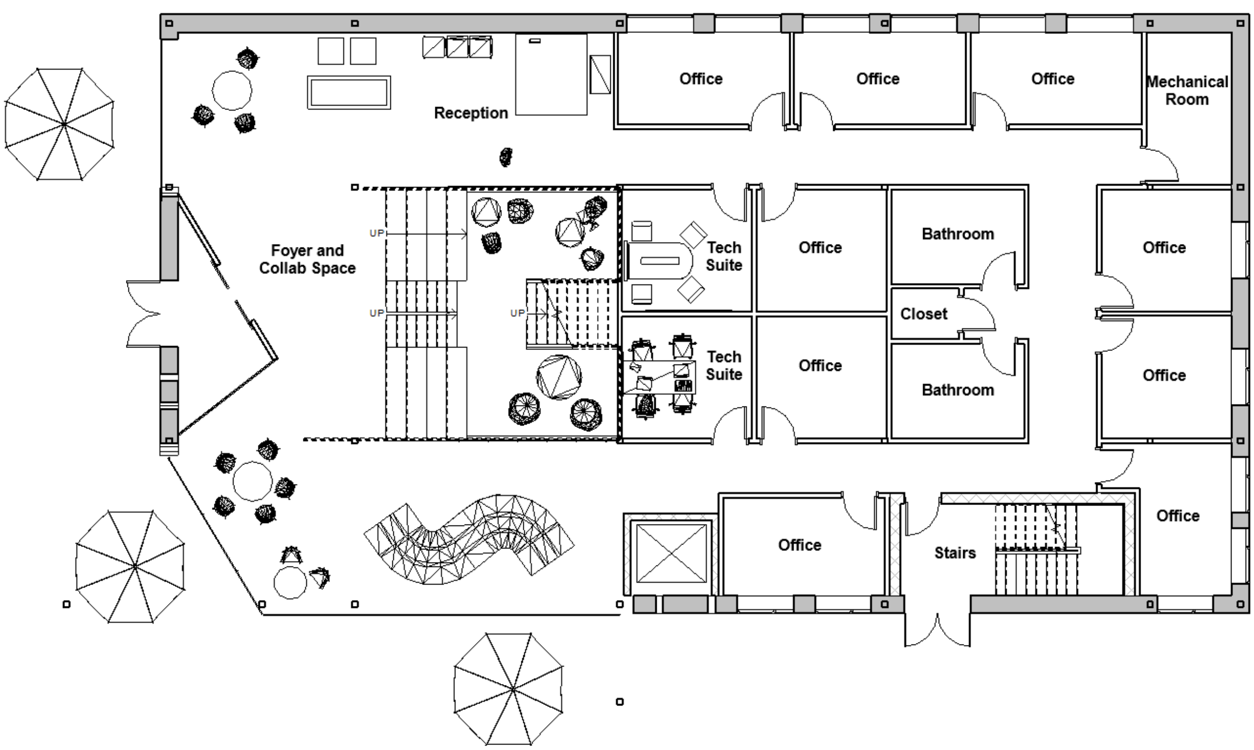


Figure 18. Level 1 Floor Plan

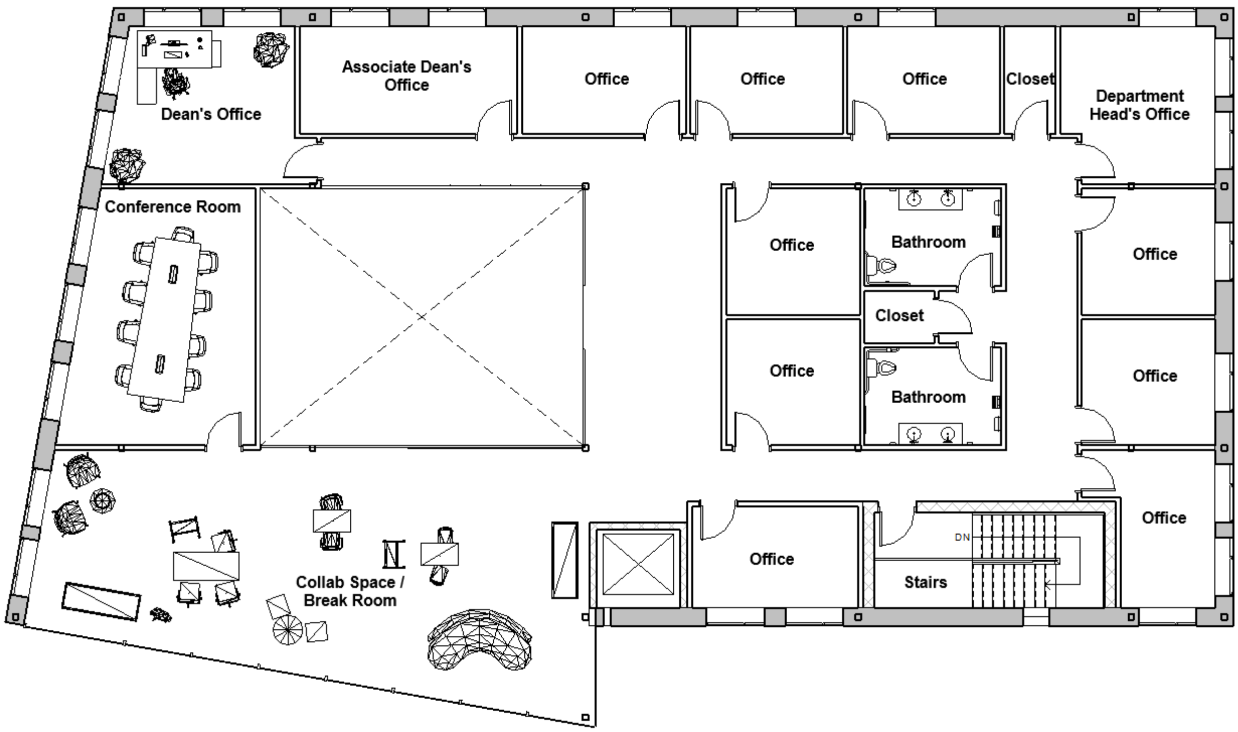


Figure 19. Level 2 Floor Plan

4.5.4 Facade

Below are some renderings of the building facade using the Enscape plugin in Revit. We used brick on the facade to blend into the architectural context of the rest of the campus and preserve the original materials as much as possible. Glass bricks were implemented as a design to create more transparency between inside and outside. The selected windows are similar to those used in other more modern on-campus buildings such as the Messenger dormitory in Foisie. On different levels of the facade, we also included curtain walls to emphasize the connection between the outdoor and indoor environment and allow natural light through. It is also used as suggested in the UPenn Campus Review - as stated before, we made it "*visible from the outside to passersby to entice them to use the building.*" (Design Guidelines and Review of Campus Projects, n.d.)

Figure 20. View From the Patio at the Front of the Building

Figure 21. View of the West Face of the Facade, Including the Globe Cutout

Figure 22. A Closer Look at the Globe Cutout on the Facade

4.5.5 Renderings of the Building

Using the Enscape plugin, we did several renderings of the building to show the completed renovation of the WPI Project Center. We created a collaborative area on the first floor to promote student learning and interactivity (Figure 23).

Figure 23. First Floor Collaborative Space

On the second floor, we created a collaborative space or faculty break room. Its purpose is similar to the collaborative space on the first floor, but it is centered more on the faculty and on group work, as in an MQP or IQP group.

Figure 24. Second Floor Collaborative Space

We created a rendering of the dean's office since it is not the most ideal space in the current Project Center. In making it a desirable and enjoyable space, the dean and therefore the faculty are more likely to be satisfied with their office spaces.

Figure 25. The Dean's Office

We aimed to make the stairs a feature of the Project Center renovation, similar to those in Foisie. Adding furniture and seating on the stairs transforms it into more than simply an egress path and promotes more collaboration and productivity.

Figure 26. Looking Up the Stairs and Collaboration Area from the Entrance

Our VR experimentation happened in a tech suite, since that is one of the rooms in the Project Center that most promotes attentiveness. We used a blue tone for the walls, since our research found that to be a calming color, and we did not add many distracting elements to the room.

Figure 27. A Tech Suite

4.5.5 Structural

While much of the existing structural support is adequate to meet the needs for the redesigned building, the addition of an overhang on the second floor put additional loads on the building. To gather and transfer these new loads, we included cantilever beams that extend from the closest columns within the exterior wall. The existing HSS 6 X 6 X 1/2” columns were also worked into walls. The calculations for total loading included in Appendix J show that the existing columns in the Project Center will suffice for our redesign of the building. This was to avoid the existing issue of the columns’ awkward positioning that detracts from the interior design of the building as well as posing a safety risk.

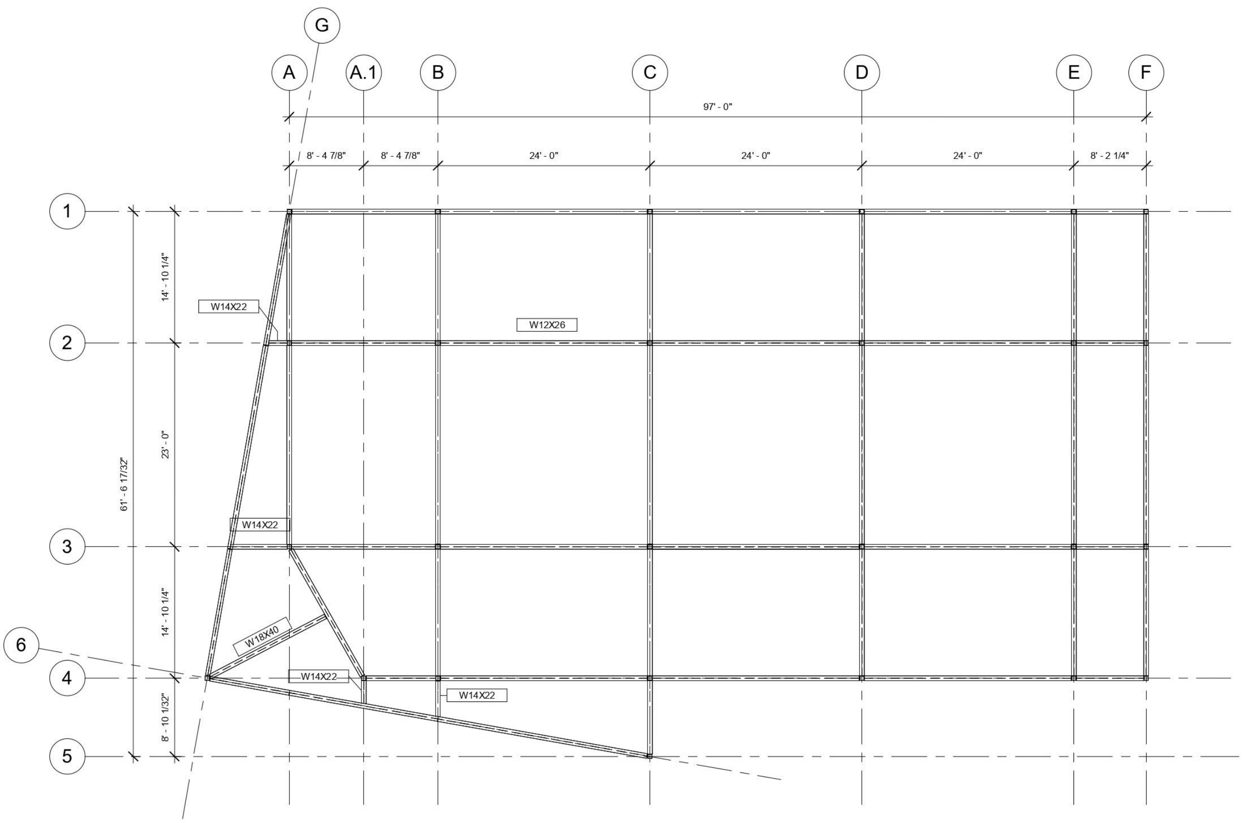


Figure 28. Level 2 and Roof Structural Plan

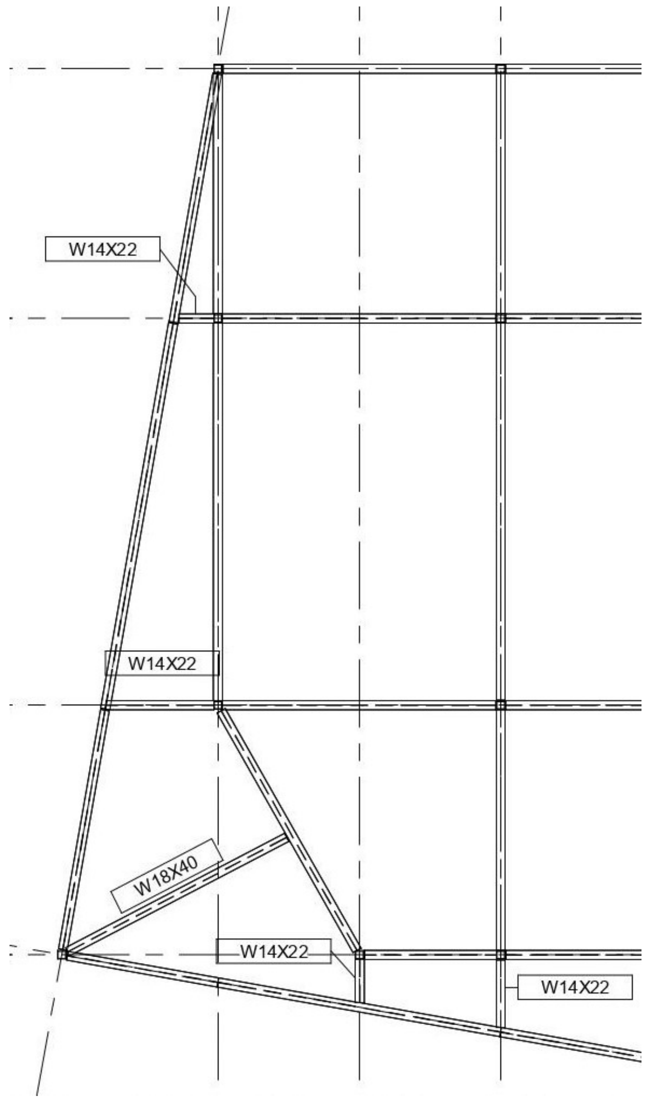


Figure 29. Enlarged View of the Structural Plan

For the overhang we needed to do load and sizing calculations to make sure that the building would be safe. We used the LRFD approach, with specific calculations included in the appendices. In Appendix K the tributary areas were calculated in AutoCAD for each of the cantilever beams. In Appendix L these areas were used to find the design load for each beam as well as what size each beam would have to be to support the structure. We found that all of the cantilevers did not carry too much load and W14x22 members would suffice. The third beam, that was supported on both ends, needed W18x40 to be able to carry the largest amount of area of the overhang. Overall, the W12x26 beams are typical throughout as shown in Figure 28 above.

4.5.6 Fire Protection

A general fire protection analysis was completed to determine whether the building was code compliant with the International Building Code, 2015 (IBC) and NFPA 101 Life Safety Code, 2012.

Educational occupancies for students above the 12th grade such as the Project Center are classified as a Business Group B per IBC 304.1 and NFPA 6.1.11.1. According to the existing building elements of the Project Center, the building is structurally supported by Hollow Structural Section (HSS) structural steel columns and W shape beams. The exterior walls are believed to possess a 2-hour fire resistance rating because they are made of brick with a thickness of minimum 3 ⅕ inches . Therefore the construction type of the building is classified as construction type III, where the exterior walls are made of noncombustible materials and the Project Center is an old school building that does not reach a height of 75 feet or higher.

The building's occupant load was calculated in Table 6 below. Non-Occupiable spaces such as corridors, stairs, restrooms, mechanical rooms, and closets are not included in the calculation.

Table 6

Building's Occupant Load

Space/Area	Use Function	Occupant Load Factor	Area	Occupant Load
Offices	Business Area	150	2932	19.6
Tech Suites	Business Area	150	260	1.7
Conference Rooms	Business Area	150	352	2.4
Collab space	Assembly (chairs & tables)	15	1487	99.1
Break room	Assembly	15	944	62.9
Total				186 Occupants

An egress analysis was completed to ensure the number of exits and egress dimensions were sufficient for our building design. The redesigned Project Center has an occupant load of 186 persons. This occupant load does not exceed 500 persons, meaning 2 exits are adequate for our building design, as seen in Figure 30. If two exits were not sufficient for our building, an automatic sprinkler design and a voice/alarm communication system would need to be provided to reduce our egress capacity factor and, hence, increase the egress capacity. The clear width of the corridors are greater than 44 inches per NFPA 101 Section 39.2.3.2. Table 6 presents the egress calculations for the doors and stair exits. With an egress capacity of 160 occupants per exit, 186 occupants/ 2 exits = 94.5 occupants per exit, making two exits code compliant. When both limit egress capacities are summed, 320 occupants exceeds the building's occupant load, ensuring our building is code compliant.

TABLE 1021.1
MINIMUM NUMBER OF EXITS FOR OCCUPANT LOAD

OCCUPANT LOAD (persons per story)	MINIMUM NUMBER OF EXITS (per story)
1-500	2
501-1,000	3
More than 1,000	4

Figure 30. Table 1021.1 from IBC

Table 7

Building's Egress Capacity

	Egress component	Door clear width	Stair width	Door egress capacity factor	Stair egress capacity factor	Door egress capacity	Stair egress capacity	Limit egress capacity
S-1	Exit stair (side)	36	48 in	.2	.3	36/.2= 180 persons	48/.3= 160	160
S-2	Exit Stair (main)	36	60in	.2	.3	180 persons	160	160

The design of the Project Center's fire protection system was compiled using the requirements of several codes. As an existing building with a Business Occupancy, an automatic sprinkler system is not required given that our building is well below the allowable building height (55ft) and allowable area (19,000 ft^2). The common path of travel does not exceed 75 ft per NFPA 101 Table A.7.6 (Figure 31). The length of the dead end corridors do not exceed 50ft for an existing business occupancy per NFPA Table A.7.6. And the exit access travel distance is not greater than 200 feet (for buildings without a sprinkler system) per NFPA Table A.7.6 and IBC Table 1016.1 (Figure 30), meaning the building does not require a fully equipped sprinkler system.

TABLE 1016.1
EXIT ACCESS TRAVEL DISTANCE[a]

OCCUPANCY	WITHOUT SPRINKLER SYSTEM (feet)	WITH SPRINKLER SYSTEM (feet)
A, E, F-1, M, R, 5-1	200	250[b]
1-1	Not Permitted	250[e]
B	200	300[e]
F-2, 5-2, U	300	400[e]
H-1	Not Permitted	75[e]
H-2	Not Permitted	100[e]
H-3	Not Permitted	150[e]
H-4	Not Permitted	175[e]
H-5	Not Permitted	200[e]
1-2,1-3,1-4	Not Permitted	200[e]

Figure 31. Table 1016.1 from IBC

Table A.7.6 ***Continued***

Type of Occupancy	Common Path Limit				Dead-End Limit				Travel Distance Limit			
	Unsprinklered		Sprinklered		Unsprinklered		Sprinklered		Unsprinklered		Sprinklered	
	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m
Business												
New	75	23[1]	100	30[1]	20	6.1	50	15	200	61	300	91
Existing	75	23[1]	100	30[1]	50	15	50	15	200	61	300	91

Figure 32. Table A.7.6 from NFPA 101

Chapter 5: Conclusion and Recommendations

Upon completion of our experimentation, we created recommendations for future MQP teams that would like to continue working on this research and discussed our conclusions based on data gathered during experimentation.

5.1 Virtual Reality Experiment Design

Originally our team obtained 30 potential participants, but at the time of testing we were only able to run tests on eight participants. The main reason for this was because testing was during finals week which led to subjects no longer being able to participate in our study. Below, we list each participant's ID, major, gender, age and the randomly assigned color sequence for the experimentation.

Table 8
Experimental Participants

Participant ID	Major	Gender	Age	Color Sequence
Participant1	Aerospace Engineering	Female	20	Blue, Red, Green
Participant2	Mechanical Engineering	Male	19	Blue, Red, Green
Participant3	Biomedical Engineering	Male	21	Green, Blue, Red
Participant4	Biomedical Engineering	Male	20	Red, Green, Blue
Participant5	Biomedical Engineering	Male	20	Red, Green, Blue
Participant6	Biomedical Engineering	Female	22	Green, Blue, Red
Participant7	Computer Science	Male	22	Blue, Red, Green
Participant8	Robotics Engineering and Electrical & Computer Engineering	Female	21	Red, Green, Blue

While we ran into some issues leading up to the day of experimentation, overall our experimentation went as planned. Placing the VR and EEG headset on each participant was a challenge, but we booked participants for 1-hour time blocks to give us enough time to get the participants ready for their task. Experimentation lasted 30 minutes maximum per participant, so we ran experiments throughout one day and collected data as people were available.

Throughout the experiment, we found that the EEG headset was very sensitive and did not collect good data if the participant had too much hair on their head. This is because the hair gets in the way of the sensors that monitor the brain's electrical activity. The females in the experiments had rather long hair while the males had shorter hair, so the EEG headset tended to collect better data from the male participants. While the EEG collected data, the VR headset also collected data in regards to the participants' response time and correct versus incorrect responses.

Each participant completed a questionnaire after completing experimentation. The majority of participants did not find it too difficult to concentrate when completing their task. On a scale from 1-5, 5 being the most difficult to concentrate, the average for the participants was 2.6 out of 5 with the lowest being a 2 and the highest being a 4. Participants found the task simple but repetitive over a very long period of time. Some lost focus during experimentation and others felt very distracted by the colors of the wall changing. The majority of participants were distracted 5 to 10 times due to the colors changing in the background and some commented that the color red was very intense while performing their task. Complete responses can be found in Appendix H.

5.2 Overall Recommendations and Conclusion

After completing our experimentation, we developed several recommendations that would be helpful to a future MQP group or someone who wanted to continue our research. Our research specifically looked into attention as a whole, but there are many different forms of attention. For example, there is selective attention, divided attention, alternating attention, and sustained attention. Further research into these types of attention could provide more information into specific events that may hinder or attract attention, which could enhance future data collection. We found that the transition between colors in the VR environment rather than each singular color has a more noticeable effect on participants' attention. Additionally, if a future MQP group were to run experiments within the immersive space as well as in a virtual reality space, the group should use the data they collect from the immersive space to develop the virtual reality setting and implement this data into their design of the Project Center. This would also create a more refined collection of data.

In addition to performing further research, we have more suggestions regarding the experimentation part of this project. There are other ways to run similar tests to achieve the same goal, such as using Lumosity concentration tests or other online brain games. There are also some ways to logistically improve the experiment as a whole. Different colors, tasks, lengths of time, and behaviors (such as productivity) could be considered to create a wider range of data. The fatigue factor is also an important idea to address, because most of our participants agreed that it was hard to concentrate on such a tedious game for the 15-minute span. All of these ideas would assist in developing an experimentation that would lead to more detailed data, which could lead to better and more helpful results.

We hypothesized that blue light would improve productivity, green light would improve attentiveness, and red light would be distracting to participants based on the research that we completed prior to experimentation. Although we were unable to have our data analyzed due to our time constraints, we found that people tended to feel very strongly opposed to the color red from the participants' responses to our questionnaire. We also learned that most participants were reacting more to the fact that the wall was changing colors rather than the feeling imbued by the individual wall colors, making all of the colors distracting as a whole.

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Appendices

Appendix A – Proposed Immersive Space Methodology

Description

The goal of this project was to determine whether the color of an environment affects an individual's productivity and attentiveness levels. The chart below shows the colors that will be studied: red, green, blue, and neutral (natural lighting). Each subject will be assigned two different tasks to perform under each of the different color variations. Each color will be presented under a normal light intensity (30 footcandles).

Factor		Variations	Hexadecimal Code #
Color		Red	CC0605
		Green	57A639
		Blue	3B83BD
		Neutral	F0EAD6

Figure 1: Color Variations

Basis of Experiment

We planned to test a single factor - color - to determine whether it impacts inhabitant productivity and attentiveness of a subject. For the purposes of our study, we used three colors and a control variable; red, green, blue and no color (natural lighting).

To investigate the effect of color, we found two experimental tasks to test the subjects' productivity and attention, which are elaborated on in Figure 2 below. All other factors will be kept constant: the color of the sheets of paper will be white, the background sound will be white noise, and the interior shape of the immersive space will be expanded. The color will be randomly set for each test subject, and each color will be investigated with the same number of subjects.

Objective	Method	Analysis	Anticipated Result

Determining how color affects subject productivity and attentiveness	Field Study	Phase A: Measure baseline vitals (heart rate, blood pressure, skin temperature, and brainwaves).	Blue light improves productivity, green light improves attentiveness, and red light is a distraction.
	N: 40 people (10 for each color)	Phase B: Enter space and complete two tasks while collecting EEG data	
	Stimuli: Color (red, green, blue, control)		
	Dependent variables: heart rate, blood pressure, skin temperature, time distracted, time completed, repetitive body movement, EEG	Phase C: Exit space, measure until return to baseline vitals.	

Figure 2: Experiment Design

The timeline of our experimentation methods is shown below to better simplify the project and provide a visual.

Prior to Experiment, Measuring the baseline					
EVENT	Participant Entrance	Briefly Inform Subject of the tasks that they will complete	Sanitization of subjects and equipment	Set Color for Experiment	Fit Subject with Measurement Device and Determine Baseline
TIME	-	1 min	2 min	2 min	2 min

Experiment				
EVENT	*Begin*	*Task A:*	*Task B:*	*Exit*

		Lecture & open response	Passage & multiple choice	
TIME		13 min	12 min	-

Post-Experiment, return to baseline and questionnaire					
EVENT	Measure with EEG Until Return to Baseline	Take Equipment Off	Post-Experiment Questionnaire	Subject sanitizes themselves and team sanitizes equipment	Subject Leaves
TIME	2X	1 min	2 min	2 min	387 + X min

Figure 3: Experiment Design Timeline

COVID-19 Safety Protocols

Due to the current COVID-19 situation, this experiment followed local and institutional recommended guidelines to promote health and safety practices. Student investigators and participants were asked to abide by the following guidelines.

Study Area:

- The study area is in Kaven Hall Lounge for the immersive space and in the Neurolab in Gateway for the Virtual Reality space. Both are set up for social distancing and ventilation per WPI earlier requirements.
- The immersive space was previously built by the previous MQP group, shown in the following pictures. The armchair seen in these pictures will be switched by a wooden chair that could easily be disinfected.

Figure 4: Immersive Space Located in the Kaven Hall Lounge

Dimensions (width x length x height) of the frame are 7.5' x 7.5' x 7.5', the cloth area are 5.5' x 5.5' x 6'

- The study and waiting areas will be large enough to accommodate **physical distancing**. The participants will be given specific times to prevent overlap of the number of participants in the waiting area.
- **Hand sanitizer stations** will be available.

Student Investigators:

- Student investigators will be required to wear **masks/face coverings** at all times.
- Student investigators will **sanitize** their hands before handling equipment and participants.
- Student investigators will also be screened for COVID-19 symptoms prior to giving the experiment to participants.
- Student investigators will not be directly supervised by a faculty member during the in-person procedures. They will follow social distancing and other COVID-19 guidelines advised by WPI.

Participants:

- Participants will be **screened by telephone** for symptoms of COVID-19 upon arrival as well as the day before. They will be required to share their most recent COVID-19 test status before the experiment.

- **Masks/Face coverings** are required for everyone when entering the building. They are to be kept on while wearing the headset and/or VR apparatus. The only times the masks may be removed will be to collect saliva for cortisol testing. During these times, physical distancing between the participant and student investigators are strictly enforced.

- Upon entering the building, participants' **temperatures will be taken** by student investigators using a no contact infrared thermometer with an instant temperature reading. Any participant with a temperature of 100.4 degrees Fahrenheit or above will be turned away.

- Participants will be asked to **sanitize** their hands when entering the building before beginning the experiment.

Equipment:

- Equipment will be **sanitized and disinfected** after each participant completes the experiment.
    - DSI-24 Headset will be disinfected and sanitized using "chemical wiping and cleaning brush" that specifically come with it.
    - VR goggles and O2 Ring, measures heart rate and oxygen levels of participants, will be wiped using 70% isopropanol or ethanol and a microfiber cloth. They will be left to air dry in a well ventilated space.
    - Microfiber cloths used to clean equipment will be washed thoroughly after every use.
    - Participant's chairs will also be disinfected with 70% isopropanol or ethanol and a microfiber cloth. They will be left to air dry in a well ventilated space.

Prior to Experimentation

The basis of this study is to better understand whether different colors alter human productivity and attentiveness while subjects complete tasks in the immersive space pictured in Figure 4.

The study will contain 40 participants where ten subjects will be randomly assigned to each of the three colors chosen by our team (red, green, and blue) and ten will be assigned to the control group (normal room lighting). The test subjects will be recruited via email distribution (located in Appendix A) and other messages, if necessary, to WPI students. The message sent out will contain a brief description of the project and a prescreening through Google Forms located in Appendix B.

The prescreening will make the data more consistent by controlling external factors. In addition, gathering the participants' emails will allow our team to contact them if necessary in the future. The email we send out to potential participants will ask for subjects to refrain from participating in the study if they have been diagnosed with ADD or ADHD, have a color deficiency, or are currently using any stimulant or depressant medications. In addition, they will be asked if they consent to be recorded during the experimentation, as this could affect the subjects' attention, and result in less consistent data.

Experimentation

When the subject arrives at the experimentation space, the investigator will introduce the DSI-24, explain what it does, and ask the participant to put it on. They will leave it on for about two minutes to determine a baseline level, which will be used to measure deviation throughout the test. The participant will then be informed about the tasks they will be doing and the order in which they will be completed. Participants will also be given the opportunity to ask questions.

Participants will enter the immersive space to begin tasks while wearing the DSI-24. The lighting will be randomly assigned to red, blue, green, or neutral, and the tasks will be in randomized order for each participant to ensure that the task order will not influence the data collected. To give our team an understanding of the subjects' productivity and attentiveness while they are within the space, we will be measuring their brain's electrical signals using the DSI-24. Depending on the individual tasks, we may also be recording speed of completion or ability to finish the task, correctness of answers, and any other related data. Once each task is completed, participants will ring a bell to notify the investigators. If the subject does not finish before the allotted time expires, we will record that on our data collection sheet shown below.

Task	Assignment	Time Allotted	Task Completed?	Actual Time to Completion	Qualitative Information (such as correctness of answers)
A	Lecture and short-response question	13 minutes			
B	Read a passage and answer three multiple-choice questions	12 minutes			

Figure 5: Data Collection Table

For Task A, the subject will watch an eight-minute lecture which will relate to coursework they might experience in the IGSD space and then answer a short, open-response question afterwards to mimic sitting in a class and listening to a lecture. We will not notify them beforehand that they will have to answer a question to minimize any biases they may form if they knew they were going to be tested. They will have thirteen minutes total to complete this task. Once they complete the task, we will analyze how much they wrote and the correctness of their response. The purpose of this task will be to measure the student's attentiveness and attention levels.

Task B will be a reading assignment. The subject will be given a passage to read and a set of multiple choice questions to answer. After completion, we will check how many questions were answered correctly. The subject will have twelve minutes to complete this task, and it will measure their productivity and attentiveness.

Post Experimentation

Upon completion of the tasks, participants can exit the space. After exiting, they will leave the DSI-24 on until they have returned to or close to baseline state. The data from the device can be used to indicate the intensity of any discomfort that the subject may feel as well as the length of time it takes them to feel comfortable again. If this process takes longer than anticipated, the subject may complete a simple task to help them return to baseline.

When they reach the baseline, our team will administer a questionnaire that will provide us with additional information for post-experimentation analysis. It will cover how the subject felt during the experiment in regards to the colors utilized as well as any other pertinent questions. The full set of questions are included in Appendix D.

While the subject completes the post-experiment questionnaire, they will use hand sanitizer before leaving the test site while we will reset the experimental equipment and return all instruments to their original positions. This will ensure that any data inconsistencies will not result from the equipment setup.

Appendix B – COVID-19 Safety Protocols

Study Area:

- The location of the study for the virtual reality experimentation was Kaven Hall 117A. This office was set up for social distancing and ventilation per CDC recommendations.
- The furniture in the office was disinfected after each use.
- The participants were given specific time slots to prevent overlap in the number of participants in the waiting area of Kaven Hall Lounge.
- Only one student investigator was in the room at a time during testing.
- Hand sanitizer was available at all times during the experiment.

Student Investigators:

- Student investigators were required to wear masks for the entirety of the experiment.
- Student investigators sanitized their hands before handling equipment.
- Student investigators were screened for COVID-19 symptoms prior to conducting in-person experiments.
- Student investigators were not directly supervised by a faculty member during the in-person procedures. They followed social distancing and other COVID-19 guidelines advised by WPI.

Participants:

- Participants were screened by telephone for symptoms of COVID-19 before the in-person experiment. They were required to share their most recent COVID-19 test status before the experiment.
- Masks were required for everyone when completing the experiment. They were kept on while wearing the headset and/or VR apparatus. During these times, social distancing between the participant and student investigators was strictly enforced.
- Participants were asked to sanitize their hands before handling the equipment and before beginning the experiment.

Equipment:

- Equipment was sanitized and disinfected after each participant completed the experiment.
    - The DSI-24 headset was disinfected and sanitized using the chemical wiping and cleaning brush that specifically came with it.
    - The VR headset was wiped down using 70% isopropanol or ethanol and a microfiber cloth. It was left to air dry in a well-ventilated space.
- The microfiber cloths used to clean equipment were washed thoroughly after every use.

Appendix C– Email Distribution Message

Title: Participants Needed for AREN MQP

Hello WPI Students!

We are writing to determine your interest in helping an AREN MQP project occurring on campus: “Immersive Space & Virtual Reality”. Our project goal is to understand what affects the color of an environment has on a human’s behavior. We will be conducting our experiments in a shell space designed by a previous MQP team that has the capability to alter four of the main factors that define environment comfort: size, color, sound, and light.

We are looking for students to join us for this round of tests. Subjects would be asked to join us for about 45 minutes (30 minutes of active study participation) where they will be asked to complete four tasks under one of four lighting conditions.

It is expected that the lighting levels in these spaces are within ranges that are typical to everyday life. However, if you have any sort of discomfort or sensitivity to light, please refrain from participating in this study, as the environments you will be exposed to may be uncomfortable.

If you are interested in joining us, please fill out the attached Google Form, and we will contact you with details if you are selected. More information can be found in the attached Informed Consent Form, and if you have any further questions, please feel free to contact us at gr-immersivespacecolormqp@wpi.edu. Thanks for your consideration!

Anyely Felix Nova, Marco Garcia-Duarte, Steven Pardo & Allison Smuk

Appendix D – Pre-Screening Google Form

MQP Pre-Screening Survey

PLEASE READ:

Hello! This survey is an application to be part of our MQP study. This study will be using an immersive space in Kaven Hall for the first half of the study in B term and a VR (virtual reality) setup for the second half in C term. Please be honest with your answers as this will affect the quality of our data.

If you apply for the study and are chosen to participate, you will be entered into a raffle for a $25 gift card to Dunkin' Donuts.

* Required

1. Are you over the age of 18? *

   Mark only one oval.

   ◯ Yes

2. Do you get anxious or overwhelmed when doing timed tasks? If yes, please rank it on a scale from 1-5:

   Mark only one oval.

	1	2	3	4	5	
Not at all anxious	◯	◯	◯	◯	◯	Very anxious (debilitating)

3. Will you be available to meet in person once or twice in C term? *

   Mark only one oval.

   ◯ Yes

   ◯ No

   ◯ Other: ____________________

4. Please type your name here to confirm your responses.

5. WPI email: *

Appendix E – Informed Consent Agreement for Participation in a Research Study

Primary Investigator: Professor M. Farzin-moghadam, Architectural Engineering
Student Investigators: Anyely Felix Nova, Marco Garcia-Duarte, Steven Pardo, Allison Smuk
Contact Information: (508) 831-6996; email: mfarzinmoghadam@wpi.edu
Title of Research Study: Immersive Space and Virtual Reality

Introduction
You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the Study
The purpose of the study is to determine whether color affects human performance in certain activities, and to determine what environments cause subject discomfort. This study is a small sample of a larger goal to analyze the relationship between color and human behavior.

Procedures to be followed
VR screening: Prior to beginning experimentation, we will read aloud questions from the WPI IRB VR Screening Process Script. Based on their responses, participants may be removed from participation.

Pre-test phase: Subjects will have an O2 ring placed on their index finger that monitors their heart rate, blood pressure, skin temperature, and brain activity. For two minutes, we will be measured to collect data before and after completing the task in order to determine the subject's baseline data.

Testing phase: Subjects will enter Professor's M. Farzin-Moghadam office where the Virtual Reality equipment will be set up. During this time, subjects will have their heart rate, blood pressure, skin temperature, and brainwaves monitored. After the experimentation tasks end, the participant will wait until their vitals reach the baseline measured at the start and end of the experiment.

Subjects should expect to join us for 30 minutes, 20 of which will be active.

Risks to study participants

For a complete list of potential risks in a VR space, please refer to the WPI IRB Virtual Reality/Augmented Reality Screening Process document, which will be attached below.

Benefits to research participants and others
There are no direct benefits subjects can expect from this study. Indirectly, the study aims to better understand how color can interact with and influence human behavior and comfort.

Record keeping and confidentiality
During the study, vital statistics and brainwaves of all subjects will be constantly measured. At the end of each subject's trial, data recorded will be time-mapped and normalized based on baseline data. You will be provided with a printout of your own data if you so choose.

After the study session is complete, the only persons with access to the data will be the student investigators and sponsors. Aggregated data will be presented in publications in place of individual results to further protect the information collected.

Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury
The risks involved in this study are minimal. In the event of injury or harm, you may ask to leave the study and your data will be expunged. You do not give up any of your legal rights by signing this statement.

Cost/Payment
Study participants will be entered into a raffle for a $25 gift card to Dunkin' Donuts.

For more information about this research or about the rights of research participants, or in the case of research-related injury, contact:
Primary Investigator: Professor M. Farzinmoghadam, Civil and Environmental Engineering
Tel: (508) 831 - 6996 Email: mfarzinmoghadam@wpi.edu
IRB Manager: Ruth McKeogh
Tel. (508) 831 - 6699 Email: irb@wpi.edu
Human Protection Administrator: Gabriel Johnson
Tel. (508) 831 - 4989 Email: gjohnson@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

_____________________________________ Date: ____________________

Study Participant Signature

____

Printed Study Participant Name

_____________________________________ Date: ____________________

Signature of Person Who Explained This Study

Appendix F – COVID Symptoms Questionnaire

Taken from the WPI COVID Symptom Tracker app.

Please select all that apply:

- ❏ I have had a symptomatic COVID-19 test or I have received a positive test result for COVID-19 in the last 14 days.
- ❏ I am experiencing COVID-19-like symptoms. This may include:
    - ❏ fever (100.0+)
    - ❏ chills
    - ❏ cough
    - ❏ shortness of breath
    - ❏ sore throat
    - ❏ fatigue
    - ❏ headache
    - ❏ muscle/body aches
    - ❏ runny nose/congestion
    - ❏ new loss of taste or smell
    - ❏ nausea, vomiting, or diarrhea
- ❏ I have been in close contact with someone diagnosed with COVID-19 in the last 14 days. Close contact means:
    - ❏ Living in the same household as a person who has tested positive for COVID-19.
    - ❏ Caring for a person who has tested positive for COVID-19.
    - ❏ Being within 6 feet of a person who has tested positive for COVID-19 for 15 minutes or more.
    - ❏ Coming in direct contact with secretions (e.g., sharing utensils, being coughed on) from a person who has tested positive for COVID-19, while that person was symptomatic.
- ❏ I have been asked to self-isolate or quarantine by a doctor or local public health official in the last 14 days.
- ❏ I feel good (No COVID-19/No Symptoms).

Appendix G – WPI IRB VR Screening Process Script

Screening process for use by WPI IRB investigators engaging subjects in Virtual Reality/Augmented Reality research studies.

The investigator should follow the prompts to exclude a participant in a Virtual Reality study if answer is [TERMINATE].

Screening should take place at a separate time to the research enrollment.

Neither the participants' personal or health information will be kept if they are not selected to participate. The recruitment document will be shredded (destroyed) if the participant is not being selected for this study or decides not to answer specific categories of the questions (general health, vision/hearing condition and psychological & neurological health-related) embedded in this recruitment template.

***these sections are required for participation in the research**

i.*BASIC REQUIREMENTS

Are you older than 18?

❏ Yes
❏ No **[TERMINATE]**

Are you comfortable with V.R. Equipment?

❏ Yes
❏ No **[TERMINATE]**

ii.*GENERAL HEALTH REQUIREMENTS

If participant is not comfortable answering these questions, the recruitment process is terminated.

Do you feel dizzy right now?

- ❑ Yes **[TERMINATE]**
- ❑ No

Do you feel lightheaded right now?

- ❑ Yes **[TERMINATE]**
- ❑ No

Do you feel nauseous right now?

- ❑ Yes **[TERMINATE]**
- ❑ No

Do you feel excessively tired right now?

- ❑ Yes **[TERMINATE]**
- ❑ No

Do you feel sick right now?

- ❑ Yes **[TERMINATE]**
- ❑ No

Have you had more than what is usual for you, of caffeine or energy drinks today?

- ❑ Yes **[TERMINATE]**
- ❑ No

Have you had migraines, headaches, or earaches recently?

- ❑ Yes **[TERMINATE]**
- ❑ No

Do you have a history of low blood pressure or fainting?

- ❑ Yes **[TERMINATE]**
- ❑ No

Do you have a history of vertigo?

- ❑ Yes **[TERMINATE]**

- ❏ No

Please tell me if you have the following:

- ❏ Wig or partial wig **[Please have subject describe and consult with Neurable to see if subject is applicable. Subject will need to be comfortable removing wig during session.]**
- ❏ I do not have any of the following.
- ❏ Other **[Please have subject describe and consult with Neurable to see if subject is applicable. Subject will need to be comfortable removing wig during session.]**

Are you currently pregnant?

- ❏ Yes **[TERMINATE]**
- ❏ No

Question is biometrics specific. **Note that if subject is pregnant, they cannot participate as the unborn child can affect the biometric readings.**

iii.*VISION & HEARING REQUIREMENTS

If the participant is not comfortable answering these questions, the recruitment process is terminated.

- ❏ No, I do not want to answer these questions **[TERMINATE]**
- ❏ Yes, I do want to answer these questions

Have you ever used VR (Virtual Reality) or AR (Augmented Reality) before?

- ❏ Yes
- ❏ No

How often do you play video games? (on a monitor, phone, console etc.)

- ❏ Very frequently (Daily)
- ❏ Somewhat frequently (1-6 times per week)
- ❏ Occasionally (1+ times per month)
- ❏ Somewhat infrequently (2+ times per year)
- ❏ Very infrequently/Never (0-2 times a year)

Please select the option that best corresponds to your current state of vision.

- ❑ I have normal vision and do **not** require the assistance of glasses or contact lenses.
- ❑ I have normal-to-corrected vision for both eyes and require the assistance of glasses or contact lenses which I own.
- ❑ I have normal-to-corrected vision for one eye and require the assistance of glasses or contact lenses which I own.
- ❑ I am blind in one or both eyes. **[TERMINATE]**

If subject says they have normal-to-corrected vision, please give reminder to bring glasses/contact lenses on the day of their scheduled appointment, otherwise they will not be able to participate.

Are you colorblind?

- ❑ Yes **[TERMINATE]**
- ❑ No

Hearing- Please select the option that best corresponds to your current state of hearing.

- ❑ I have normal hearing and do **not** require the assistance of hearing aids or other hearing devices.
- ❑ I have normal-to-corrected hearing for both ears and require the assistance of hearing aids or other hearing devices which I own.
- ❑ I have normal-to-corrected hearing for one ear and require the assistance of hearing aids or other hearing devices which I own.
- ❑ I am hard of hearing. **[TERMINATE]**

If subject says they have normal-to-corrected hearing, please give reminder to bring assisted hearing devices on the day of their scheduled appointment, otherwise they will not be able to participate.

Are you highly prone to motion sickness? (From travel, heights, roller coasters etc.)

- ❑ Yes **[TERMINATE]**
- ❑ No
- ❑ Not sure **[Give disclaimer to subject that they will be in VR for X minutes, and it is their discretion whether they are comfortable participating.]**

iv.*NEUROLOGICAL & PSYCHIATRIC REQUIREMENTS

If you the participant is not comfortable answering these questions, the recruitment process is terminated.

- ❏ No, I do not want to answer these questions **[TERMINATE]**
- ❏ Yes, I do want to answer these questions

Have you ever had a brain injury that resulted in memory loss or unconsciousness?

- ❏ Yes **[TERMINATE]**
- ❏ No

Are you currently diagnosed with any of the following? Please select all that apply.

- ❏ Autism **[TERMINATE]**
- ❏ Bipolar disorder [**TERMINATE]**
- ❏ Cerebral Palsy **[TERMINATE]**
- ❏ Encephalitis (inflammation of the brain) **[TERMINATE]**
- ❏ Epilepsy **[TERMINATE]**
- ❏ Intellectual disability [**TERMINATE]**
- ❏ Major depression [**TERMINATE]**
- ❏ Muscular dystrophy **[TERMINATE]**
- ❏ Obsessive-compulsive disorder (OCD) [**TERMINATE]**
- ❏ Post-traumatic stress disorder (PTSD) **[TERMINATE]**
- ❏ Schizophrenia [**TERMINATE]**
- ❏ I would prefer not to answer **[TERMINATE]**
- ❏ Other **[Please have subject describe and consult with Neurable to see if subject is applicable]**
- ❏ I am not not diagnosed with any of the following. **[Move onto next question]**

Are you taking any of the following medications?

- ❏ Antidepressants (e.g. Prozac, Cymbalta, Nardil) **[TERMINATE]**
- ❏ Antipsychotics (e.g. Thorazine, Abilify) **[TERMINATE]**
- ❏ Anxiolytics (e.g. Xanax, Lunesta, Ambien) **[TERMINATE]**
- ❏ Mood stabilizers (e.g. Tegretol, Gabapentin) **[TERMINATE]**
- ❏ Stimulants (e.g. Ritalin, Adderall) **[TERMINATE]**
- ❏ I would prefer not to answer **[TERMINATE]**

- ❏ Other **[Please have subject describe and consult with Neurable to see if subject is applicable]**
- ❏ I am not taking any of the medications. **[Move onto next question]**

v.DEMOGRAPHIC & CONTACT INFORMATION

If the subject is to be enrolled, you may want to gather contact information. The above screening may then be brought to the enrollment/consent process for the research

Appendix H – Post-Experimentation Questionnaire

Name: ____________________________ Date: ____________

1. Was it difficult to concentrate?
    a. Rank your difficulty level from 1-5 (1 being not difficult at all and 5 being extremely difficult)
    b. Why?

2. How many times were you distracted? Circle one.
    a. 0-5
    b. 5-10
    c. 10+

Appendix I – Post-Experimentation Questionnaire Responses

Participant ID	Major	Gender	Age	Color Sequence	Was it difficult to concentrate? Rank your difficulty level from 1-5	Why? Please be specific.	How many times were you distracted? 0-5, 5-10, or 10+
Participant1	Aerospace Engineering	Female	20	Blue, Red, Green	2	Very long period of time	5-10 times
Participant2	Mechanical Engineering	Male	19	Blue, Red, Green	3	Got harder has the test went on, the colors were distracting	5-10 times
Participant3	Biomedical Engineering	Male	21	Green, Blue, Red	2	Zoned out here and there	5-10 times
Participant4	Biomedical Engineering	Male	20	Red, Green, Blue	2	Pretty calm, VR is not super clear (not in HD), kinda grainy	5-10 times
Participant5	Biomedical Engineering	Male	20	Red, Green, Blue	2	Room was changing color, red felt more intense	5-10 times
Participant6	Biomedical Engineering	Female	22	Green, Blue, Red	4	Repetitive for a long period of time and the change of colors	5-10 times
Participant7	Computer Science	Male	22	Blue, Red, Green	3	The background, the black screen is bothersome	5-10 times
Participant8	Robotics Engineering and Electrical & Computer Engineering	Female	21	Red, Green, Blue	3	The color changing made it confusing	0-5 times

Appendix J – Column Loading Calculations

MQP Dead Load

	Total SF	Beams	2nd Floor Slab	1.5 B22 Galvanized Steel Decking (1.78psf)	1.5" Lightweight Concrete Roof Slab	2" Roof Insulation Board	MEP	Columns (all are 20ft, except A.1-5)	Total (lbs)	Total (kips)
		Square footage (sf)								
A1	80.87	808.70	4447.85	143.95	1172.62	40.44	404.35	704.8	7722.7	7.7227
A2	231.09	2310.90	12709.95	411.34	3350.81	115.55	1155.45	704.8	20758.8	20.7588
A3	302.06	3020.60	16613.30	537.67	4379.87	151.03	1510.30	704.8	26917.6	26.9176
G4	84.09	840.90	4624.95	149.68	1219.31	42.05	420.45	704.8	8002.1	8.0021
A.1-5	128.28	1282.80	7055.40	228.34	1860.06	64.14	641.40	352.4	11484.5	11.4845
B2	386.23	3862.30	10930.70	353.76	2881.73	99.37	993.70	704.8	19826.4	19.8264
B3	378.43	3784.30	10501.70	339.87	2768.63	95.47	954.70	704.8	19149.5	19.1495
B4	223.84	2238.40	12311.20	398.44	3245.68	111.92	1119.20	704.8	20129.6	20.1296
C2	453.56	4535.60	19091.05	617.86	5033.10	173.56	1735.55	704.8	31891.5	31.8915
**C3	453.56	4535.60	18906.80	611.89	4984.52	171.88	1718.80	704.8	31634.3	31.6343
C5	64.58	645.80	3551.90	114.95	936.41	32.29	322.90	704.8	6309.1	6.3091
D2	454.25	4542.50	25463.90	824.10	6713.21	231.49	2314.90	704.8	40794.9	40.7949
**D3	454.25	4542.50	23217.70	751.41	6121.03	211.07	2110.70	704.8	37659.2	37.6592
E2	304.61	3046.10	12761.10	413.00	3364.29	116.01	1160.10	704.8	21565.4	21.5654
**E3	304.61	3046.10	15169.55	490.94	3999.25	137.91	1379.05	704.8	24927.6	24.9276
B1	168.14	1681.40	9247.70	299.29	2438.03	84.07	840.70	704.8	15296.0	15.2960
C1	197.75	1977.50	10876.25	352.00	2867.38	98.88	988.75	704.8	17865.5	17.8655
D1	197.75	1977.50	10876.25	352.00	2867.38	98.88	988.75	704.8	17865.5	17.8655
E1	132.61	1326.10	7293.55	236.05	1922.85	66.31	663.05	704.8	12212.7	12.2127
F1	40.43	404.30	2223.65	71.97	586.24	20.22	202.15	704.8	4213.3	4.2133
F2	92.86	928.60	5107.30	165.29	1346.47	46.43	464.30	704.8	8763.2	8.7632
F3	92.86	928.60	5107.30	165.29	1346.47	46.43	464.30	704.8	8763.2	8.7632
F4	40.43	404.30	2223.65	71.97	586.24	20.22	202.15	704.8	4213.3	4.2133
**E4	132.61	1326.10	2472.80	80.03	651.92	22.48	224.80	704.8	5482.9	5.4829
**D4	197.75	1977.50	5634.20	182.34	1485.38	51.22	512.20	704.8	10547.6	10.5476
**C4	231.30	2313.00	8822.55	285.53	2325.95	80.21	802.05	704.8	15334.1	15.3341

Beams	10	psf				
2nd Floor Slab	55	psf				
Roof Deck	1.78	psf		https://civil.colorado.edu/~willam/4830%20Vulcraft%20Steel%20Deck.pdf	https://www.everything-about-concrete.com/density-of-	https://a-s.com/news/Weights%20of%20Building%20Materials.pdf
Columns	35.24	lb/ft				
MEP	5	psf				
Concrete Roof	14.5	psf				
Insulation	0.5	psf				

MQP Live Load

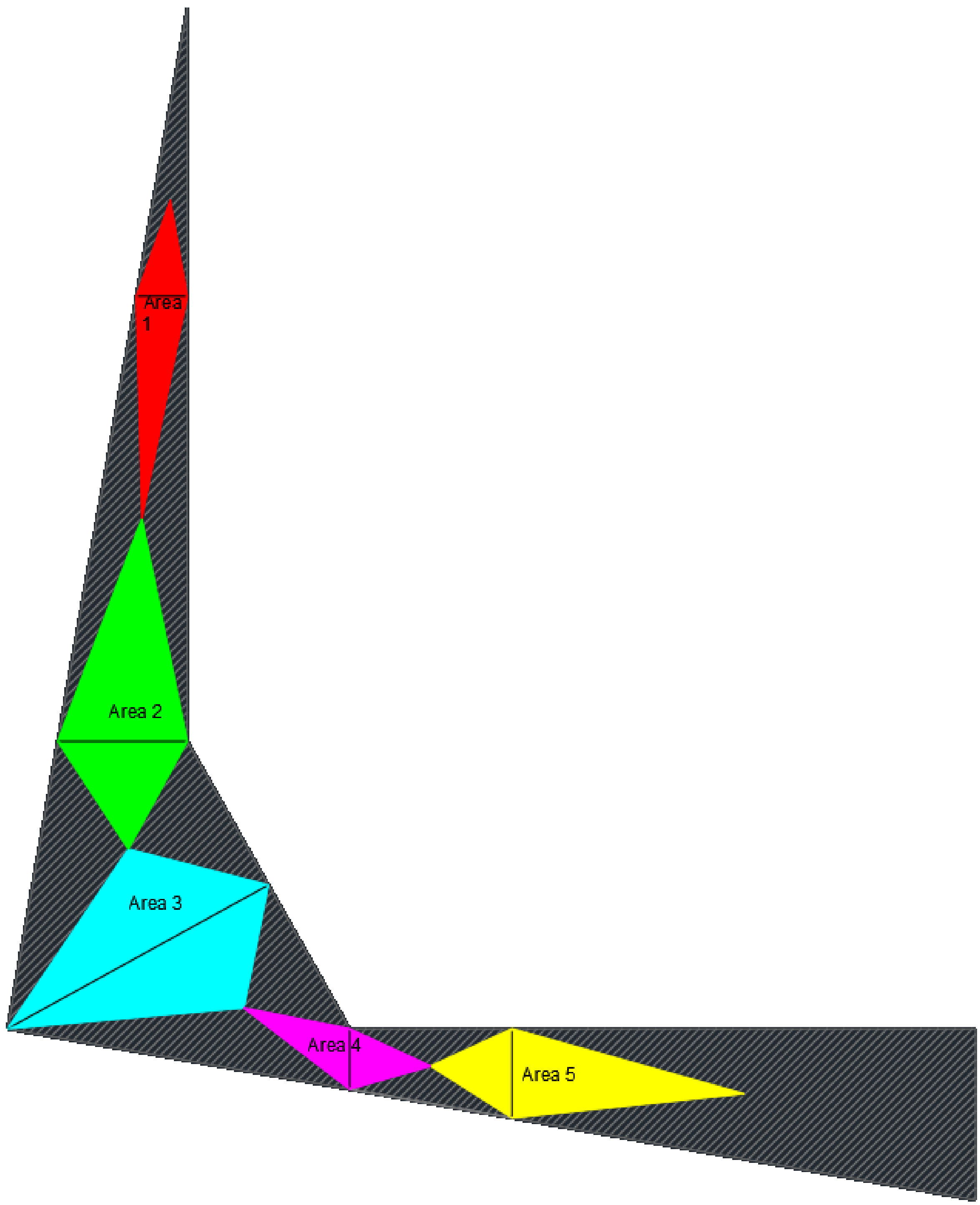
**C3, D3, E3, C4, D4, and E4 involve egress stairs and elevator in square footage

	Total SF	Office	Corridor	Assembly	Stairs	Bathroom	Closet	Floor (psf*sf)	Roof (.7*55 psf*total sf)(1.1)	Total (lbs)	Total (kips)
		Square footage (sf)									
A1	80.87	80.87	0.00	0.00	0.00	0.00	0.00	4043.5	3424.8445	7468.3445	7.4683445
A2	231.09	83.15	0.00	147.94	0.00	0.00	0.00	18951.5	9786.6615	28738.1615	28.7381615
A3	302.06	0.00	0.00	302.06	0.00	0.00	0.00	30206.0	12792.2410	42998.2410	42.998241
G4	84.09	0.00	0.00	84.09	0.00	0.00	0.00	8409.0	3561.2115	11970.2115	11.9702115
A.1-5	128.28	0.00	0.00	128.28	0.00	0.00	0.00	12828.0	5432.6580	18260.6580	18.260658
B2	386.23	106.24	49.57	42.93	0.00	0.00	0.00	13570.6	8416.6390	21987.2390	21.987239
B3	378.43	0.00	0.00	190.94	0.00	0.00	0.00	19094.0	8086.3090	27180.3090	27.180309
B4	223.84	0.00	0.00	223.84	0.00	0.00	0.00	22384.0	9479.6240	31863.6240	31.863624
C2	453.56	77.13	243.85	0.00	26.13	0.00	0.00	25977.5	14700.1085	40677.6085	40.6776085
**C3	453.56	8.15	215.08	94.40	26.13	0.00	0.00	29666.9	14558.2360	44225.1360	44.225136
C5	64.58	0.00	0.00	64.58	0.00	0.00	0.00	6458.0	2734.9630	9192.9630	9.192963
D2	454.25	231.49	107.23	0.00	0.00	107.36	16.90	29218.9	19607.2030	48826.1030	48.826103
**D3	454.25	177.90	119.98	0.00	0.00	107.36	16.90	27559.4	17877.6290	45437.0290	45.437029
E2	304.61	174.80	15.93	0.00	0.00	9.32	31.97	12631.6	9826.0470	22457.6470	22.457647
**E3	304.61	158.29	108.20	0.00	0.00	9.32	0.00	17269.5	11680.5535	28950.0535	28.9500535
B1	168.14	168.14	0.00	0.00	0.00	0.00	0.00	8407.0	7120.7290	15527.7290	15.527729
C1	197.75	197.75	0.00	0.00	0.00	0.00	0.00	9887.5	8374.7125	18262.2125	18.2622125
D1	197.75	197.75	0.00	0.00	0.00	0.00	0.00	9887.5	8374.7125	18262.2125	18.2622125
E1	132.61	91.83	0.00	0.00	0.00	0.00	40.78	7038.3	5616.0335	12654.3335	12.6543335
F1	40.43	40.43	0.00	0.00	0.00	0.00	0.00	2021.5	1712.2105	3733.7105	3.7337105
F2	92.86	92.86	0.00	0.00	0.00	0.00	0.00	4643.0	3932.6210	8575.6210	8.575621
F3	92.86	92.86	0.00	0.00	0.00	0.00	0.00	4643.0	3932.6210	8575.6210	8.575621
F4	40.43	40.43	0.00	0.00	0.00	0.00	0.00	2021.5	1712.2105	3733.7105	3.7337105
**E4	132.61	44.96	0.00	0.00	0.00	0.00	0.00	2248.0	1904.0560	4152.0560	4.152056
**D4	197.75	102.44	0.00	0.00	0.00	0.00	0.00	5122.0	4338.3340	9460.3340	9.460334
**C4	231.30	24.98	0.00	135.43	0.00	0.00	0.00	14792.0	6793.3635	21585.3635	21.5853635

Office:	50	psf
Assembly:	100	psf
Corridor above 2nd Floor:	80	psf
Roof	55	psf
Bathroom:	75	psf
Closet:	60	psf
Stairs:	100	psf
HSS 6x6x1/2 @10' (Table 4.4)	355	kips

Total Calcs per Column				
			55psf=.055kips	1.2D+1.6L+0.5S
	Live Load (kips)	Dead Load (kips)	Snow Loads (kips)	Total Load on Column (kips)
A1	7.4683445	7.7226986	4.44785	23.44051452
A2	28.7381615	20.7587902	12.70995	77.24658164
A3	42.998241	26.9175668	16.6133	109.4049158
G4	11.9702115	8.0021302	4.62495	31.06736964
A.1-5	18.260658	11.4845384	7.0554	46.52619888
B2	21.987239	19.8263572	10.9307	64.43656104
B3	27.180309	19.1494732	10.5017	71.71871224
B4	31.863624	20.1296352	12.3112	81.29296064
C2	40.6776085	31.8915058	19.09105	112.8995056
**C3	44.225136	31.6342928	18.9068	118.174769
C5	9.192963	6.3090524	3.5519	24.05555368
D2	48.826103	40.7949044	25.4639	139.8076001
**D3	45.437029	37.6592092	23.2177	129.4991474
E2	22.457647	21.5653956	12.7611	68.19125992
**E3	28.9500535	24.9275918	15.16955	83.81797076
B1	15.527729	15.2959892	9.2477	47.82340344
C1	18.2622125	17.865545	10.87625	56.096319
D1	18.2622125	17.865545	10.87625	56.096319
E1	12.6543335	12.2126958	7.29355	38.54894356
F1	3.7337105	4.2133154	2.22365	12.14174028
F2	8.575621	8.7631908	5.1073	26.79047256
F3	8.575621	8.7631908	5.1073	26.79047256
F4	3.7337105	4.2133154	2.22365	12.14174028
**E4	4.152056	5.4829288	2.4728	14.45920416
**D4	9.460334	10.5476432	5.6342	30.61080624
**C4	21.5853635	15.3340798	8.82255	57.34875236

Appendix K – Tributary Areas of Cantilevers



Appendix L – Beam Sizing Calculations

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Total= 1.2D+1.6L+0.5S													
2	Loads (psf)	Dead Load	Live Load 1	Live Load 2	Snow Load		Moment Calculation	Fy=V=X*L	Ma=V*.5*L	LRFD adjustment factor=0.9		*=assumed minimum size		
3		86.78	50	100	55							**= found through depth calculations		
4														
5	Cantiliver 1		Area sqft				Length (ft)	Moment (lb/ft)	Moment (kips/ft)	Adjusted Moment		W requiered*	14	
6		Top Area	6.5				2.625	7581.552878	7.581552878	6.82339759				
7		Bottom Area	15.09									Beam Sizing	W14x22	
8														
9	Top	1375.634												
10	Bottom	4400.78724												
11	Total (lbs)	5776.42124												
12														
13	Cantiliver 2		Area sqft				Length (ft)	Moment	Moment (kips/ft)	Adjusted Moment		W requiered*	14	
14		Total	57.16				6.67	55594.16239	55.59416239	50.03474615				
15												Beam Sizing	W14x22	
16														
17	Total	16669.91376												
18														
19	Cantiliver 3		Area sqft				Length (ft)	Moment	Moment (kips/ft)	Adjusted Moment		W requiered**	18	
20		Total	77.6				14.83	167808.5209	167.8085209	151.0276688				
21												Beam Sizing	W18x40	
22														
23	Total (lbs)	22630.9536												
24														
25														
26	Cantiliver 4		Area sqft				Length (ft)	Moment	Moment (kips/ft)	Adjusted Moment		W requiered*	14	
27		Total	15.122				3.125	6890.811863	6.890811863	6.201730676				
28												Beam Sizing	W14x22	
29														
30	Total (lbs)	4410.119592												
31														
32														
33	Cantiliver 5		Area sqft				Length (ft)	Moment	Moment (kips/ft)	Adjusted Moment		W requiered*	14	
34		Total	37.3				4.06	22082.38628	22.08238628	19.87414766				
35												Beam Sizing	W14x22	
36														
37	Total (lbs)	10878.0228												