Human Emotional States in the Built Environment

A Major Qualifying Project submitted to the faculty of

Worcester Polytechnic Institute

In partial fulfillment of the requirements for the Bachelor of Science
by

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Abstract

This project refines and produces designs drafted in previous project iterations to build a space to examine the effects of light, sound, and spatial form on human stress response and performance through architectural and mechanical design. A Personal Emotional Augmented Controlled Environment or PEACE Project Space was designed and assembled, where an experiment could be conducted using an EEG headset, O2 ring, web camera, and The Positive And Negative Affect Schedule scale survey. This project's PEACE space development and corresponding experiment design will allow for future collection and analysis of data to contribute to future improvements in the way architectural design meets human needs.

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Capstone Design Statement

The goal of this Major Qualifying Project was to design and build a dynamic architectural space that can be manipulated in terms of spatial volume, light, and sound. The space was developed to be used for adaptable, psychological experimentation. This project delivered the design, construction, and preliminary optimization of a Personal Emotional Augmented Controlled Environment, or PEACE Space, as well as the development of a correlated experiment design with prefatory data collection. To complete this project, the four basic architectural engineering disciplines were integrated through the design and application of structural, mechanical, and electrical building systems and construction elements.

This project demonstrates the fulfillment of design requirements set forth by the Accreditation Board for Engineering and Technology (ABET). The team of three architectural engineering majors drew upon knowledge from prior courses and project experiences, as well as the skills and information gathered throughout the timeline of this MQP, in order to demonstrate proficiency across all architectural engineering curriculum areas. Collaboration among team members ensured that the project delivered satisfied set expectations.

Architectural Design

Architectural design was utilized to create the space. Measurements of the room were taken to ensure an adequate spatial environment would be produced for participants to enter and engage in. CAD software such as Rhinoceros3D and AutoCad were used for the design of the space. Structural elements were also investigated when designing the 80/20 frame. Since the frame would act as the shell for the space it was important to determine possible loads. The construction and installation of the space using the 80/20 frame demsonstated knowledge in key building principles. Finally, the space would not be complete without an adequate lighting system. Lighting calculations were made for the space using throw ratios, area, and quantity of lumens.

Mechanical & Electrical Systems

In order to have a functioning immersive space, a rigorous mechanical and electrical system had to be planned. Motors were sized and wired to microcontrollers and arduinos in order to program and control the room. A fabric mesh panel system as also designed to create a dynamic environment based on selected design elements. This installation highlighted the electrical systems and mechanical concepts within our program.

Project Organization, Planning, & Communication

To ensure the success of the project, we researched the problem and designed and prototyped a space that would test the problem in order to then be able to find solutions to that problem. We also designed an experiment that would test a participant's stress levels using EEG and O2 ring equipment. To meet the ABET desin requirement, we considered the systems or processes from other architectural engineering curricular areas, worked within the overall architectural design, communicated and collaborated with other design or construction team members.

Marketability

If the space were made fully operable and optimized in terms of manufacturability, transportability, and cost, it could be reproduced and marketed.

Licensure Statement

Professional licensure is a regulatory process that makes sure practitioners meet set standards of proficiency within their respective profession (U.S. Department of Education ,n.d.). Architectural engineering licensure is an important step in establishing credibility as an engineer. It is granted by the state to individuals who have demonstrated that they meet the minimum requirements in education and field experience. This process involves completing an accredited engineering program, passing the Fundamentals of Engineering (FE) exam, gaining field experience, and then passing the Principles of Engineering (PE) exam (National Society of Professional Engineers, n.d.).

Obtaining and maintaining an engineering licensure is also critical in being able to advance within the profession. It shows potential employers and clients that the engineer is well qualified and thus promotes a higher salary and career opportunities. By law, many jurisdictions require licensure to provide engineering services. Not having licensure therefore limits the ability of engineers to do certain tasks, such as signing off plans and documents (Massachusetts Society of Professional Engineers, n.d.).

Licensure not only benefits the engineer but also the public and the profession as a whole. It helps in promoting public safety through setting, following, and enforcing practice standards. This promotes consistency within the industry which helps to further build trust between the engineering industry and the community.

Executive Summary

This project studies the interactions between dynamic architecture and human emotion in a built environment. Using a combination of architectural and mechanical design and bio, it focuses on examining the effects of light, sound, and spatial form on human stress response and performance.

The PEACE (Personal Emotional Augmented Controlled Environment) Project Space was designed and developed into an 80/20 structural frame with custom 3D-printed wall motor mounts and mechanical system parts, and an operable wall system.

The experiment, designed to be conducted in the PEACE space, uses combinations of warm or cool light produced by LEDs, in conjunction with white or pink noise played through a pair of speakers. Lighting options were selected with consideration of the relationship between light intensity, or illuminance and correlated color temperature, or CTT (K). The sound stimuli also intersects two variables; pitch (frequency) and volume (power). Research shows both benefits and inefficacy for different combinations of these variables in an environment, motivating this experiment to develop a quantifiable understanding of how to minimize stress while maintaining focus.

In the experiment plan, an EEG (electroencephalogram) device captures brainwave data that can indicate an array of emotions. This project in particular researched the use of a 3-node Wet Electrode EEG headset to capture Alpha (Hz) and Theta (Hz) brain waves. Computer software displays a frequency value correlated with the different brain waves, to then be interpreted in association with various emotions. We designed a EtLT data pipeline to automate the data collection and analysis of our experiment.

In terms of data collection, the experiment also utilizes an O2 ring to monitor heart rate. To assist in timeline synchronization as well as record visual data, a web camera captures video, During data collection through these methods, participants would perform a simple choice activity, such as LEGOs or playdough. A Positive And Negative Affect Schedule (PANAS)-scale survey was chosen to be distributed before and after the experiment as a way of gauging participant perceptions of emotions upon entering and before exiting the PEACE space.

Future iterations of this project can expand on the initiated development of a projector system. This would further possibilities for visual stimuli in future experimentation in terms of color, pattern, and brightness. A mesh fabric panel system was also developed to explore the spatial form of the built environment but requires further work in regards to visual continuity and mechanical design.

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1. Introduction

1.1 Background and Motivation for this project

People spend the majority of their lives inside. It is a common saying that you spend “one third of your life” at work (Naber, 2007), and for many workers that means in an office space. Similarly, college students are expected to spend 12 hours a week in the classroom and 30 hours a week studying (Lumen, n.d.). It is an established fact that the space you are in can affect your subconscious and mood (Harouk, 2020). Commonly architectural engineers understand that certain design principles can contribute to an individual's comfort levels and productivity. The realm of environmental psychology focuses on just that kind of research. The American Psychological Association has found research-based design choices that they recommend should be implemented in therapist offices that can contribute to a patient’s healing process (DeAngelis, 2017). It stands to reason that similar implementations could benefit a student in the classroom or a study space and a worker in their office. The creation of a controlled physical space in which a student’s mood and attention could be tested with many different variables would be very useful in finding out the best design choices to be implemented.

Our approach was the design and construction of the Personal Emotional Augmented Controlled Environment (PEACE Space), as well as the design of an experiment and data pipeline to be conducted in this space. For this project, we chose to design a work-rest environment rather than replicate a classroom or office for the proposed experiment space because we felt that our research would be more applicable to the development of an environment more directly correlated with the study of improving mental health. This approach could contribute to future creation of more rest spaces on college campuses like WPI, where it is crucial that students, faculty, and staff have viable opportunities to recharge mentally and physically in an environment that minimizes stress while maintaining focus levels throughout the day.

1.2 Problem Statement and Research Questions

This project aims to create a controlled environment where a range of interior variables can be altered and experimented with to gauge a person's emotional reaction. The goal is to create both the space and the tools necessary for this testing to occur. An example of this is looking at the interaction of light, sound, and space with a person’s stress levels and performance abilities.

1.3 Overview of the Report

In order to lay the foundation for our Major Qualifying Project (MQP) we go over the background for our motivations. Interactive architecture is a new multidisciplinary field that uses technology to make the room changeable. A Similarly interesting connection is healthy emotional well being and learning environments. Thus we compare current interactive architecture and emotional well being, theories and case studies.

It is in our Peace Space section that we define what the room is and how we are testing our variables. We highlight how even though it isn't a changing variable, spatial volume is an essential feature in our Peace space. We go over other key concepts and iterations to our development process and design elements. Categorized by Light or Sound we go over details in how we design/implement them physically while accounting for cost. In this section we also go over how we account for flexible spacing. This is highlighted by our mention of Actuators we customly built on our frame. Lastly, we go over and account for the furniture in the room.

For our Methodology chapter we go over our research questions and objectives for our experiment. Here we break down our testing variables by light and space. We then break down our data and analysis with a pipeline we have made to automate this section. Due to ongoing discovery of learning, researching and weighing pros and cons we had multiple iterations of the data pipeline.

2. Literature Review

2.1 Introduction

This section serves to provide an overview of current research on interactive architecture, emotional well-being, and their connection. In this review, we start by introducing interactive architecture, its objective, and its key features. We then discuss the topic of emotional well-being and the challenges it presents in academic environments, including academic stress and social expectations. It explores the connections between physical space, mental health, performance, and theories and models of emotional well-being and healing environments. The section also includes a review on several case studies of interactive architectural design. By reviewing these case studies, we aim to provide a background for the project as well as identify gaps in current research that the project can address. The section concludes with overviews on the driving research behind light and sound stimuli selection, and data pipelines.

2.2 Overview on Interactive Architecture

Interactive Architecture is a field that combines architecture, design, and technology to create interactive and responsive environments that can adapt and respond to the needs of their users. The goal of this field is to create spaces that are not just static and functional but can engage with people, adapt to their needs, and enhance their experience (Schueler, N. 2010).

One of the key features of interactive architecture is the use of sensors and actuators to collect data and control the behavior of the environment (Krakowsky, T. 2008). This can include temperature sensors, motion detectors, light sensors, and much more. This data is then used to control lighting, temperature, sound, and other aspects of the built environment.

2.3 Emotional Well-Being and Challenges in Learning Environments

Emotional well-being refers to an individual’s ability to manage their emotions in a healthy way, cope with stress, and maintain a positive outlook on life. In the academic environment, emotional well-being can be a challenge in maintaining due to the pressures of coursework, exams, and deadlines, as well as social and personal expectations (Oxford Brookes University, n.d.). One of the biggest challenges to emotional well-being in the academic environment is academic stress. This stress can stem from a variety of sources, including the workload, competition with other peers, fear of failure, and pressure to perform well academically. As a result, this type of academic stress can lead to burnout, anxiety, and depression (Naz Böke, B., Mills, D., Mettler, J., & Heath, N. 2021).

Furthermore, social and personal expectations can also contribute to the emotional stress in the academic environment. Students may feel the pressure of conforming to social norms or expectations set by their families, peers, or communities that can lead to feelings of inadequacy or self doubt. Additionally, isolation, lack of social support, or even financial struggles can negatively impact an individual's emotional well-being in the academic environment (Pritchard, M., & Wilson, G. 2003).

Optimizing the architectural design of working and learning spaces to adapt to human needs in ways that improve emotional well-being is critical in an endeavor to combat these stressors that humans already face in their personal and home lives (Wakefield, 2002). As a result, this inevitably often improves performance as well. Light, for example, is a design variable that can greatly impact emotional well-being in an environment. Existing research proves that proper lighting in a learning environment is vital, and that there are connections between lighting, mood, and cognitive performance. In "Learning the Hard Way: The Poor Environment of America's Schools," author Julie Wakefield explains that research “has also shown that there is a significant effect of poor lighting on children's ability to learn. Sunlight is important for human health.” Wakefield references a two-year study from six schools in North

Carolina, which “compared data from students attending school with full-spectrum light with those attending traditionally lit classrooms. Students in full-spectrum light were healthier overall and attended school 3.2 to 3.8 days more per year. They also exhibited more positive moods.” Gaining this understanding later assisted in the selection of options for experiment stimuli.

2.4 Existing Research on Interactive Architecture and Emotional Well-being

Authors, Avani Parikh and Prashant Parikh, break down how impactful architecture is to the humans who use it, in their book, *Choice Architecture: A New Approach to Behavior, Design, and Wellness.* This is because architecture promotes certain behaviors over others. They reason that since architecture impacts human behavior, and human behavior impacts health, architecture impacts health. With this logic the authors declare all architects have an innate responsibility to make sure that it benefits people. This is shown when stated “... that there just is no neutral architecture. In other words, health and wellness are already part of utility, firmness, and beauty whether one likes it or not. The only choice an architect has is to acknowledge this brute fact or not." (Parikh, & Parikh, P. 2018) In this quote specifically, the authors highlight health and wellness as one of the integral parts of architecture.

Earlier this year researchers at Xi'an University of Architecture and Technology tested the moods of travelers on public transportation. Their experiment embodied the idea that to improve architecture one has to account for emotional well being. Hence, embodying the ideas of the Parikh’s. The research involved adding numerical value to degrees of happiness, panic, anxiety and tiredness. By doing so they were able to use a Support Vector Machine to test the correlation between occupation, age,personal income, temperature and more. The findings of the experiment helped better understand the emotional health of passengers in long-distance traveling in China. Which can lead to better transportation design (Health & Medicine Week 2023).

2.5 Models of Emotional Wellbeing and Healing Environments

Cognitive psychology has come to realize that a person’s emotions can quickly be impacted by their setting (Ulrich, 1983). Ulrich examines affective and aesthetic reactions to an environment and calls for more quantitative research looking at what factors may play into a person’s reaction. When approaching the topic of well-being and healing environments, there is a large body of research that has focused on nature environments and how exposure to green space can increase working memory, cognitive flexibility, and attention-control tasks (Schertz & Berman, 2019). By using sounds, and images to induce a sense of “soft fascination”, these environments can be seen as restorative, even if just a representation. Healthcare environments have been examined for patient satisfaction and emotion, showing no one-to-one relation of color to emotion, but people do report different feelings with varying color (Tofle, 2004). These environments have long used artwork and daylighting to minimize the sense of isolation and sterility, but nurse performance also increases when the environment shows nature and outdoor light, minimizing errors (Iyendo, 2014).

2.6 Case Studies of Interactive Architectural Design

This phase of the PEACE project builds upon previous teams' work, iterating to fruition. We review WPI works along with other artists and engineers in order to learn from their experiences and recommendations.

2.6.1 Precedent 1: Adaptive Architectural Design

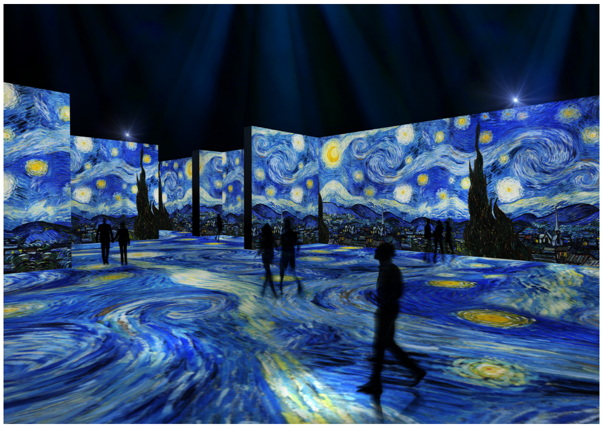
This project was a Major Qualifying Project completed in 2021 by Gelila Hailemariam, Tina Ly and Tam Tuong [1]. The focus of their experiment was to collect data in an Immersive Space to gain research that would assist in their design of a counseling center for WPI that promotes calmness. The experiment looked for a correlation between stress and certain lighting conditions using a dry EEG headset and O2 ring to measure various physical and neural conditions. In the procedure of the experiment participants used Virtual Reality headsets to explore the different lighting variables. Due to Covid-19 restrictions at the time, the data obtained from testing was skewed as only a limited number of students could be tested. Recommendations made in the paper were to make more drastic changes between normal and high lighting, to ensure there is a limited amount of bluetooth devices interfering with the EEG connection, and to ensure the data converts to a more compatible format. Last, they recommended a shorter experiment timeline.

2.6.2 Precedent 2: Kinetic Architecture (Mechanical & Art)

Art installations have begun using mechanical systems along with audiovisual technology to add new dimensions and communicate more than just oil on canvas. "Immersive Experiences" have gained in popularity all around the world since 2020, telling artists' stories by making their pieces dynamic and interactive. Projectors and mirrors are primarily used in these exhibits with some integrating virtual reality to personalize each participant's audiovisual experience.

Figure 1

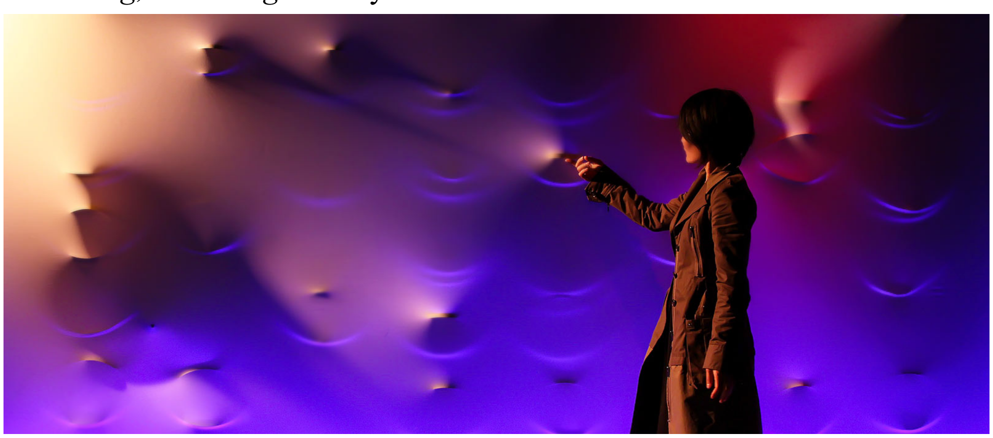
Van Gogh: The Immersive Experience



Artists such as Behnaz Farahi have used similar concepts to create her “Living, Breathing Wall” (Ferahi, 2013). This wall uses a projector to display her graphic work, while motors push fabric from behind to move the wall as the watcher walks by. The input here is spoken word, and the art’s message is to be aware of how the environment can change by our actions. Taking this to a literal level, our input as EEG signal, O2 levels, and movement, all can program the architecture to react.

Figure 2

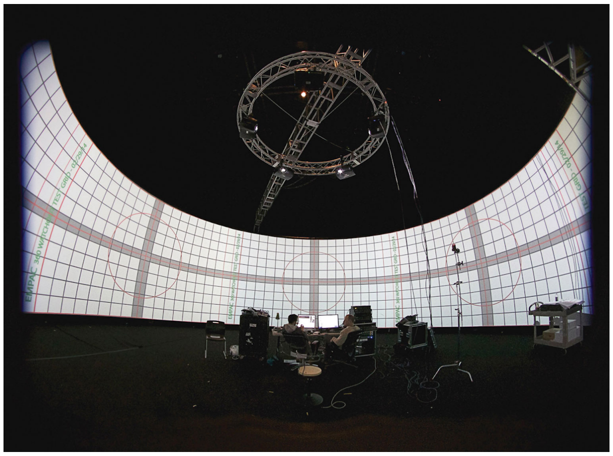
The Living, Breathing Wall by Behnaz Farahi



EMPAC’s Studio 2 projects media onto a 360 degree tensioned micro-perforated screen, allowing for the fabric to not impact the acoustic qualities of the space while maintaining visual continuity. This room is acoustically deadened with diffusive and absorptive panels placed on all walls. This space is considered multi-modal in that the experience can be visually and acoustically altered for any installation, making it exceptional for artistic and exploratory endeavors.

Figure 3

Experimental Media & Performing Arts Center (EMPAC) Studio 2

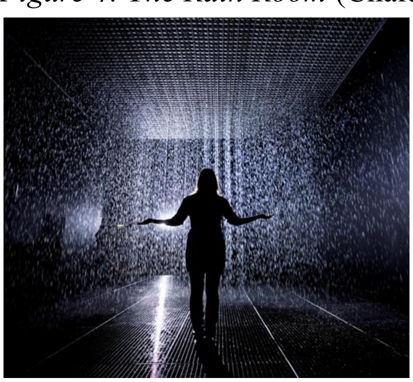


2.6.3 Precedent 3: Interactive Architecture (The Rain Room)

In a more dramatic form of interactive architecture, the Rain Room is an art installation that regulates human emotions by creating a sensory experience that is calming and breathtaking. Inside this room, rainfall is simulated using a sophisticated sensor and water nozzle system. As visitors walk throughout the room, sensors pick up their location and movements to create a dry zone around them. This allows them to experience the sensation of being in the rain without getting wet. Because of this, the Rain Room provides visitors an immersive experience that encourages them to contemplate and also interact with the space. As a result, this installation has been shown to lower stress and anxiety among visitors (Chalcraft, E. 2012).

Figure 4

Figure 4: The Rain Room (Chalcraft, E. 2012)



2.7 Driving Research for Selection of Stimuli

In order to accurately incorporate light and sound stimuli into the PEACE space, several variables needed to be researched, compared, and selected. The relationships between light and sound variables produce different interactions so it was important to consider our research goals when selecting stimuli.

With the goal of developing a work-rest oriented space that optimizes mental rest, we wanted to compare conditions of a more typical working or learning environment, such as an office or classroom, to other combinations of stimuli more associated with resting spaces, in order to find an optimal combination.

2.7.1 Light

In studying the effects of illuminance, it was found that high intensity light is most commonly used in a working or learning environment, as bright light increases visual acuity and decreases human error (Kort et al., 2014). The scope of this project, though, aimed to investigate comparatively, so while one light stimuli option would be high in illuminance, the other would be low. Figure XX shows a common range of light intensity values in footcandles and their space uses. Despite the benefits to bright light, research also shows that extended exposure can actually negatively impact alertness and mood, or overexposure in the daytime can disrupt sleep at night (Kort et al., 2014). Underexposure, however, can also disrupt sleep in terms of circadian rhythm patterns.

Figure 5

Spaces & Foot-candle Measurements

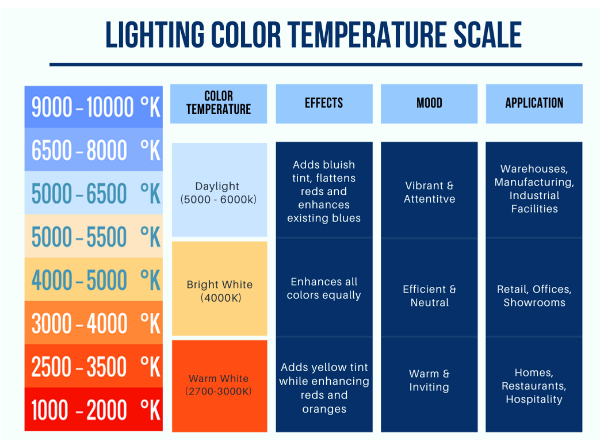
SPACES & FOOT-CANDLE MEASUREMENTS	
Workspace or Garage	80 - 100 FT CANDLES
Kitchen Work Areas	70 - 80 FT CANDLES
Bathroom	70 - 80 FT CANDLES
Home Office	60 - 80 FT CANDLES
Dining Room	30 - 40 FT CANDLES
Kitchen	30 - 40 FT CANDLES
Living Room	10 - 20 FT CANDLES
Bedroom	10 - 20 FT CANDLES
Hallway	5 - 10 FT CANDLES

The other determining factor of light stimuli, Correlated Color Temperature, is similar in the way it ranges in unit value and corresponds with associated effects. CCT, however, uses the unit of Kelvin and identifies with a warm or cool appearance. Figure YY displays a full range of

CCT values from 1000K to 10000K with its common uses and ambiental associations. The lighting industry typically uses a more narrow Kelvin range of 2500K to 6000K, which we used as the parameter for our experiment design when selecting LED lights for the PEACE Space. Given that higher Kelvin values more closely replicate daylight and aid in energy and attentiveness (Wakefield, 2002), full-spectrum lighting at 6000K was chosen for one light stimuli option. Similar to how too much bright light can cause adverse effects, though, too much cool light can do the same. Warm light in later times of day especially reaps benefits such as decreased stress levels. To examine this emotional response more, the second light stimuli option was chosen to have a lower CCT value of 3000K. This difference in color temperature allows for comparison of the benefits and disadvantages to both warm and cool light settings in the PEACE Space.

Figure 6

Lighting Color Temperature Scale (Straits Lighting n.d.)



In order to select illuminance values that correspond to each of the Correlated Color temperature choices, we found research that explains clear interactions between the two variables (Davis et al., 1990). Named the Kruithof curve, this relationship has been studied to show that "we generally find low brightness environments pleasing under low color temperatures, while high brightness environments tend to be more pleasing under higher color temperatures." Therefore, we chose an illuminance of 25 footcandles at 3000K and 50 footcandles at 6000K.

2.7.2 Sound

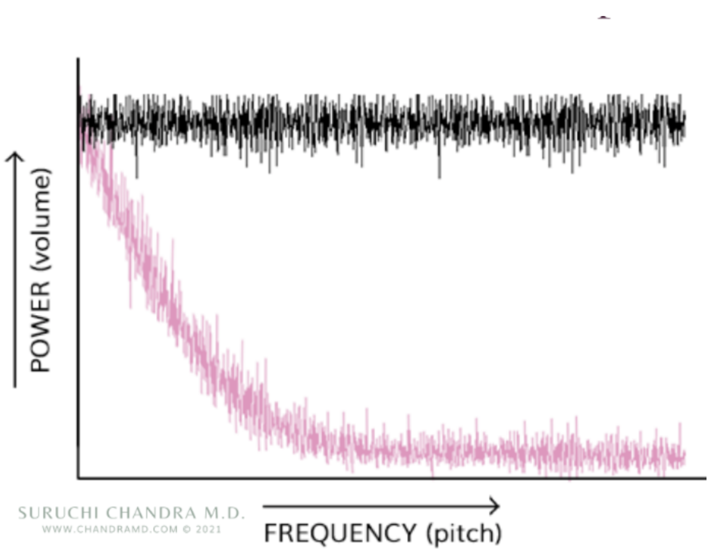
White noise is most common due to the fact that it includes all audible frequencies (Afshar, et. al., 2016). Energy, or power, is equally distributed across these low and high frequencies, also known as "broadband noise," creating a steady humming sound that can be used for sound masking which can aid in focus and sleep. We wanted to assess the effects of this noise in the PEACE space during an experiment, and compare it to less commonly used colors of sound.

In choosing a second sound stimulus option, we explored many different spectral values and their researched impacts. We found that in addition to white noise, research of pink noise was most prevalent to this project in terms of effects on human response (Lu, et al., 2020). Like white noise, pink noise also consists of all audible frequencies, but power is distributed at lower frequencies, producing a deeper sounding hum.

Looking at these frequency spectrums graphically, pink noise has a downward slope of -3dB/octave while white noise appears as a flat line. This is because pink noise is linear in logarithmic scale; the power spectral density, or power per frequency interval, is inversely proportional, 1/f (Bak, et al., 1987). In other words, "each octave interval (halving or doubling in frequency) carries an equal amount of noise energy." Pink noise is even more associated with sleep and relaxation than white noise, which we thought would be beneficial to explore in correspondence with a more restful environment.

Figure 7

White noise vs. pink noise frequencies (Chandra, 2021)



Applying these sound stimuli to our project incorporated our research goals and our planned methods of data collection. "Pink noise: Effect on complexity synchronization of brain activity and sleep consolidation" from the *Journal of Theoretical Biology* discusses research that found that when color noise exposure was combined with light stimuli, Electroencephalography (EEG) technology showed a decrease in complexity of brain waves (Fang, et al., 2012).

However, conclusions from most studies were skewed when analyzed, due to the fact that various factors such as demographics yielded different results. “[L]ight music, an example belonging to pink noise, is proved beneficial for elder people to improve their sleep quality as a long term effect (Chan et al., 2010).”

This served as motivation for this project to further research the effects of white noise vs pink noise on brain activity and therefore mood and performance.

2.8 Overview on Data Pipelines

A data pipeline is a system of processes to change and move data. They are essential to machine learning capabilities, reporting and analytics. The motivation to build a data pipeline is to have an output people outside of analytics can process. Usually what happens in a data pipeline is refinement, cleaning, aggregating and combining. In the pipeline anonymity is usually introduced as well.

There are various types of Data Pipeline designs. Two in particular are ELT pattern and EtLT pattern. The E’s, L’s and T’s stand for different processes. The order for ELT pattern is extract, load and transform. Extract is for extracting raw data from the data producers. Loading signifies storing the data. Transform stands for changing of the data in any way. Changing the data in this design would look like producing graph visualizations. The other type of design is ELT. In this design data is loaded before it is transformed. ELT design is the most optimal design for data science, data products and data science. EtLT’s are similar but they have an extra transform between extracting data and loading the data in storage. The extra transform in this case is usually for erasing sensitive and identifying information. EtLT’s are seen as a more sophisticated version of ELT’s (Densmore 2021).

3. PEACE Space

3.1 Design Concept of PEACE Project

The PEACE (Personal Emotional Augmented Controlled Environment) Space, an iterative design project to gain a better understanding of the human emotional responses to architecture, uses multiple systems to create varying modes to measure in experimentation. In this iteration, we focus on developing systems for light, sound, and spatial volume.

3.2 Development of the Design Concept

Evident in the years of past research showing emotional impact of design features but no direct correlation, this project seeks to simultaneously look for a possible correlation using scientific measurement, and also develop dynamic architecture construction that could be adjusted for a single person session. This space is modeled with the intention of creating an adaptive personal break area in a corporate office. The user would enter regardless of their current perceived emotional state and decide how they would like to feel upon exiting. The program would then measure their physical state using EEG and O2 sensor data, altering the space to adapt to their emotions as needed.

3.3 Design Elements

An effective design is crucial to the overall success of a space and what it represents. Design elements serve the purpose of creating an environment that is not only aesthetically pleasing but also efficient and capable of enhancing a user's experience. Here we discuss the design of the PEACE space and its components.

3.3.1 Light

Lighting is an essential design element that impacts the appearance of a space. It can be used to create a particular mood, provide functionality, and highlight architectural features. There are different types of lighting fixtures and systems that can both compliment the design aesthetics of a room and create a desired ambiance. In this project, we explored two methods of lighting the space: a projector system and LED light strips.

3.3.1.1 Projector System Connection & Classifications

While previous MQP works utilized the common lighting method of using LED light strips, our team decided to explore a new option and use projectors (Collins, A., Kopellas, W., & Simpson, D. 2020). This meant that the primary source of lighting for the space would be produced by projectors casting light on each wall. The advantage of using projectors over the LED strips was the versatility of display options, whether it was a specific color, pattern, brightness level, or video, to create a higher quality immersive space.

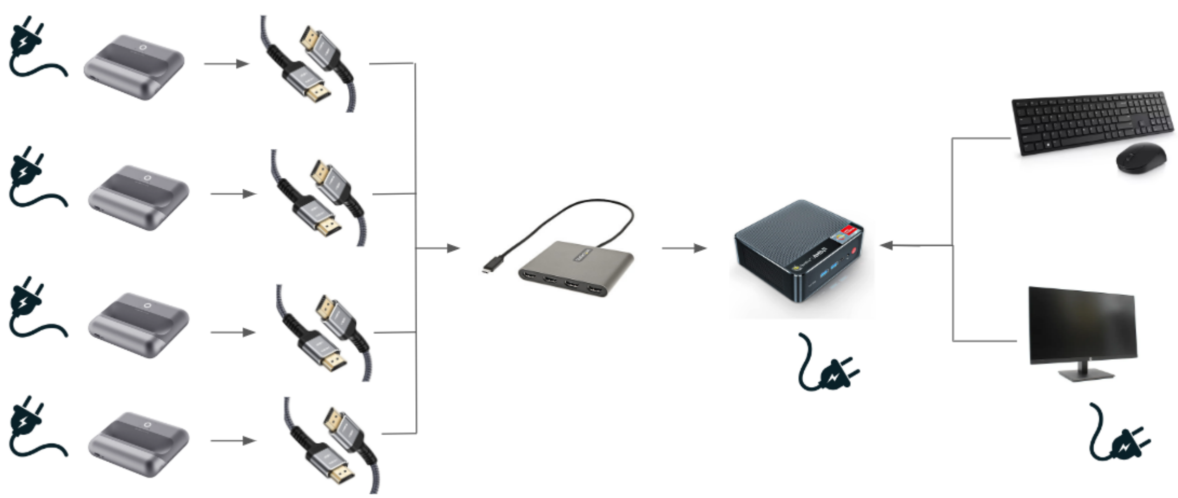
In order to fully illuminate the space, four projectors would be needed, each one corresponding to different walls. These four projectors would all be connected to the selected quad HDMI display adapter dongle (see Figures 5 & 6) which would be connected to a computer that controls the entire setup.

Figure 8

StarTech USB-C to 4 HDMI Adapter Dongle

Figure 9

Projector Display Connection Setup Diagram



Determining the position and location of these projectors depended on the type of projectors that were chosen based on their throw ratios. A projector's throw ratio describes the relationship between the distance from the projector to the screen/surface and the width of the screen/surface (USA Projector, 2020). Projectors are then classified based on their throw ratios as either a Long-Throw, Short-Throw, or Ultra-Short Throw projector (see Table 1 for projector classifications).

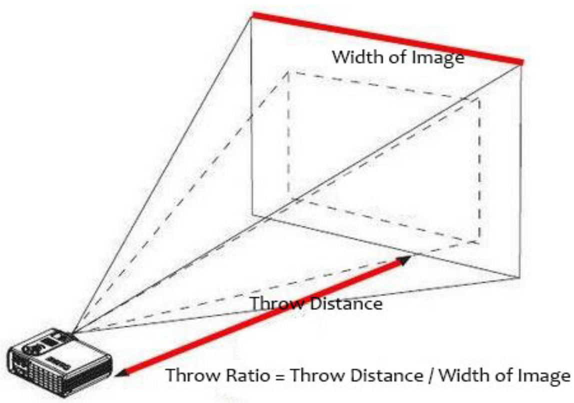
Table 1

Projector Types Based on Throw Ratio Range

Long Throw	Short Throw	Ultra Short Throw
>1	0.4-1	< 0.4

Figure 10

Projector Throw Ratio Relationship (*USA Projector, 2020*)



Projection Testing

Before developing any plans, however, we ran two test scenarios using two borrowed long throw projectors to evaluate the practicality of using projectors for the space:

- Test #1: Crossing projected images
- Test #2: Projecting onto fabric material

In the event that we had to cross projectors from one another to cast onto the desired wall area, we wanted to know how it would affect the projected image's color and resolution. The first test involved positioning two projectors on the floor and casting them perpendicular to each other. Upon casting two different images, there was no effect on picture quality or color (see Figure 8). This test proved that projectors could be positioned across one another without compromising the projected image.

Figure 11

Projector Test #1 - Crossing projected images

The next scenario we wanted to test was how a projected image would appear on a fabric material that could later be used in a panel system. In the first attempt, a projector was placed 1 foot away from the held fabric which produced a small and blurred image. In the second attempt, the projector was moved back by 4 feet away from the fabric which produced a more legible and clearer image (see Figure 9). This test demonstrated the importance of projector spacing and its throw ratio in order to achieve a well-cast image and lit space.

Figure 12

Projector Test #2 - Projected Image on Fabric

Projector Selection & Lighting Plans

Due to the compact size of the room and the goal to decrease the distance required to project onto the entire wall area, we selected three projector options, one short-throw and two ultra-short throw projectors (see Table # for a comparison between each projector):

- Option #1: AAXA P400 Short Throw Mini HD Projector
- Option #2: Optoma Technology Ultra-Short Throw DLP Projector
- Option #3: JMGO O1 PRO Ultra Short Throw Smart LED Projector

Table 2

Projector Comparison & Specifications

		
AAXA P400 Short Throw Mini HD Projector	**Optoma Technology Ultra-Short Throw DLP Projector**	**JMGO O1 PRO ULTRA SHORT THROW SMART LED PROJECTOR**
0.7 Throw Ratio	0.27 Throw Ratio	0.21 Throw Ratio
400 lumens	4000 lumens	1500 lumens
Full HD (1080p)	1280 x 800p	1920 x 1080p
4 x 4.5 x 2.3 in	18.7 x 18.1 x 8.8 in	14.96 x 16.61 x 8.74 in
1.24 lbs	8.7 lbs	17.63 lbs
$269	**$1349**	**$870**

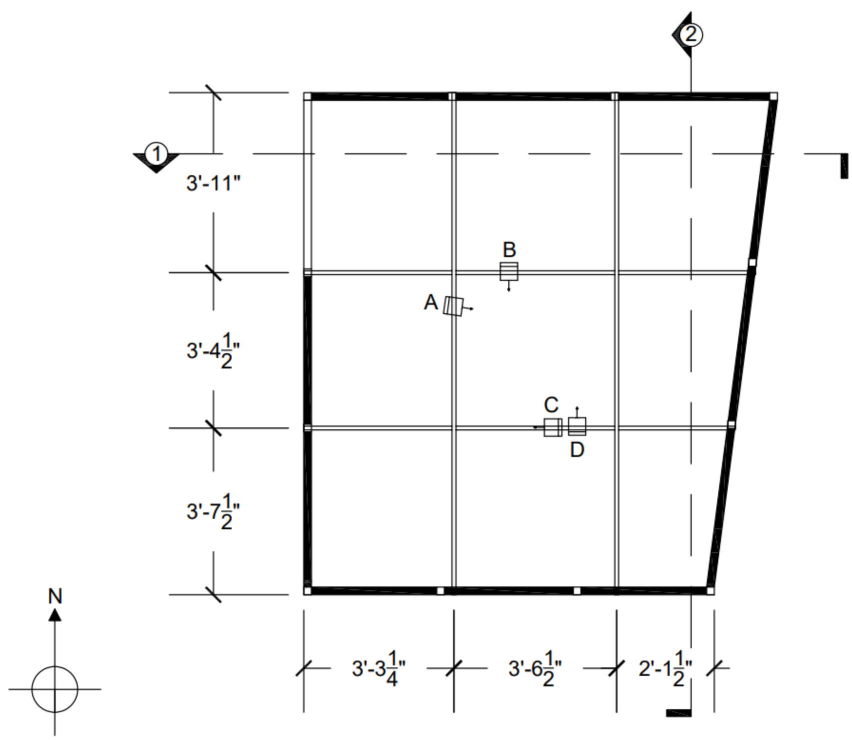
Knowing the specific throw ratios and dimensions of each projector allowed us to calculate the location of each projector and create their respective lighting plans for the space. It was important to design these lighting plans to first determine both the effectiveness of their cast area on the walls and the amount of space an occupant would have to move around, before purchasing a set. As a reference for space, we used the average height of a man (5ft-9in.) within our section plans. In our plans, each projector was given a letter to represent which wall it would be protecting onto, and is as follows:

- Projector A: projects onto the East wall
- Projector B: projects onto the South wall
- Projector C: projects onto the West wall
- Projector D: projects onto the North wall

The first projector option was the AAXA P400 Short Throw projector. It was chosen for its small size, light weight, and low cost compared to other similar short-throw projectors. Due to these factors, its lighting plan was designed with the idea of attaching them to the ceiling frame and pitched downward at an angle facing each wall (see Figure 10).

Figure 13

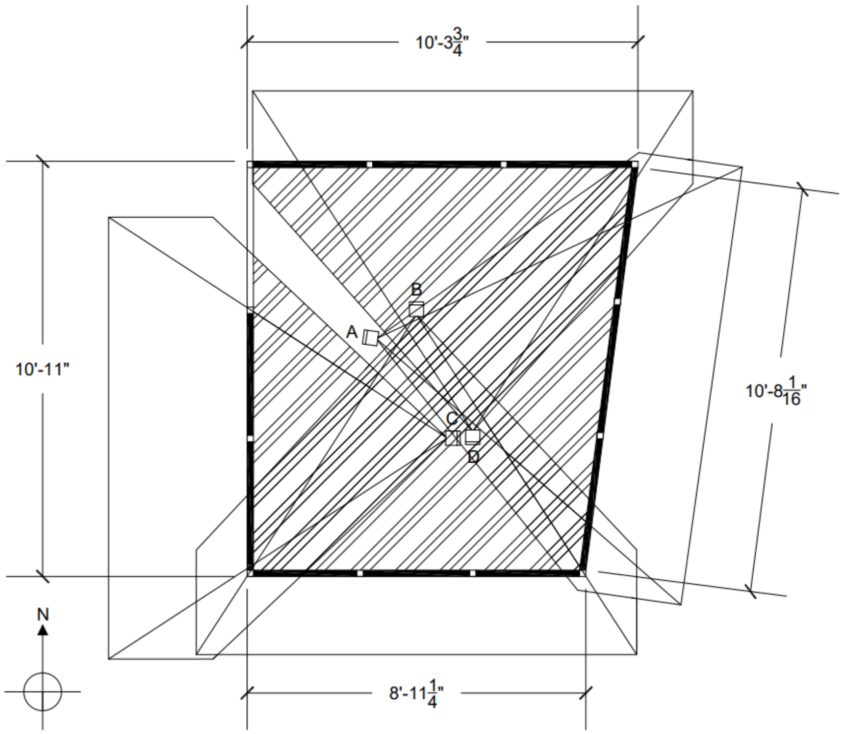
Ceiling Plan - Option #1 Projector Placement



From designing the plan, it was determined that this projector setup was able to fully light and cover each wall with the exception of a small gap in the direction of the door opening on the northwest side of the room (see Figure 11). It also meant that the light projected would cross based on their positions.

Figure 14

Lighting Plan - Combined Cast Area of Option #1 Projectors



While this setup was able to achieve a near-total coverage of light on all walls, occupants in the space would have limited movement in the center of the room while standing due to the projected light crossing other projectors. Occupants would also be in direct contact with the projected light, which could lead to an unpleasant experience and cause unwanted shadows within the space (see Figures 12 & 13). Additionally, the projectors do not provide a viable amount of lumens into the space for them to be the primary source of lighting for the space.

Figure 15

Section Plan 1 [South] - Cast Area of Option #1 Projectors

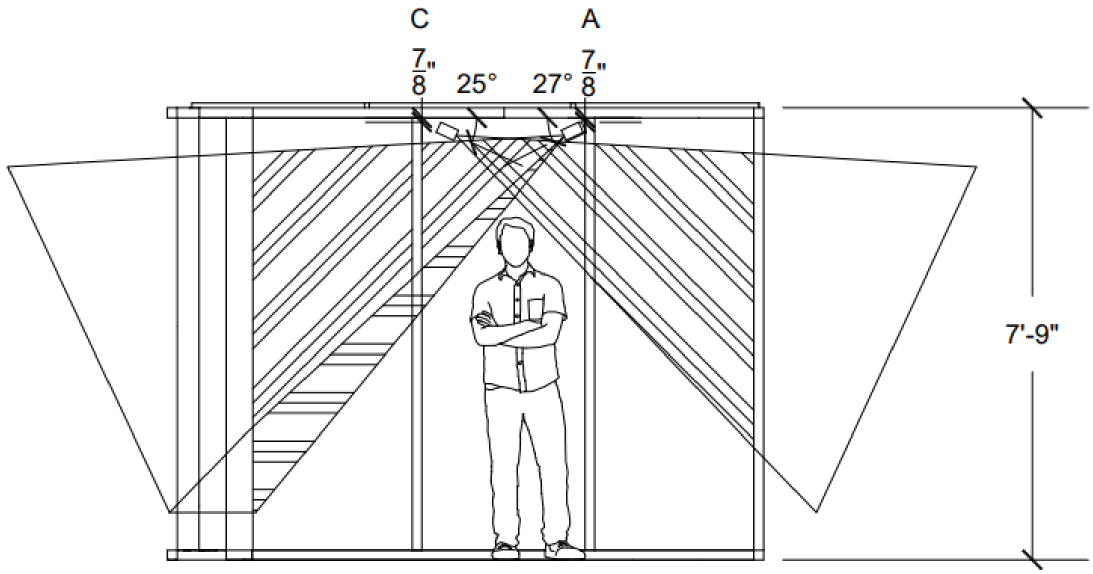
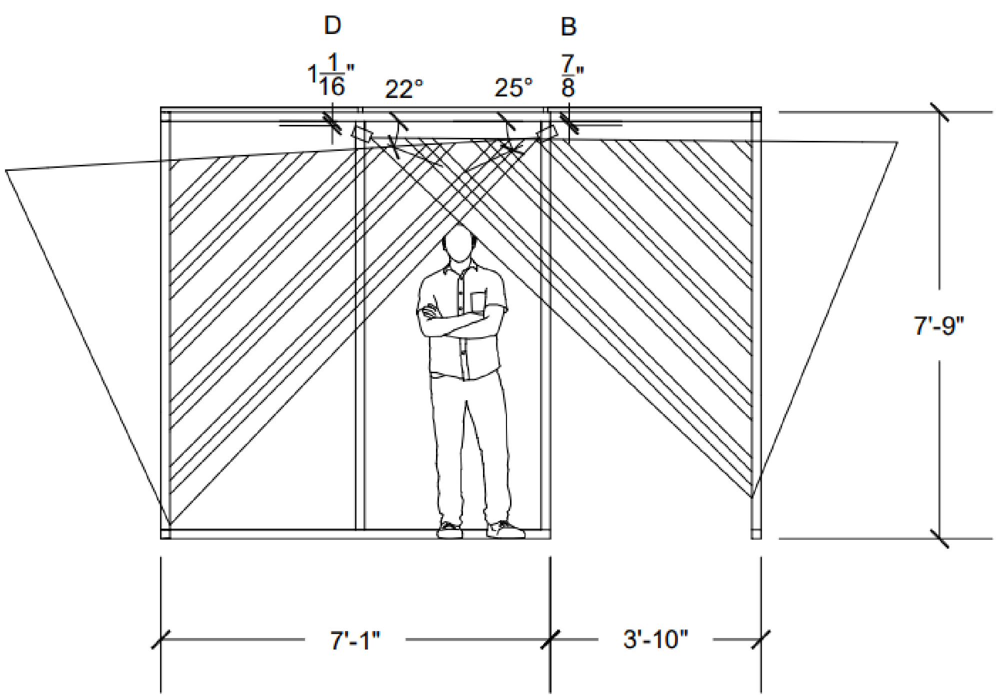


Figure 16

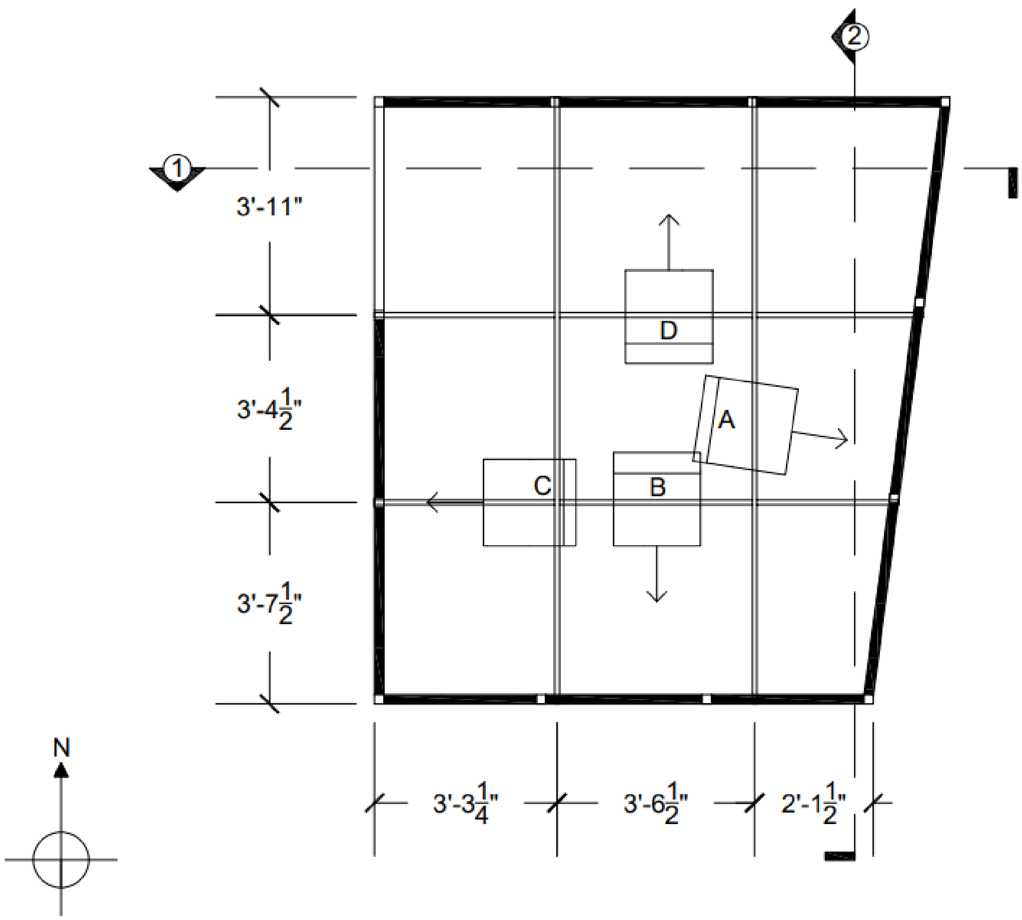
Section Plan 2 [West] - Cast Area of Option #1 Projectors



The second projector option was the Optoma Technology Ultra-Short Throw DLP Projector. It was chosen for its lower throw ratio and higher brightness level. While significantly heavier than projector Option #1 at 8.7 pounds each, these projectors were also designed to be attached to the ceiling (see Figure 14) in order to provide open space on the floor for occupants to move around freely.

Figure 17

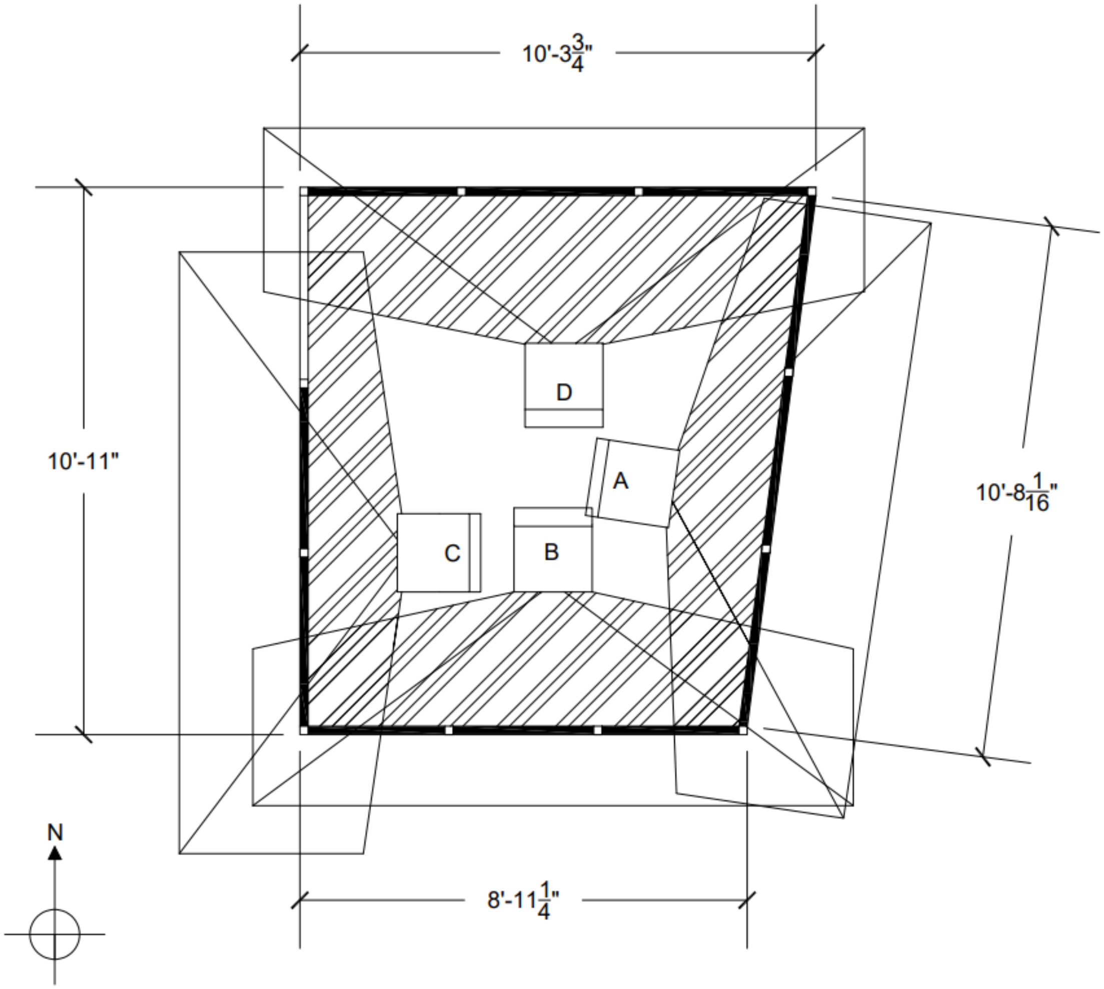
Ceiling Plan - Option #2 Projector Placement



This projector layout enabled all the walls to be fully lit without any gaps and managed to keep the center of the room open for occupants (see Figure 15).

Figure 18

Lighting Plan - Combined Cast Area of Option #2 Projectors



Based on the trajectory and span distance calculations, the open space in the center of the room is adequate for an occupant to stand up without being in direct contact with the projected light (see Figures 16 & 17) which was an improvement over projector Option #1. Here, the projectors are closer to their respective walls while still fully lighting the surface and do not cross one another when projecting.

Figure 19

Section Plan 1 [South] - Cast Area of Option #2 Projectors

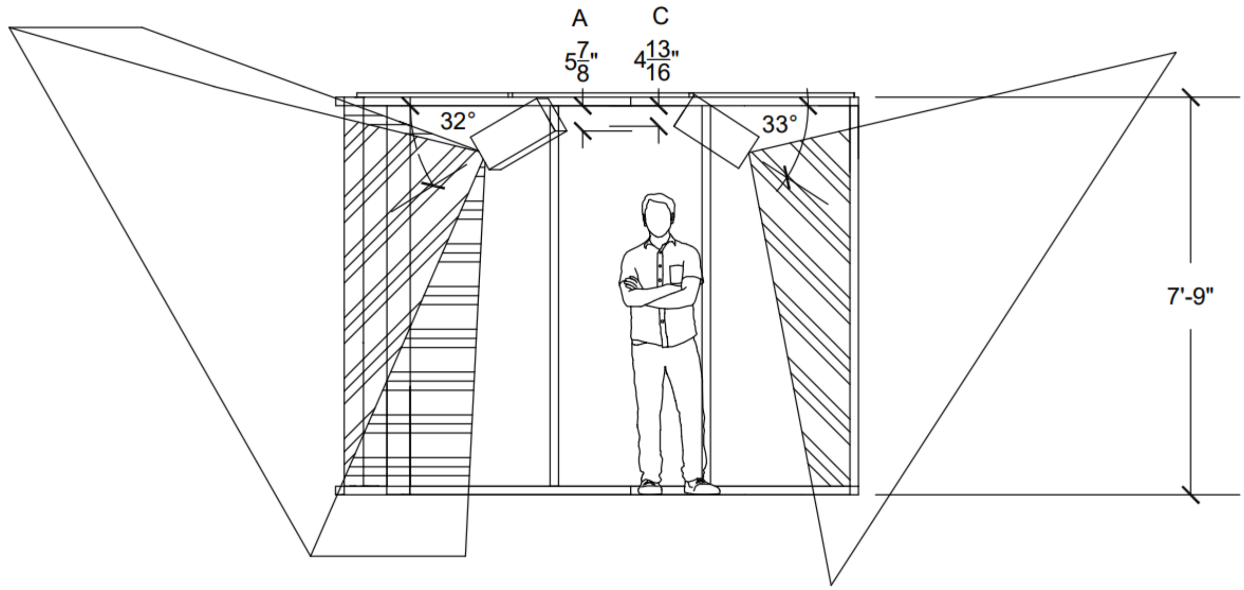
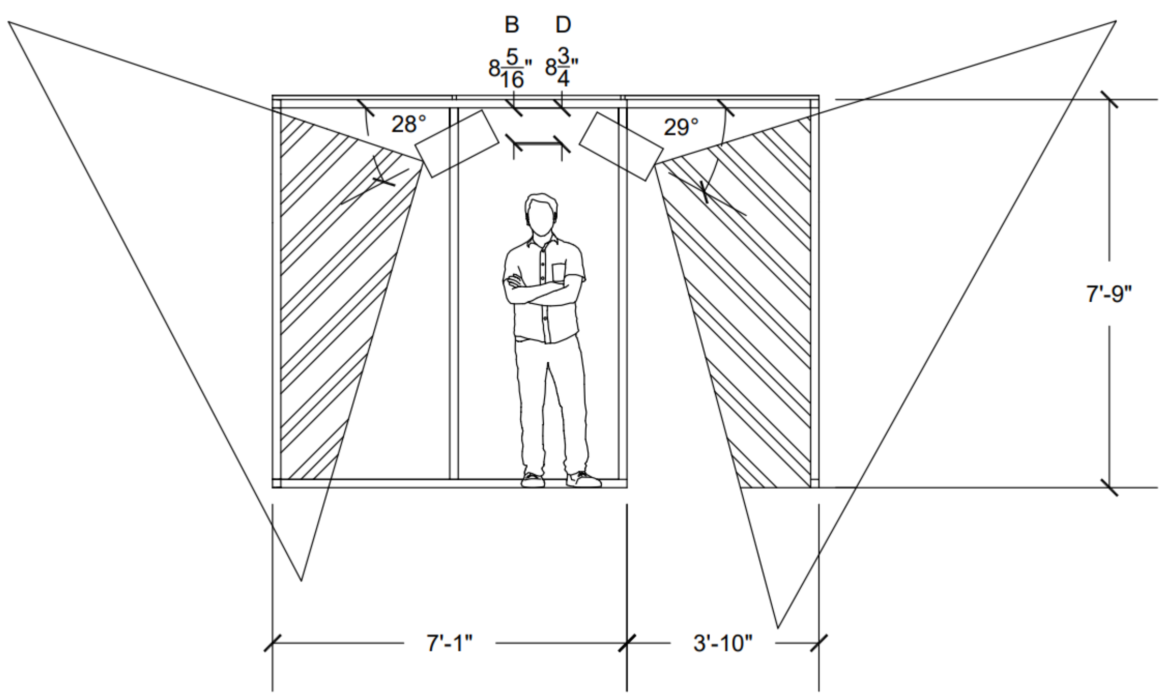


Figure 20

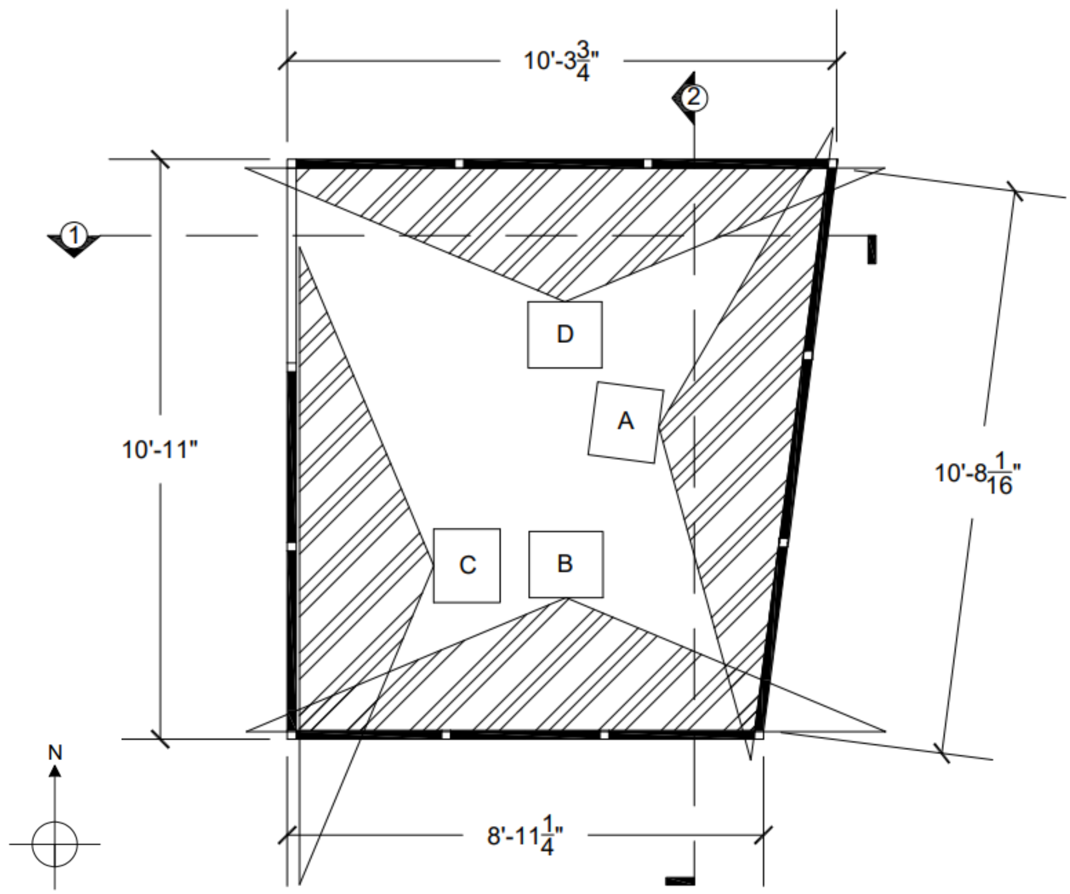
Section Plan 2 [West] - Cast Area of Option #2 Projectors



The third projector option was the JMGO O1 PRO Ultra Short Throw Smart LED Projector. It was chosen for its smaller size compared to Option #2 and its more cost-effective price compared to other ultra-short throw projectors. Due to its heavier weight, however, its lighting plan was designed by having the projectors sit on the floor and project upwards toward their respective walls.

Figure 21

Lighting Plan - Combined Cast Area of Option #3 Projectors



This design plan was able to project onto most of the wall area with the exception of the top of the walls having an 8-inch gap (see Figures 19 & 20).

Figure 22

Section Plan 1 [South] - Cast Area of Option #3 Projectors

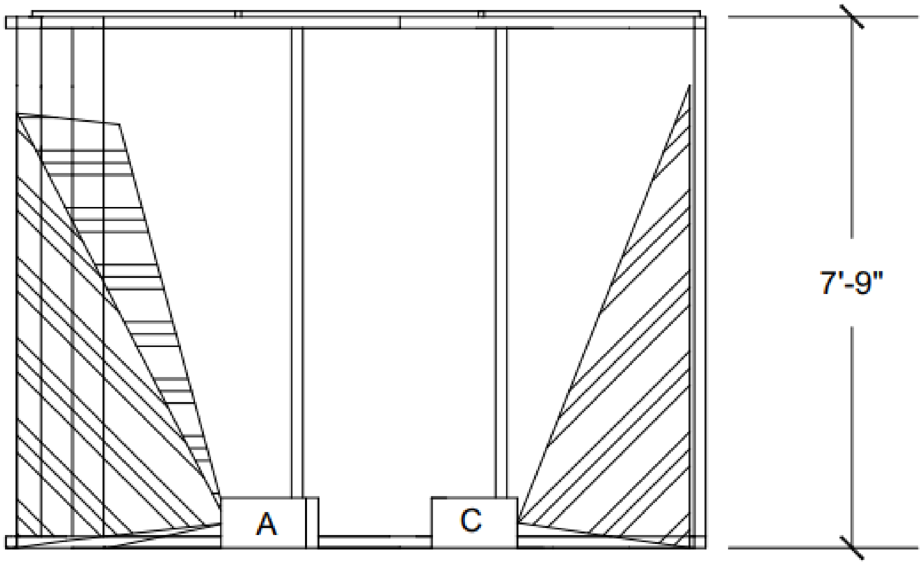
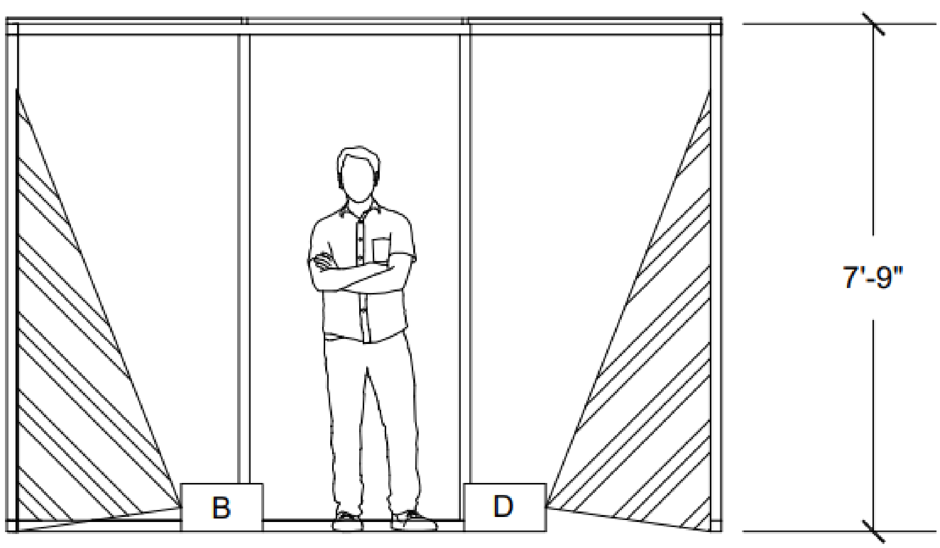


Figure 23

Section Plan 2 [West] - Cast Area of Option #3 Projectors



While this layout is easily adjustable since the projectors are not attached to the frame, it does sacrifice square footage from the overall space for its occupants.

3.3.1.2 LED Light-Strip System

LED light strips were also explored for their cost-effective functionality of lighting the space. It was important to select LED strips that were addressable so that they could be programmed with specific settings for specific scenarios. The advantage of using addressable LED light strips is that, unlike traditional LED light strips, each LED can be individually controlled which means that each LED can be a different color or brightness (Shenzhen MSH LED Strip Company, 2022). This allows for flexibility in creating different lighting effects and patterns for specific occasions within the desired space.

The LED light strip that was selected was BTF LIGHTING RGBW RGBNW SK6812 (see Figure 21). It was chosen for its overall lower cost compared to projectors and its ease of installation for lighting the space. It would be controlled via a programmed Arduino that would change the light settings based on the intended purpose of the room.

Figure 24

Selected Addressable LED Light Strip (BTF LIGHTING RGBW SK6812)

3.3.2 Sound

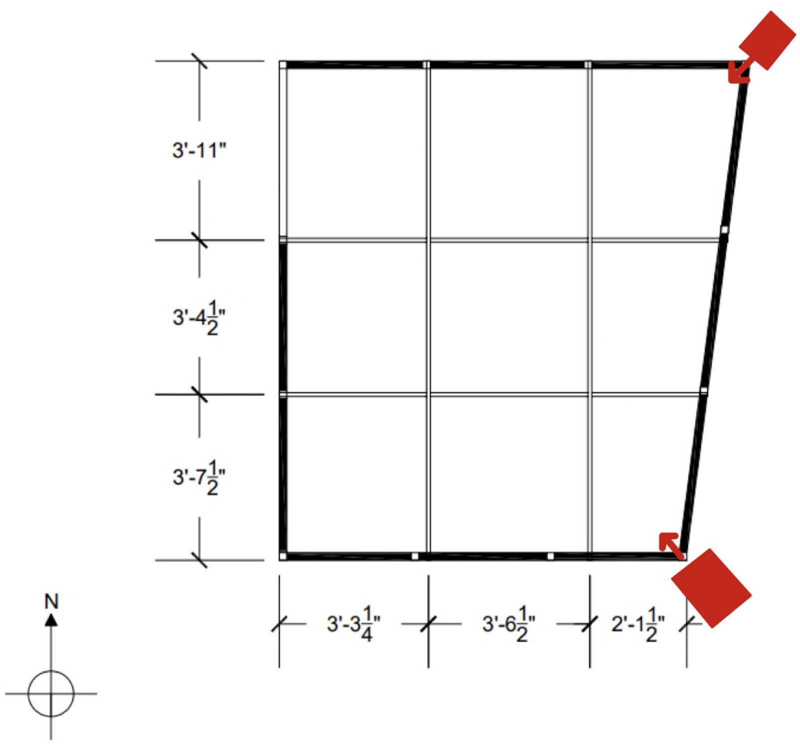
In order to create a space similar to that which might be created in an office relaxation space, we chose to use two bookshelf speakers. Making an immersive and enveloping space, they are placed in adjacent corners to create a symmetrical sound field around the listener. The speakers were not mounted to the frame to avoid vibration and we found that placing them on the ground helped minimize unwanted reflections. After motor placement, the speakers could be placed on stands at ear level of the participant for a more true sound, but for the purposes of this project phase, the floor was sufficient.

Figure 25

Edifier R1280T Bookshelf Speakers

Figure 26

Speaker Placement



3.3.3 Spatial Quality

80/20 aluminum extrusion was pre-selected to be the frame material. It allows for modular assembly, is easy to design additions to, and can be assembled and disassembled in the case it needs to be moved. We initially designed the frame and each joint scheme as shown in Appendix X, but were reassured by 80/20's design team that using t-nuts with predrilled settings would be structurally sufficient for this purpose.

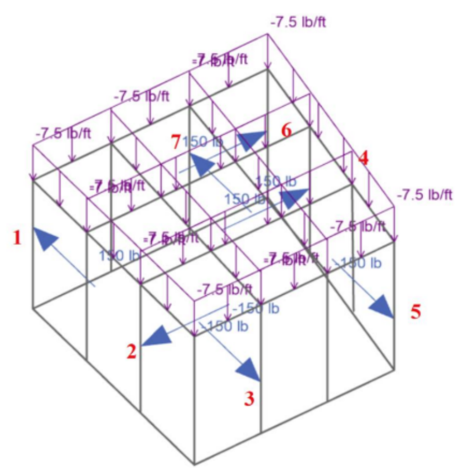
Based on previous research done by Liu and Timpanaro (2021), the unit frame will be built using 80/20© aluminum extrusion with proprietary joint connections specified in the next section. A frame prototype was designed and analyzed in RISA with the following strength parameters:

150lb random lateral load (accidental or spurious fall)

7.5lb/ft distributed load

Figure 27

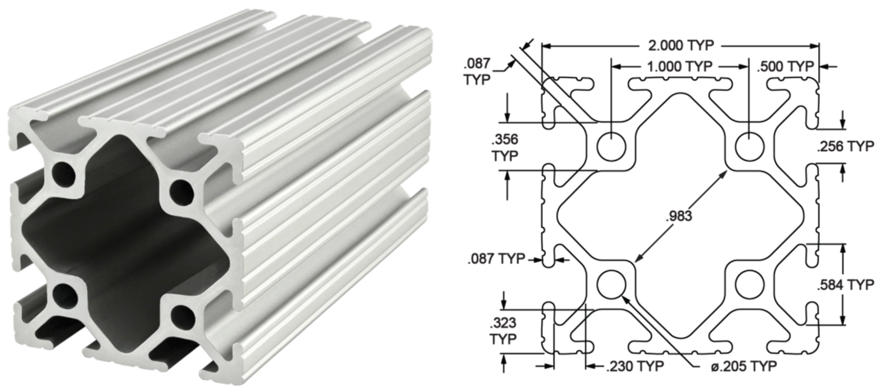
RISA model with dead and point loads (Liu & Timpanaro, 2021)



Using RISA and hand calculations, Liu and Timpanaro concluded that 80/20© #2020 2.00" X 2.00" T-Slotted Profile will be the best option for the structure.

Figure 28

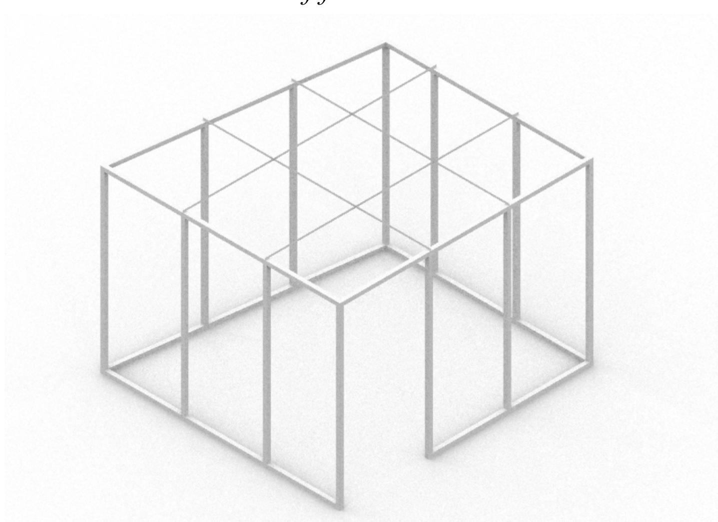
Part #2020: 2.00" X 2.00" T-Slotted Profile



To accommodate for installation, maintenance, and work space, our team edited the original plan to allow for a one-foot gap between the room's walls and frame. See Appendix E for dimensioned plans.

Figure 29

Rhinoceros 3D Model of frame



We were reassured by 80/20's design team that using t-nuts with predrilled settings would be structurally sufficient for this purpose (See Appendix E). For cost efficiency purposes, the ceiling assembly uses #1010 1.00" X 1.00" T-Slotted Profile. It was decided that there would be no direct weight hanging from the ceiling and these members would only hold the four walls together.

3.4 Prototyping of the Interactive Room

Prior to purchasing and construction, a frame and mesh system was prototyped using ⅛" plywood and string to physically conceptualize the mechanical system. The structural frame is to hold all design components (motors, lights, etc), and also hang the fabric mesh which will be a finishing and projection surface. Modeled in Rhino (Figure 29), the frame was lasercut at 1/10 scale. Thread was used to understand the shape that each fabric piece could be when held at proposed motor locations (Figure 31). The Rhino model was then updated with a solid form of this shape (Figure 30), flattened, and printed to create a sewing pattern.

Figure 30

Rhinoceros 3D Model of frame with fabric mesh

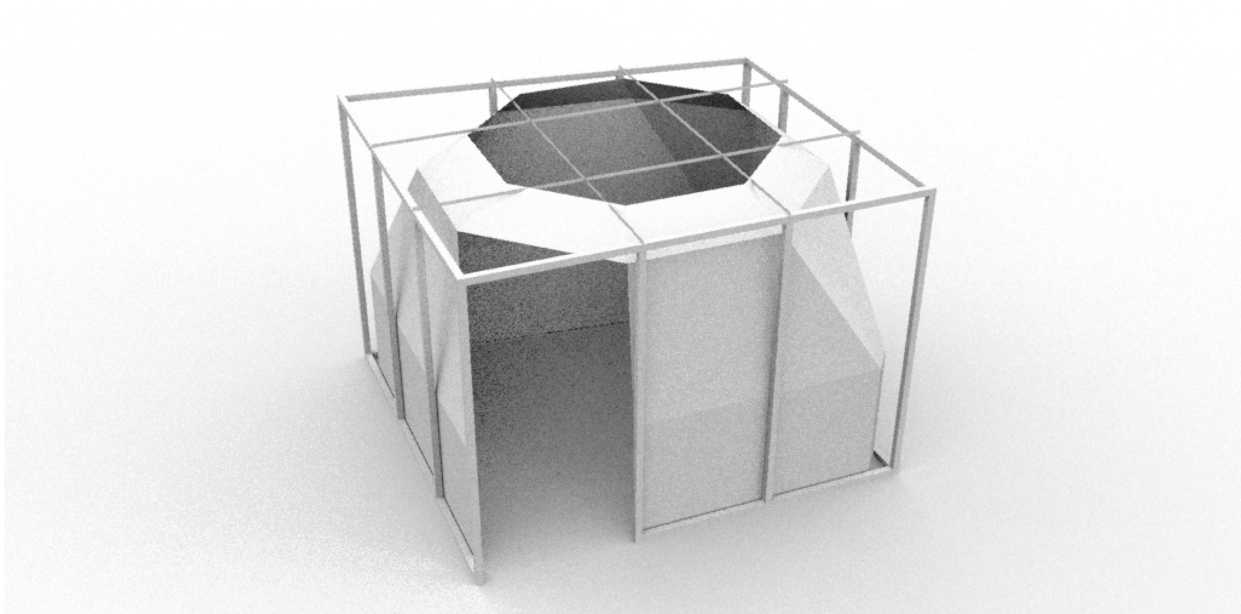


Figure 31

Laser Cut Model

The following panel scheme as prototyped by the previous iteration (Negash, 2022), consisted of a joint that connected four pine frame, canvas wrapped, equilateral triangular panels with lengths of 36.8”. These panels were intended to be operated at the joints by a linear actuator mounted to the frame.

Figure 32

Rendering of canvas wrapped, triangular panel frame (Negash, 2022)

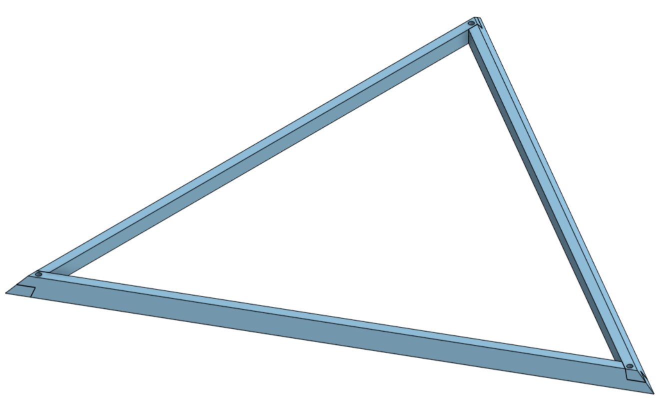
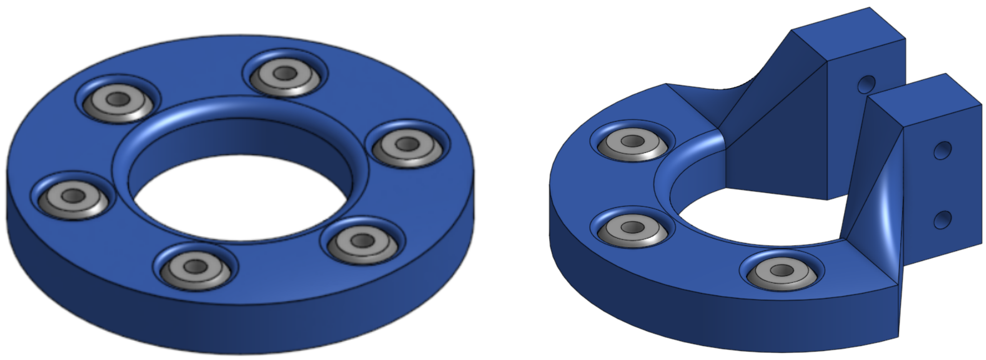


Figure 33

Summer 2022 Joint Iteration (Negash, 2022)



After discussion and examination by our team, when assembled into a multi-piece wall, this joint scheme was determined to be over-constrained and not manipulable enough as we sought to create a seamless, continuously variable space. Having three points of movement on each triangular piece at the designed size (which was governed by the number of motors the budget allowed), made it so 6 panels needed to move together when each joint was manipulated. This can be demonstrated by manipulables such as magnetic triangles (PicassoTiles®). 6 panels covered nearly the entire wall, limiting the wall to only move at one point.

Our iteration of the wall construction utilizes a 4-way stretch spandex fabric, forming a visually uniform and omnidirectional surface. Stretch fabric also creates a visually consistent surface with size variability, an important aspect in changing the space with minimal interference to the participants' awareness. This fabric is then "puppeted" by linear actuators mounted on the frame and attached to the fabric with string. As shown in Figure 34, thread anchored at points where motors could be easily mounted created a template for where seams would provide good structure and minimize non-uniform pull and wrinkling in fabric. This was proven a successful scheme with scale prototyping.

Figure 34
Fabric connections

A major limitation of this stretch fabric scheme was the construction process. As visualized below, the 3D Rhino model was translated into a 2D pattern quite easily (Figure 35), and each piece cut and sewn. Using the stretch constant This pattern was printed to scale using a plotter printer. Dividing larger pieces made construction quite manageable, but as a slippery fabric is sewn, it gets off track little by little, creating much error at the end of a large stitch. We found that pinning seams approximately every 3 inches and not making stitches larger than 30 inches minimized this error.

Figure 35

2D sewing pattern for mesh

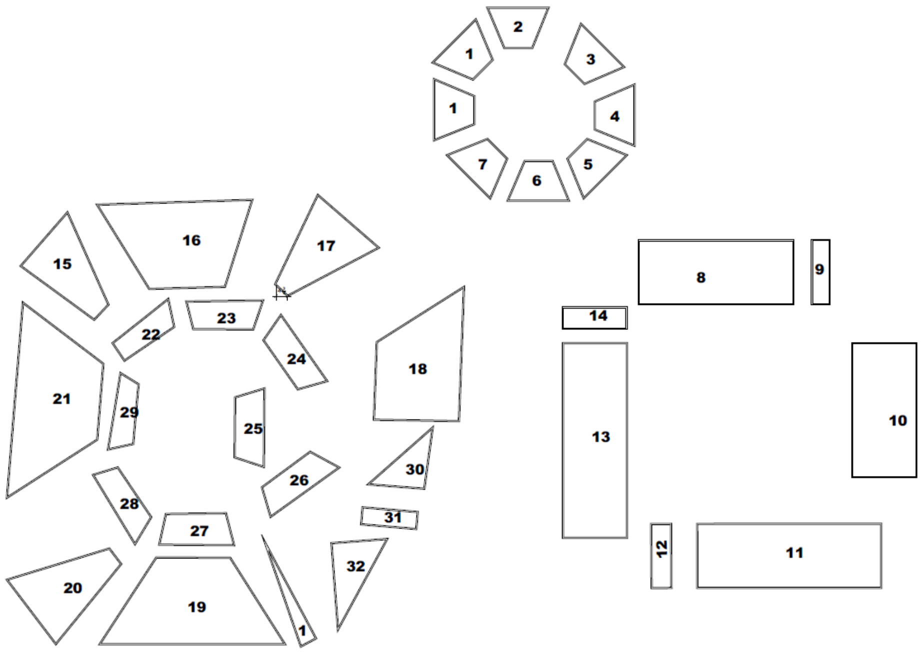


Figure 36

Sewing process at 3 point joint

Figure 37

View upwards of mesh prototype when hung

Figure 38

Mesh prototype hung

Through prototyping the mesh, the 60% scale that we decided to cut the spandex to and estimated that it would be able to compensate for was sorely proven incorrect. (See Section 3.4.1 for spring constant calculation). If this were to be remade, this fabric should be cut to at least

85% of full size in order to be able to stretch to 100%. This part is very experimental though with stretch values not being precise. Creating a small-scale model would be wise.

3.4.1 Actuation System

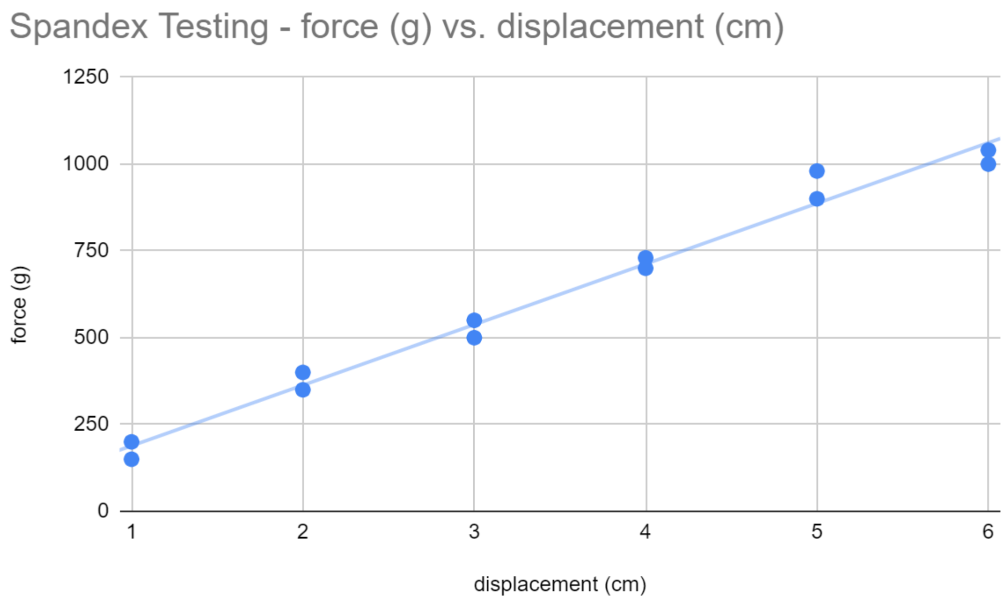
Following the decision to move ahead with an omnidirectional mesh design, the room required a motor design that could be addressed using a microcontroller. Using the calculations in Appendix 1, it was calculated that the entire mesh system would weigh about 17 pounds. The spandex spring constant was also tested using a spring scale and meter stick. The graph below shows the distance a given point on the fabric has moved as the force changes. The spring constant was less helpful of a value than the approximate stretch given a force. We decided to plan for more than 6 inches of stretch between the smallest and largest room setting. If 1000 gram-force (9.8N) gave us about 6 inches of stretch, we would want much more force to reach 12+ in of stretch.

Figure 39

Force vs. Spandex Stretch testing

Table 4

Spandex Testing



Using this approximation, we moved forward with the following motor specification requirements:

Force: 66N

Speed: N/A. Observed that slower draw requires less force for equal distance.

Stroke Length: 20+ in.

In selecting motors, cost efficiency and safety factors forced us to choose quite large motors. Steppers and servos with our required torque and holding torque ratings could cost up to twice that of linear actuators. We also wanted to ensure that any future project iterations would still be able to utilize them and that any unexpected behaviors in the mesh could be addressed with extra power. Linear actuators with a higher force are more economical and will still provide movement in the direction we need. Actuators with the stroke length we desired though are not available off the shelf with force ratings below the magnitude of 100N. This design constraint brought us to select a very powerful motor. See Appendix A for the linear actuator specification sheet.

Figure 40

Vevor 20in Heavy Duty Actuator

3.4.2 Frame Installation

The 80/20 Frame was received in pieces labeled A-P. For safety and assembly purposes, three people are needed to hold and assemble. We assembled it beginning with the walls laying flat on the ground, similar to traditional wood frame construction techniques. After raising the walls, they were connected to each other at the floor and ceiling levels using the slide in t nuts. This stage in construction was quite unstable, and having two people to hold pieces and one to install was important. The ceiling pieces were then secured in place. For disassembly, we recommend removing the ceiling first, then pulling each wall down and placing it on the ground.

Figure 41

Walls built prior to attachment of ceiling

3.4.3 Custom-Built Motor Mounts

In this section, we discuss how we developed our own mounting solutions and parts for the linear actuator motors through inspiration from on-the-market products and iterative design. This process led to the manufacturing of 3D-printed motor mounts that were used to set up the PEACE space.

3.4.3.1 Motor Attachment Inspiration

Once motors were selected for the space, we needed to develop an attachment method for them onto the frame. Since the linear actuators would point inwards toward the space, their attachment would be perpendicular to the vertical frame studs. This meant solving two concerns: what type of device would hold them and how to securely fasten that device onto the stud frame.

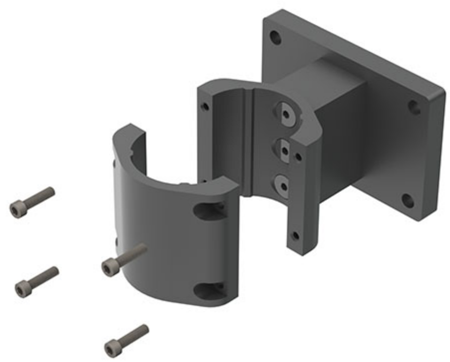
To answer the first concern, we explored clamp-style products that would grip the linear actuators into place. The thought was to clamp down the barrel of the linear actuator and then attach it to the frame using these products. The first products we looked at were pole mounting brackets (see Figures 26 & 27).

Figure 42

Pole Mounting Bracket Product #1 (ErgoMart. n.d.)

Figure 43

Pole Mounting Bracket Product #2 (DecTronUSA. n.d.)



While these products were intended for attaching poles to walls, we thought that if we found the correct dimensions for the intended linear actuator, we could simply purchase and use them to hold the linear actuators to then place them all around the frame.

Trying to find an existing clamp with adequate dimensions for the intended linear actuator, however, proved to be challenging. This was due to the unique geometry of the linear actuator's barrel diameter which was tear-drop shaped and not perfectly round. This meant that there would be a gap when clamping it down using any on-the-market products since they are intended for circular poles.

As a result, these products gave us the inspiration and idea to design and produce our own custom motor mounts and parts using 3D printing.

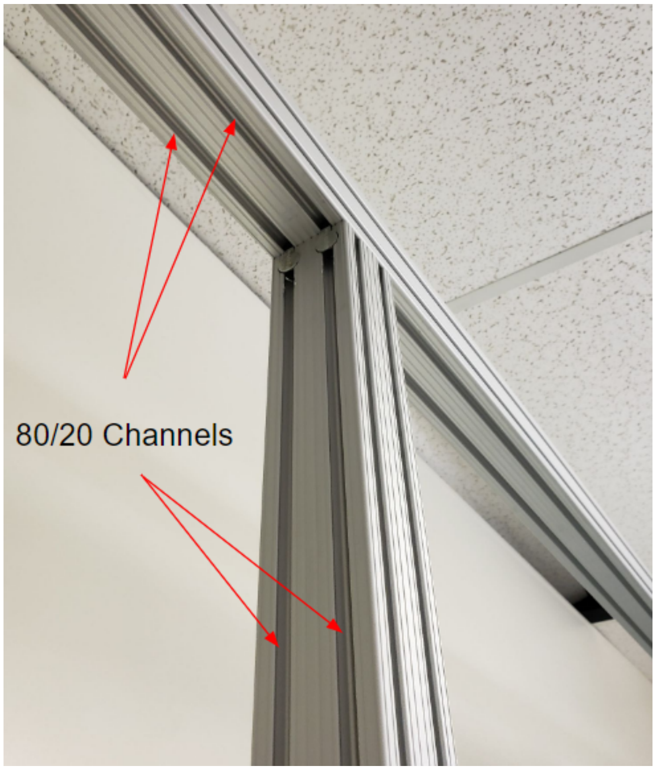
<u>3.4.3.2 Design Development & Prototyping</u>

Before designing the bracket that would hold the linear actuator, we wanted to first explore solutions on how to connect the device itself to the frame, regardless of the clamp design. The idea was that the design of the clamp would be influenced by the connection method to the frame.

When brainstorming these connection methods to the frame, it was important to take advantage of the 80/20 frame profile. This meant utilizing the two parallel inner channels present throughout the entire frame (See Figure 28). The following connection methods highlight this application.

Figure 44

80/20 Frame Channels



The first connection method to the frame involved sliding down button cap screws into 80/20 channels and inserting them through the custom bracket which would then be tightened with hex nuts to secure the bracket into place (See Figure 29). The concept is to use the channels with screws as anchors so that the bracket remains in place. For additional support, a back plate can be placed and connected to the main front bracket using longer screws on each corner (See Figure 30).

Figure 45

Attachment to Frame - Method #1

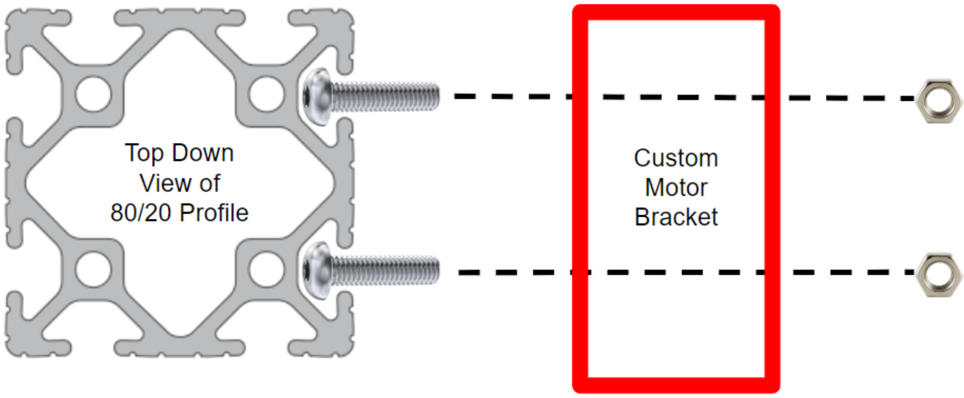
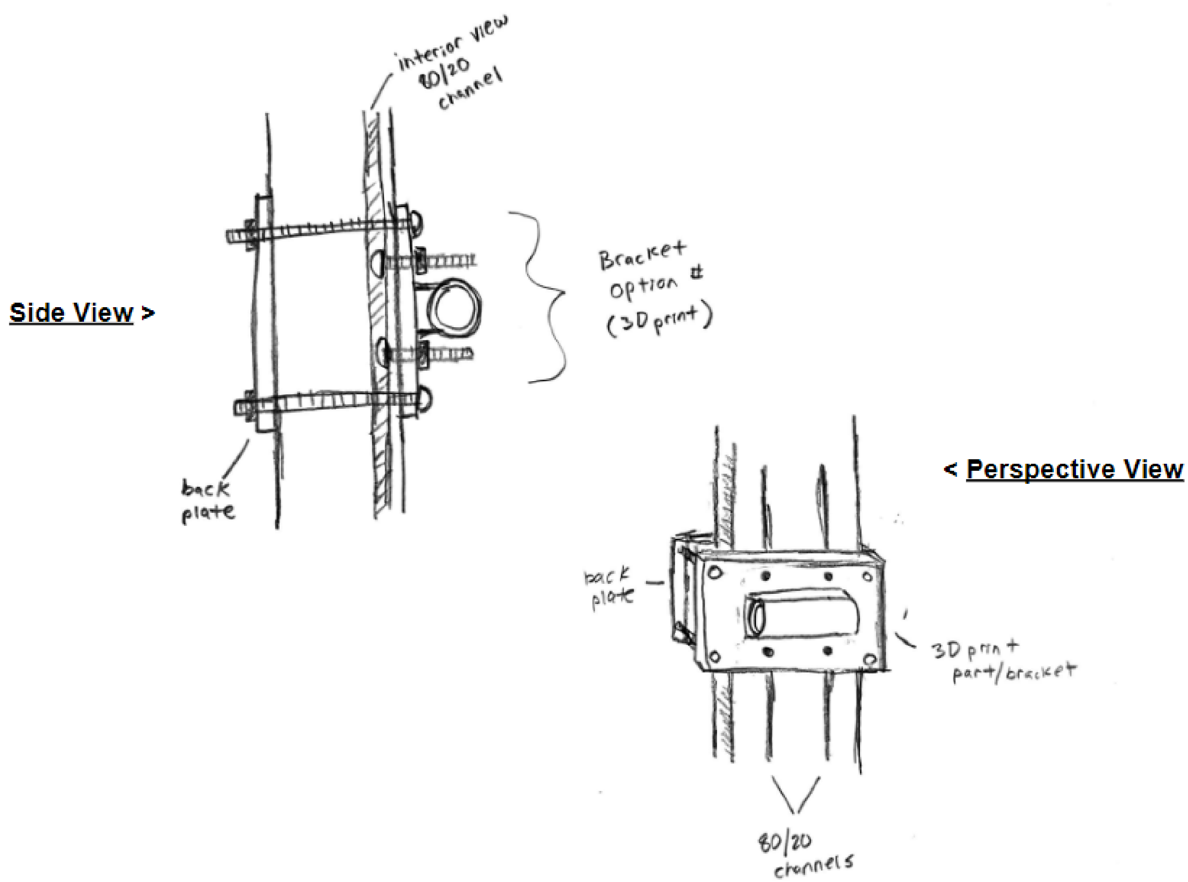


Figure 46

Conceptual Bracket Design Sketches



The downside to this approach is that the entire frame would need to be taken down or disassembled in order to insert and slide the screws down each channel. Since the frame was already constructed, we had to find a new solution to avoid unnecessary reinstallation, while still maintaining a similar connection concept.

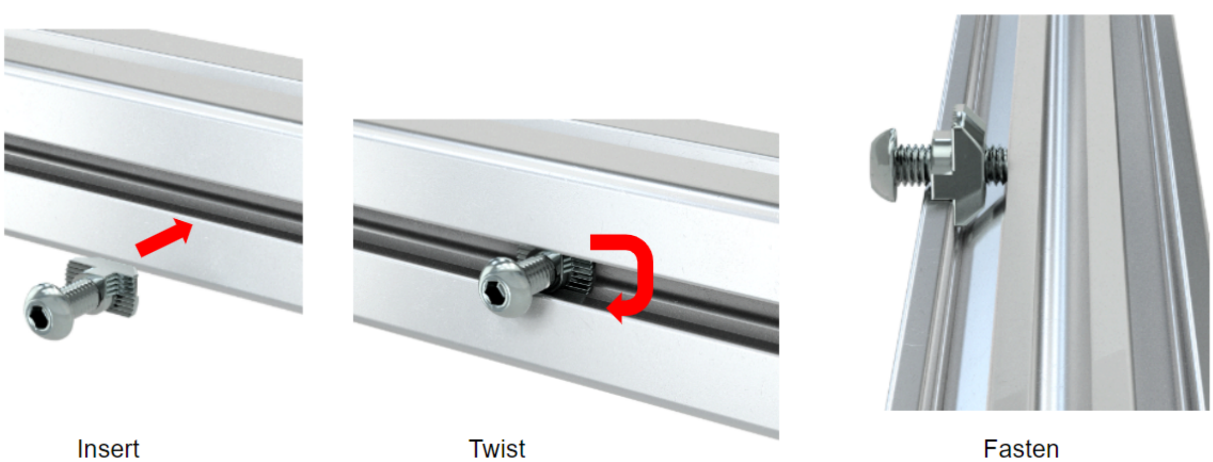
To overcome the disassembly concern, the second connection method utilized drop-in T-nuts (see Figure 31). This method is similar to the first except that instead of using the button heads of screws as anchors, we would use drop-in T-nuts and insert them into the channels to then twist and lock them into place without taking apart the existing frame (see Figure 32). These T-nuts were ordered through 80/20 and were part no. 14162 in their catalog (see Appendix D for required hardware).

Figure 47

Drop-In T-Nuts - Part No. 14162

Figure 48

Attachment to Frame - Method #2

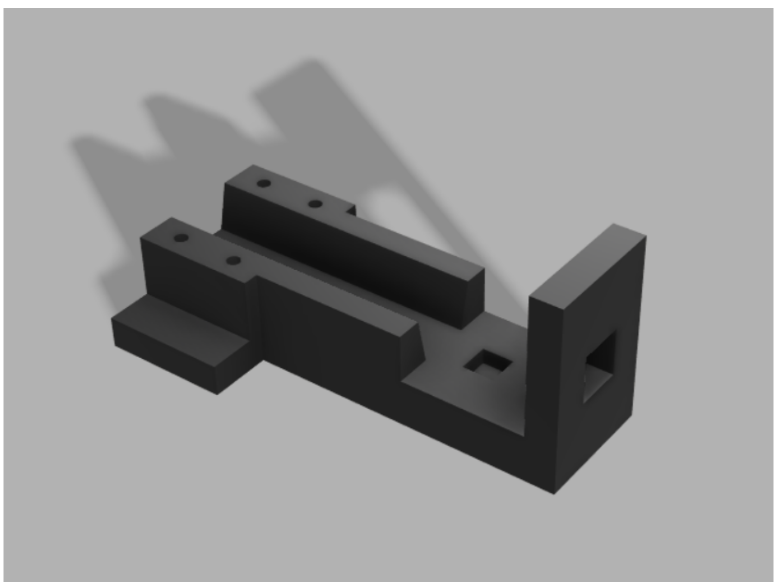


The design of the linear actuator mount, therefore, factored in this connection method. Once the connection method was selected, the mounting assembly parts were designed using Autodesk Fusion 360 and then tested by 3D printing them using a Creality Ender 3 S1 printer. The mount assembly consisted of two separate parts: the bracket mount and the clamp.

The bracket mount (see Figure 33) served as the place where the linear actuator would sit and be the contact point to the frame. Because of this, the bracket mount was designed with extruded rails on each side to prevent the linear actuator from shifting around or falling out. In order to prevent the actuator from slipping laterally within the mount, a back plate was added. This back brace also became a type of locking mechanism once the actuator was inserted.

Figure 49

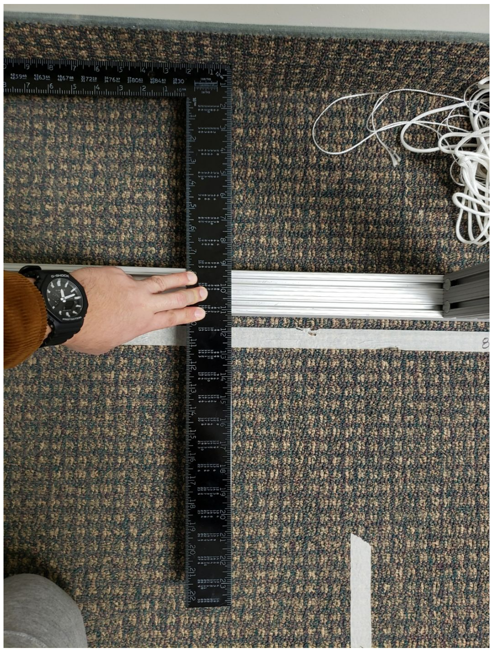
Bracket Mount Model for Linear Actuator



When the installation of the frame was completed, it was noted that there was valuable space between the erected frame and the walls of the room (see Figure 34). Since we wanted to maximize the overall space within the room, we addressed these gaps by creating two variations of the bracket mount that would only vary in extrusion length: one denoted as SMALL (which was the original model created) and the second denoted as LARGE (see Appendix D for complete dimensions of each part). This would increase the volume of space available for the room since the actuators would sit further back from the frame, taking advantage of the gaps.

Figure 50

Example of Available Depth Between Frame & West Wall



The second variation of the bracket mount (LARGE) consisted of extruding the back end of the original model (SMALL). Due to this longer extrusion, this type had to be separated into two pieces: the extended bracket mount and the back brace (see Figures 35 & 36). This was done so that the maximum length could be achieved without exceeding the bed size of the 3D printer. Once printed, these two parts would be connected using 2-inch screws and tightened with nuts (see Appendix D for a complete assembly guide).

Figure 51

Extruded Bracket Mount - LARGE

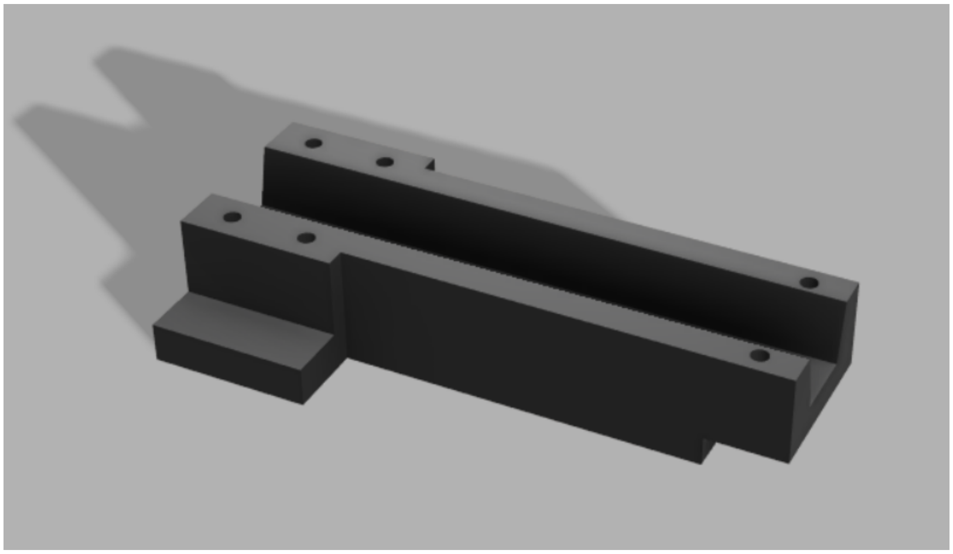
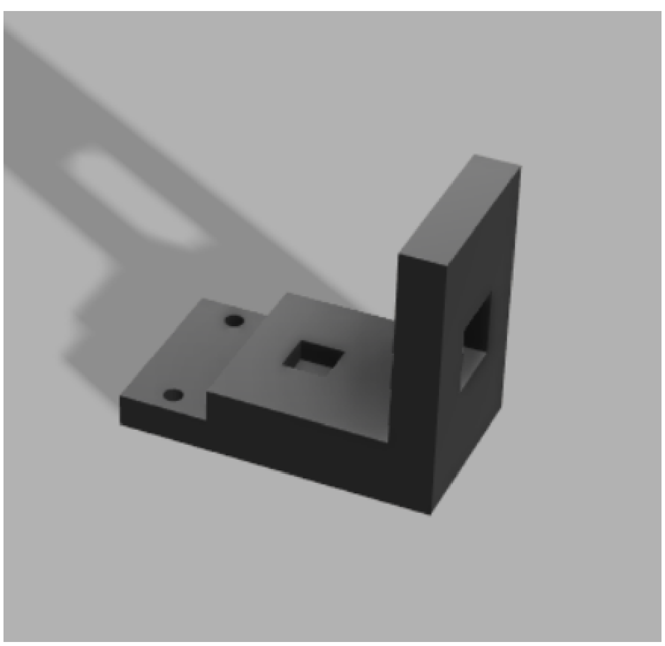


Figure 52

Back Brace for LARGE Mount Type



Since each side of the frame had varying depths, it was important to distinguish which walls received what type of mount. Table 3 lists these lengths with the corresponding mount type assigned.

Table 3

Available Depth & Corresponding Mount Type per Wall

Wall	Depth (in.)	Bracket Mount Type
North	7.5	SMALL
South	7.0	SMALL
East	14.0	LARGE
West	9.0	LARGE

After both variations of mounts were created, the clamp was then designed (see Figure 37). Since the bracket mounts only differed in extrusion lengths, the clamp was compatible with both types of mounts. The clamp would enclose the actuator and tighten down both the actuator and the mounting bracket to the frame. Assembled together, the clamp and bracket mount produced a secure and tight fit for the actuator's unique body shape (see Figure 38).

Figure 53

Motor Mount Clamp

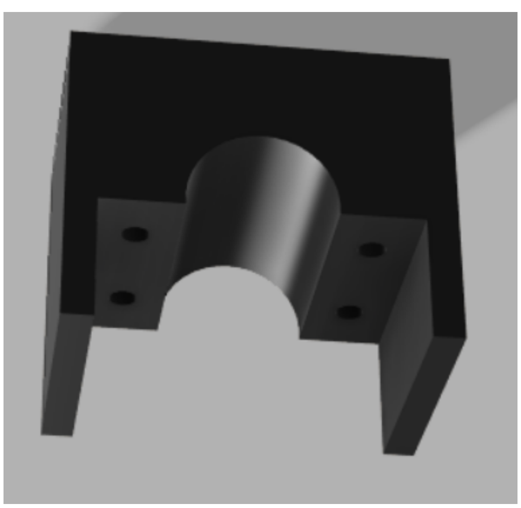
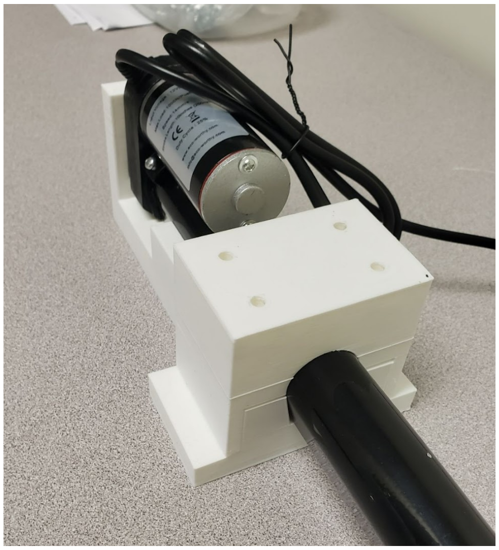


Figure 54

Side Profile of Clamp Connected to Bracket Mount



The plan was to have 3-1/2 inch screws go through both the clamp and the mounting bracket and connect directly into the 80/20 channels using the drop-in T-nuts at the end of the screws. This meant that the clamp would not be able to separate from the bracket mount without uninstalling the entire assembly. This provided extra support and rigidity to the entire assembly once it was attached to the frame (see Figure 39).

Figure 55

Testing Motor Mount [SMALL] on Frame

3.4.4 Microcontroller System

The dynamic wall system is split into five sections, each with its own microcontroller, power supply, and breadboard. We designed the system to operate at full expansion with 37 motors, and sized devices accordingly. Each motor requires 3A of power (5A for good measure), with 40A power supplies able to handle eight motors and 30A, six. Each Arduino also requires extra power, which we handled by adding a 5A switch power supply. The motor controller we chose is a BTS7960 43A High Power Motor Driver Module for Arduino. This can control up to two motors. Three 40A and two 30A power supplies provide power to these and the motors. See Appendix B for wiring diagrams and naming key.

While we did not create a script for the motors in the stage of this project, we planned for the motors to move in chunks, whether that be whole walls or levels (top/middle/bottom). This may be adjusted in the tuning of the space and motors re-paired in motor controllers. See Appendix B for a diagram of which motors are paired.

See Appendix A for Specification Sheets of all electrical components.

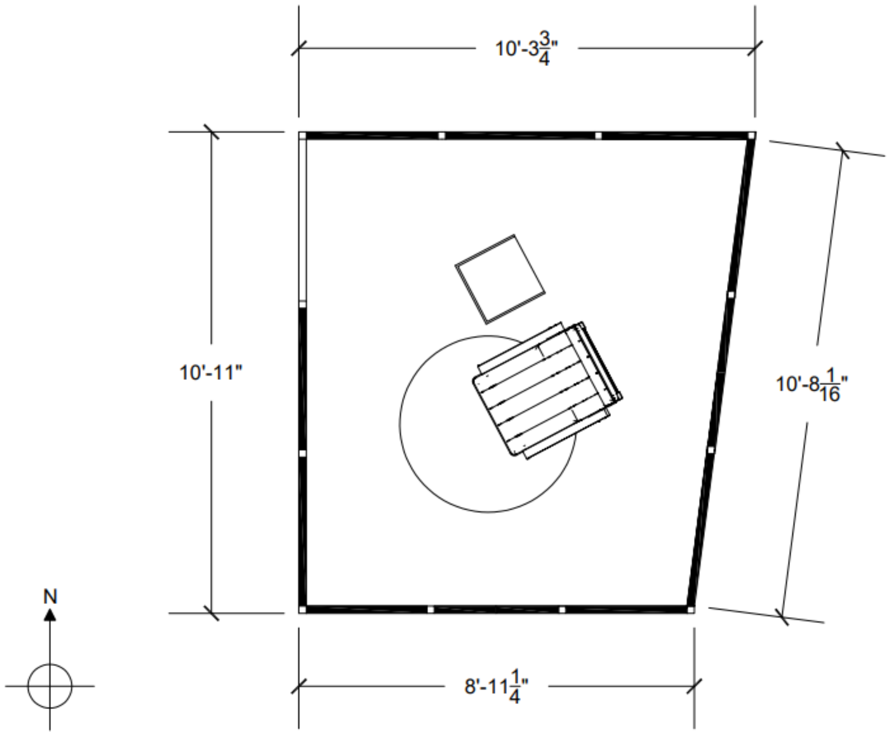
3.4.5 Furniture

Furniture selection and placement can significantly affect the functionality, flow, and aesthetics of a room. Furniture was thus selected with the goal of creating a testing space that is both comfortable and casual for participants while maintaining a low budget. Three main pieces of furniture were chosen to create this environment: an armchair, a side table, and a small area rug.

The IKEA POÄNG armchair was selected for its relaxed and cost-efficient price. Participants can recline for a more comfortable position or sit up closer to the side table for writing-based activities. It is oriented facing southwest. Similarly, the Mainstays End Table was also chosen for its low price and provides a surface for participants to write or perform other activities. Finally, the Wayfair Basics Area Rug was placed in the center of the space to provide a more relaxed setting.

Figure 56

Furniture Layout within Designed Space



4. Methodology and Data Pipeline

The main methods we used to design and develop the experimental tools during this project was focused on how to determine stress levels from the subject. This chapter focuses on how we approached, researched, planned, and executed the process of designing the experiment, We explained our experimental design approach and our timeline. We broke down what and how we tested our objectives. We document our multiple iterations for a data pipeline. We do this by showing how we collect data from different technological metrics and going about properly cleaning and storing them.

4.1 Research Questions and Objectives

We went into this experiment hoping to create a system of experimentation that was general enough that it could observe the effect many aspects of the room have on an individual's emotional state. In order to design our system we focused on using light and sound to influence an individual's emotional state. Specifically, our objective is to develop a data pipeline that could help test the hypothesis that pink noise and warm light reduce stress more and promote more positive emotions compared to standard white noise and cool light. We hope that through the experiment we designed future teams will be able to test each lighting with each noise in an effort to isolate each variable. In order to ensure that we accounted for all aspects of the design we looked at:

- What physical characteristics were important to observe?
- What should the system's relation to the room be?
- What would a generalized experiment look like?
- What were the sources of data we would be collecting?
- How should data be cleaned, synchronized, and stored?

4.2 Experiment Design

Our goal for this project was to create an experiment that collected data on how a participant reacts to the stimuli in the built environment. We specifically utilized the example of light and sound on a participant's stress levels while we designed the experiment and built our data pipeline. The example experiment we designed plans to test this by placing a participant in a set environment and having them perform a single task. One of the two lighting options, warm and cool, and one of the two sound options, 250 Hz at 50 db and 532 Hz at 20 dB, will be randomly chosen and used over the course of one session. We are collecting data in the form of a Questionnaire which will give us a .csv file, O2 ring which will give us a .csv file, a EEG device which will give us an .h5 file, and video footage which will be used to verify data in the form of a .mov file. The data will then be put into our data pipeline to be cleaned and uploaded to the database.

4.2.1 Timeline

Table X

Experiment Phasing

	Setup						Main Experiment	Exit Check	
Time (min)	0	2	3	5	2	3	12	3	
Elapsed Time	0	2	5	10	12	15	27	30	30
Participant Task	Participant Enters Space	QUALTRICS Informed Consent	Fit-Out with EEG and O2 Ring (Time 0)	Onboarding Survey + PANAS Questionnaire (iPad)	Study Instructions	Mindfulness Exercise	Free Choice Activities: Legos, sudoku, coloring pages,Word search, crossword	PANAS Questionnaire (iPad)	Participant exits space
Operator Task						Final Equipment Check	Monitor Equipment (EEG, O2, Video Footage)		
Light	Normal						L1S1/L1S2/L2S1/L2S2		
Sound	Normal								
Data Phases	Phase 0 (Pre data collection)			Phase 1 (During onboarding)		Phase 2 (Mindfulnes s ex.)	Phase 3 (With Independent Changes)		

We created our experiment so that it could be easily modified to test a number of factors within the finalized physical space. This experiment models what it would look like to test how the sound and lighting in a space can affect a participant's mood. Specifically looking at a participant's stress while in rooms with cool or warm lighting and 250 Hz at 50 dB and 532 Hz at 20 dB. We did this by assigning a participant to a room that has been randomly given one of the two sounds and one of the two lightings. The goal was to create an experiment that could see if a trend forms between participants in a given room and under which conditions they show the most relaxed state. We collected data from four sources: an EEG device, an O2 ring, a camcorder, and a questionnaire. The electroencephalography (EEG) device was chosen to collect brain waves within a range that indicate stress and focus. The O2 ring was chosen to take each participant's heart rate as well as the exact time the experiment took place. The camcorder was chosen to help verify data results. The questionnaire was chosen to allow the participant to self-report their emotional state before and after the experiment and follows the Positive and Negative affective Schedule that contains questions certified in the field of psychology to give values for the given moods. The questionnaire, following the PANAS scale, was given once at the beginning of the experiment and once at the end of the experiment. This helped us gauge their emotions before entering and to control for outside emotions and isolate the specific affect our room had on the participant. Each experiment should end with: A PANAS score for entering and exiting the experimental space, a report of their heart rate throughout the experiment, and a report of their alpha and beta brain waves over the course of the experiment. That data is then put into a file named the participants identification number and uploaded into the pipeline with a summary of any anomalies or comments the experimenter wants to share.

4.2.2 Stimuli

The following light and sound stimuli variations were chosen to be applied in the experimental space:

Table X

Lighting Variations

	Correlated Color Temperature (Kelvin)	Illuminance (foot-candles)
L1	3000K	25 fc
L2	6000K	50 fc

Sound Variations		
	Noise Correlated Color	Power (decibels)
S1	White	40-50 dBA
S2	Pink	40-50 dBA

4.2.3 Task

In conducting the experiment, participants would be given a choice to perform one or more simple activities during the brief timeline of data collection. Examples of these task options include playdough, LEGOs, or a coloring book. The intent of offering a choice between simple tasks like these is because the main goal in this project's hypothetical experimentation is not to actively measure specific performance parameters such as reaction time or memory. In a real work-rest space like our iteration of the PEACE space replicates, the goal is not to complete a task under pressure, but rather to optimize relaxation and energy restoration in a short amount of time without sacrificing cognitive performance. The range in quantitative and qualitative data collection methods was designed to allow measurement of this approach.

4.3 Data Pipeline

One of the key objectives of our project is to create a data pipeline. Specifically, that entails our data collection and analysis be part of its own design process. Below we break down our design goal, data producers, what happens in our data pipeline, and our data consumers where the data is loaded and stored. We also reveal our different iterations for design.

4.3.1 Data Producers

These data produces are what generate raw data for the extracting phase of the pipeline and the overall experiment:

Table X

Data Producer	The Type Of Data Produced
Camera	.mov
EEG Open Signals Headset	.csv
O2 Ring	.csv

PANAS Qualtrics Survey	.csv

4.3.2 Data Pipeline Design

After going over the needs of our experiment our team decided on EtLT. In this plan we would be extracting data from our data producers. Our first transformation would do several things. It would ensure anonymity of the participants by categorizing based on random participant ID's. We would clean the data for potential data recording errors. Lastly, we would put all data for one participant in a single csv file. The loading phase would be data storage. Then we would be able to transform for data visualization. In the last transformation we would be able to compare our participants' data and decide whether or not to accept our hypothesis.

4.3.3 Data Collection

The goal for data collection was to obtain data that would allow the team to determine a participant's stress levels. The objective was to be able to take data collected from our three primary producers from each group assigned to a room type and compare and contrast the differences from each room type. The group took data from three different data producers, including the EEG, O2 Ring, and PANAS survey, as well as a video documenting the experiment.

4.3.3.1 EEG

The group used a Wet Electrode EEG headset with 3 nodes to collect data from different brain waves produced by the participant. . The two shorter nodes go anywhere between the two temples and the forehead, with the device's grounding node on the neck. The software utilized is called OpenSignals. In the experiment, the EEG uses a 300 hz sampling rate to ensure a detailed but wide scope of data is being recorded. The EEG is able to read multiple types of brain waves: Alpha, Beta, Delta, Gamma and Theta. Each follows a specific frequency range and a different association for the firing of neurons (Abhang et al., 2016).

Table X

Characteristics of the Five Basic Brainwaves

Type	Normal Levels	High Levels *Association*	Low Levels	*Hertz*
Alpha	Relaxation	Lack of Focus, Meditation	Anxiety, Stress and Meditation	8-12
Beta	Focus-related tasks	Anxiety and Stress	Apathetic and depressive moods	Above 12
Delta	Deep Sleep, subconscious tasks	Learning difficulties	Poor sleep	0.1-3.5
Gamma	High level cognitive processing	Happiness	Mental and Learning Disorders	Above 30
Theta	Imagination and sleep	Depressive and Attention Disorders	Anxiety and Stress	4-8

Every participant produces one EEG file. Through the data pipeline, it is analyzed to measure specific brain waves. Because the project uses stress as a measurement for success or failure of its objective, the team is focusing on the Theta(4-8hz) and Alpha(8-12hz) waves described in the table above. The data collected helps to measure stress and reinforce which lights and sounds correlate with reduced stress compared to their counterparts.

4.3.3.2 O2

The O2 Ring is a Wellue product. In the scope of our experiment, once the ring is placed on the participants finger it vibrates signaling it is recording heartbeat. When the experiment is concluded and the ring is taken off the recording is sent to a mobile device in the possession of the experiment facilitator. The app utilized for accessing the data is ViHealth. From there the data for the participant can be added to a folder for the participant. Once the data is collected it will be cleaned in the first transformation before being loaded into data storage.

4.3.3.3 Video

The camera is turned on as the first step in the experiment to account for everything working and to record potential anomalies. The start time is collected by utilizing the camera's timestamp. The start time is noted in the pipeline when other data producers are turned on. The start time of the experiment is used to synchronize the time values collected by the EEG and O2 ring. Once the camera is turned on, the experiment facilitator then ensures that the camera is properly facing the participant. Overall, this measurement is essential in ensuring that everything is working together and helps us piece the data together with real time footage.

4.3.3.4 PANAS

The Positive And Negative Affect Schedule (PANAS) is a research questionnaire used in group studies to measure positive and negative impact. The most basic form of the PANAS test consists of 20 total item scales, having 10 corresponding to positive emotions, and 10 to negative emotions. Each emotion is rated on a scale from one to five to judge the participants' affect. Additional categories, such as serenity, can be added to focus on a more specific category of positive or negative emotions. The PANAS scale was developed in 1998 by researchers at the University of Minnesota and Southern Methodist University and is used widely in group studies. The test serves two purposes in our experiment. It serves as an additional data source to measure the effects of varying characteristics of the room on participants emotional state throughout the experiment, as well as acts as a baseline measurement of the participants emotions before the experiment was conducted, with the ladder acting as a control to prevent 'misinterpretation' of the correspondence of other data collected in the experiment with the current emotional state of the participant during the experiment.

The PANAS scale was used at the start and end of the experiment. The participant took the PANAS test immediately after being equipped with the EEG and O2 ring. The participant then completed the next stages of the experiment, and eventually took it again before completing the procedure. By doing it both times we can see if there is any impact the room had on the participant. Overall, this questionnaire is an ideal way to collect participant emotional data indirectly which ensures more accurate data.

4.4 Data Pipeline Design Iterations

While designing the pipeline, we considered different options to be used for its components. For data storage, we initially considered using services such as AWS's RDS, as well as MongoDB, an open source NoSQL document database project. However, in accordance with WPI policy, we decided on creating a Microsoft Sharepoint through WPI to be used as the pipeline's data warehouse. This site is owned by WPI and allows for the easy authorization of new members.

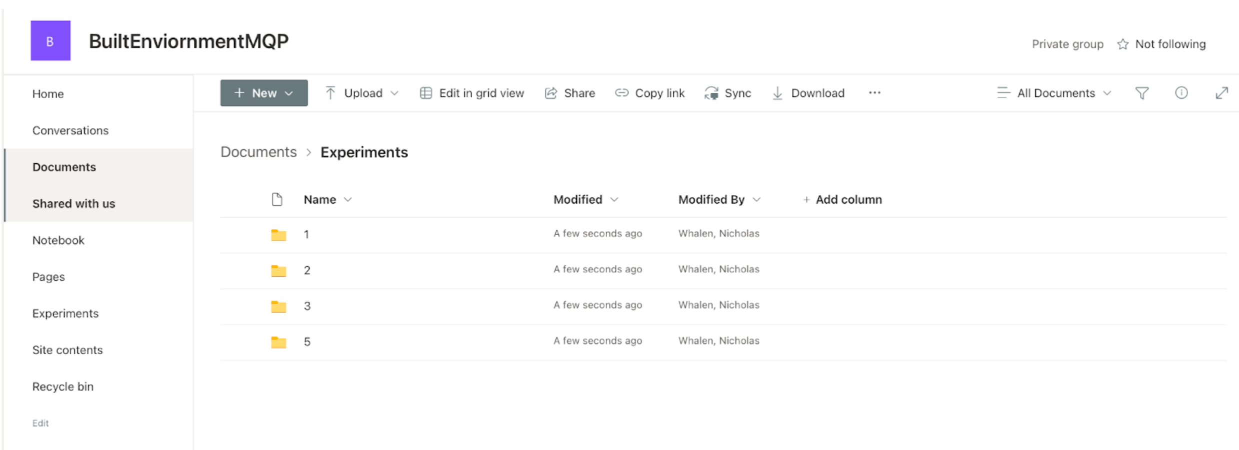
When designing the flow of events for the usage of the pipeline, our objective was to create a clear, concise process that could be completed without the need for extensive technical knowledge. The steps required to use the pipeline are as follows:

1. Compile all data sources (files from O2 ring, EEG, PANAS test, video of experiment) into a single folder
2. Run the program by calling it in the terminal and providing the following command line arguments:
    a. Path to the folder on the local machine
    b. ID number assigned to the participant
3. Prompt the user with questions to write a brief report of the experiment, requesting inputs for prompts such as the names of those who ran the experiment, as well as any notes about the experiment.

Following these steps produces a new folder containing the cleaned O2 and EEG CSV files, as well as their visualizations, and a CSV containing an aggregate of the participant's PANAS score's. A text file is produced containing the name's of the people running the experiment and their notes.

Figure 57

Sharepoint site to serve as data warehouse



4.4.1 Data Pipeline Code

The pipeline was built in Python using Python's standard library, the Pandas and Numpy libraries, as well as OpenSignals' Biosignals' Notebook library. The pipeline works by reading in a folder and iterating over its contents. For every file in the folder, the file name is checked to contain one of three keywords: 'PANAS', 'O2', and '.h5'. Each of these keywords corresponds to one of the data sources; 'PANAS' to the CSV file obtained from the Qualtrics survey, 'O2' to the CSV file from the O2 Ring, and '.h5' to the H5 file produced by the EEG.

To process the PANAS data, a search was performed using Python’s CSV reader to search for rows containing the participant’s ID number, and read them into an array. The data was then averaged for each PANAS category, and written to a CSV output file.

The O2 Ring data is read in using Python’s CSV Reader, and was cleaned and plotted on a graph showing Heart Rate in beats per minute on the Y-axis, and Time in seconds on the X-axis.

The EEG data is read using Biosignals Notebooks from an H5 file into a Pandas DataFrame. The is then cleaned and plotted, similar to the O2 ring

5. Results

5.1 PEACE Project

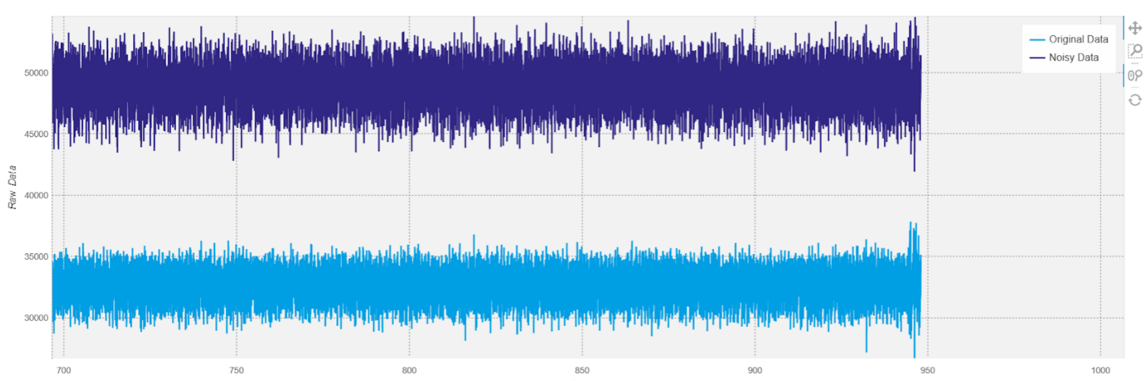
This phase of the PEACE project brought to fruition construction plans and ideas, simultaneously progressing experimental research and opening up the door to product development. Constructing plans from Liu and Timpanaro's work was crucial in prototyping motor configurations and mesh details. Moving forward, the mesh needs to be redesigned with more emphasis on constructability. Stretch fabric does provide the most visually cohesive construction, covering motors and microcontroller systems while diffusing light. The motor system is robust and can move many schemes of paneling, but may benefit from more iterative design, with omnidirectional movement being a focus.

5.2 Experiment Tools and Results

In conjunction with the PEACE space, the data pipeline and its supporting materials allow for the experiment to be run immediately by the project's subsequent team. The team produced a fully functioning data pipeline to allow for the easy and consistent cleaning and storage of the data collected. Cleaning the data is important to provide a concise, consistent result, and eliminate anomalies produced during data collection. Every data source collected from the experiment is organized into a folder labeled by the participants' ID number and then uploaded to the Sharepoint data warehouse.

Figure 58

Cleaned vs original data collected from EEG



The manual designed by the team provides step-by-step instructions for usage of the pipeline, and alleviates the need for computer science majors on the project. The project can instead focus on using data science majors to perform data analysis. To ensure the pipeline's usability, the team ran the experiment using sample participants from within the group, using the manual to guide the experiment. This process helped the team identify areas of the manual that needed further clarification, and improve its overall intuitiveness.

5.3 Findings and Limitations

A limitation for our team was that we collectively did not have a strong data science background. This was the first time we were learning about machine learning and artificial intelligence terms. While we were able to learn as we went, our efficiency was slowed as we took more than the intended time to learn new concepts and faced beginner challenges.

6. Conclusions and Recommendations

6.1 Summary of the Research Result

As a product of the research and development performed in this project, the space needs a final mesh installation and then will be ready to use for experimental research. As outlined in detail in this report, prototyping of the room was a crucial step in ensuring that each feature would perform its task as we intend it to. An 80/20 frame with linear actuators, speakers, addressable LED strips, and an omnidirectional wall system can create and replicate a multitude of environments, all valuable in discovering how emotional states are impacted by architecture. The system built in this project will be crucial in collecting high quality qualitative data on emotional responses and can potentially be adapted to be a marketable product.

6.2 Future Work & Research

6.2.1 Microcontroller System

The integration of motors with biometric readings needs to be fine-tuned with Mechanical/Electrical/Computer/Robotics Engineering expertise. Our design intends for each motor to move independently of one another, ideally with a few overall movement directions (ex. grow larger, shrink smaller, move wall towards/away from participant, relocate center point of room…).

6.2.2 Product Development

We would like to see this construction not only as an experimental space, but also as a product prototype that could be brought to market. Sensory spaces have long been a fixture of elementary schools, but as working from home proves that many people work better in spaces that they are comfortable with, we should develop a way to form these spaces in public spaces and offices.

6.2.3 Projector Lighting & Visual Display System

Future teams can expand on the projector lighting system explored in this project. Due to budget constraints, purchasing all four projectors was not feasible and therefore could not be installed or utilized within the space. The projector selection and projection calculations have been finalized, therefore the next iteration of this project would see the quad projector connection setup to the computer. Once set up, teams could also explore new experiment variables such as surround video paired with the LED light strips and a selected sound to take advantage of the new visual display option from the projectors all synced together.

6.2.4 Prior Data Science Experience

We recommend future teams have substantial data science experience. This is for two reasons. One being to mitigate the problems our team had learning this material. The second being that the last stage of our data pipeline is predominantly data analytics. However, a sole student majoring in computer science could help with optimizing our code and automate the data analytics section of the pipeline.

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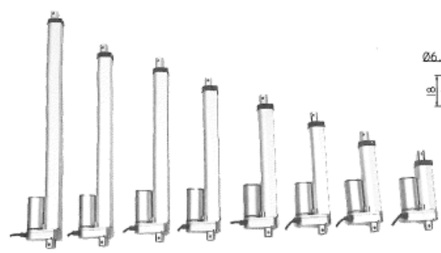
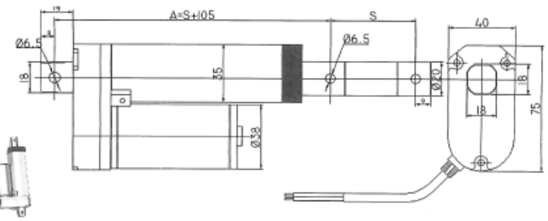
Appendices

Appendix A: Specification Sheets

LINEAR ACTUATOR





SPECIFICATIONS	OK-50	OK-100	OK-150	OK-200	OK-250	OK-300	OK-350	OK-450
Stroke Length	50mm	100mm	150mm	200mm	250mm	300mm	350mm	450mm
Rated Load	900N							
Travel Speed (Max)	10mm/s							
Rated Voltage	12VDC							
Rated Current	3Amps							
Limit Switches	Fixed Inner (not Adjustable)							
Operation Temperature	-20℃ to +65℃							
Protection Class	IP65							
Duty Cycle	25%							
Noise Level	<=50dB							

INSTALLATION

WARNING: 1.The load added onto the actuator must be less than or equal to the rated load of actuator.
2.Install actuator so the force of the load acts in the center of the extension tube and the rear mounting adapter.

1. Mount the actuator by securing the top and bottom mounting holes to two fixed positions. The stroke length of the actuator (e.g.12 inches) and the limitations of the particular application will detemine the location of the fixed mounting positions.

IMPORTANT: Confirm that the two-way movement of the linear actuator is smooth and within the actuator's stroke length after it has been installed. Additionally, confirm that no obstacles exist along the travel path of the actuator.

2. Secure the top and bottom mounting holes of the linear actuator onto the two mounting fixtures using 5/16" diameter bots.
3. Connect the red wire to the positive post and the black wire to negative post of the DC power supply.
4. The operation of the linear actuator should be tested manually after the installation is completed. Users should use caution to ensure that:
   - The travel distance of the actuator satisfies the requirement of the structural design.
   - The extended and retracted limit switches operate normaly (The limit switches should stop the motor when the extension tube if fully retracted or fully extended)
   - If the motor runs too slow or does not give ful force,(1) the power supply is insufficient and needs to be increased or(2) the load being applied to the actuator is too great and needs to be reduced to less than or equal to 225 lbs

Appendix B: Wiring Diagrams for Microcontroller System

Table B1. Wiring Diagram for Arduino to Motor*

Arduino to Motor Wiring				
Arduino #	**Motor Controller ID**	**Arduino Pin Forward**	**Arduino Pin Reverse**	**Motor**
1	A			1
				2
	B			3
				4
	C			5
				6
	D			
	E			
2	F			11
				12
	G			13
				14
	H			15
				16
	I			17
				18
	J			
	K			

	L			
3	M			21
				22
	N			23
				24
	O			25
				26
	P			
	Q			
	R			
4	S			30
				31
	T			32
				33
	U			34
				35
	V			36
				37

**Note 1: Grey cells signify motor controllers & respective motors that have been assigned to Arduinos. Corner motors have not yet been assigned.*
Note 2: See key in Figure B1.

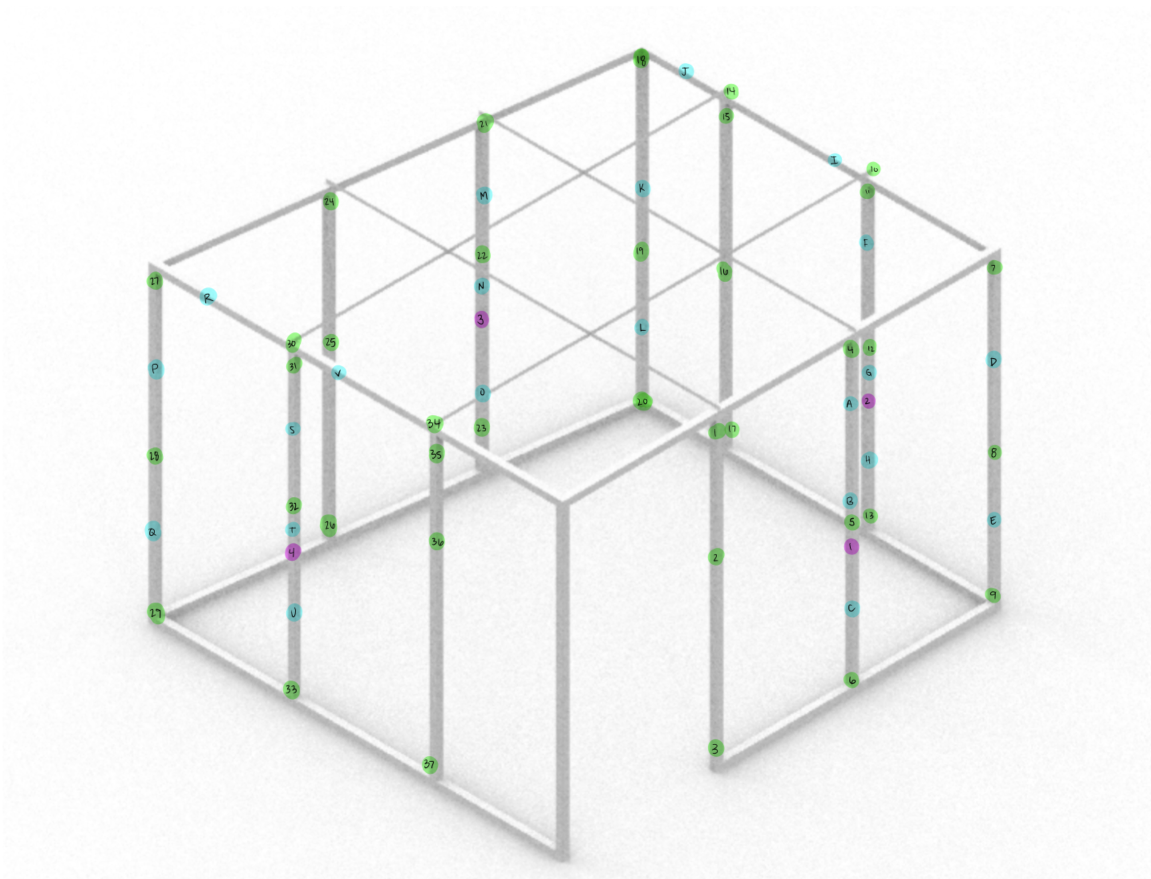
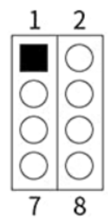


Figure B1. Key for *Table B1. Wiring Diagram for Arduino to Motor*



Terminal wiring instructions

1.Prwm：forward level or pwm signal input,high level valid

2.Lpwm:reverse level or pwm signal input,high level valid

3.R_En:forward drive enable input,high level enable,low level off

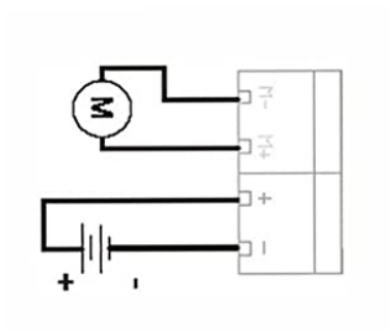
4.L_En:reverse driver enable input,high level enable,low level off

5.R_Is:forward drive side current alarm output

6.L_Is:reverse driver side current alarm output

7.VCC:+5V power input,connected with 5V power supply of MCU

8.GND:signal common ground terminal



Wiring instructions

Methond 1:

VCC is connected to 5v power supply of Mcu,GND is connected to GND of MCU.

R_EN and l_When en is short circuited and connected to 5V level, the driver can work,

L_PWM,input PWM signal or high level motor for ward

R_PWM,input PWM signal or high level motor reverse

Methond 2:

VCC is connected to 5V power supply of MCU,GND is connected to GND of MCU.

R_EN AND L_EN short circuit and input PWM signal for speed regulation

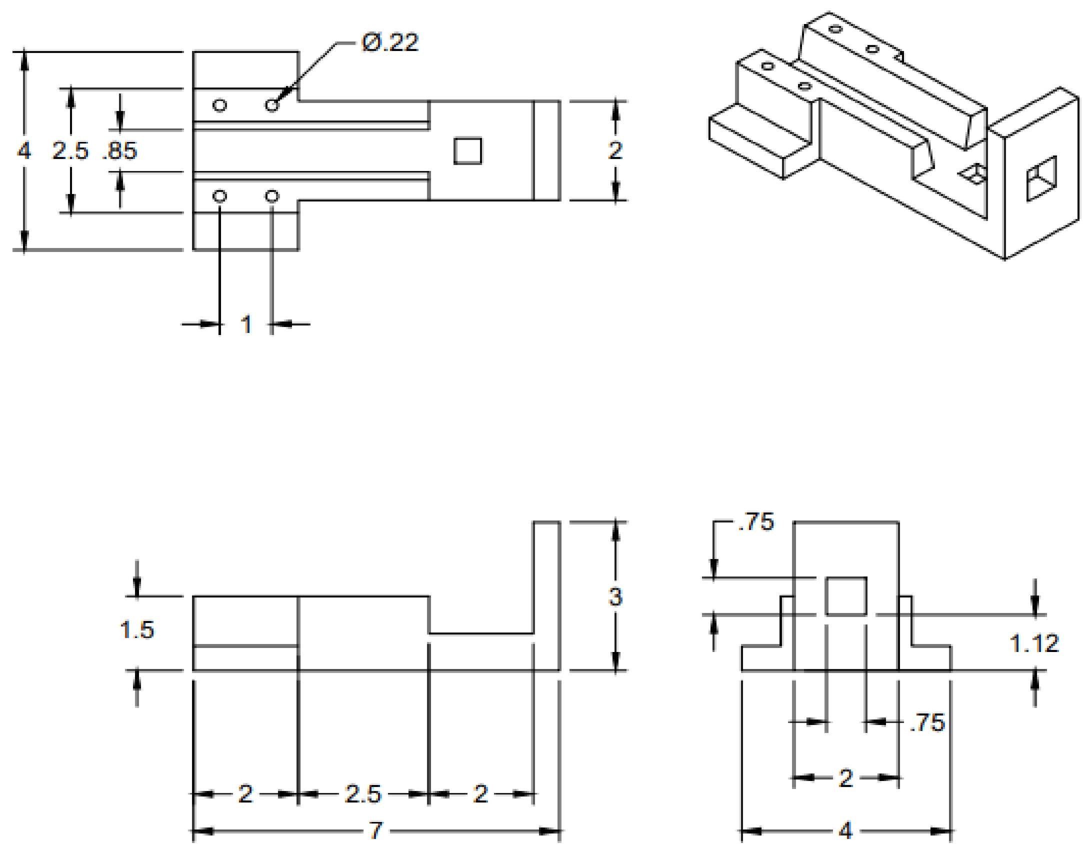
L_PWM,pin input 5V level,motor forward

R_PWM,pin input 5V level,motor reversal

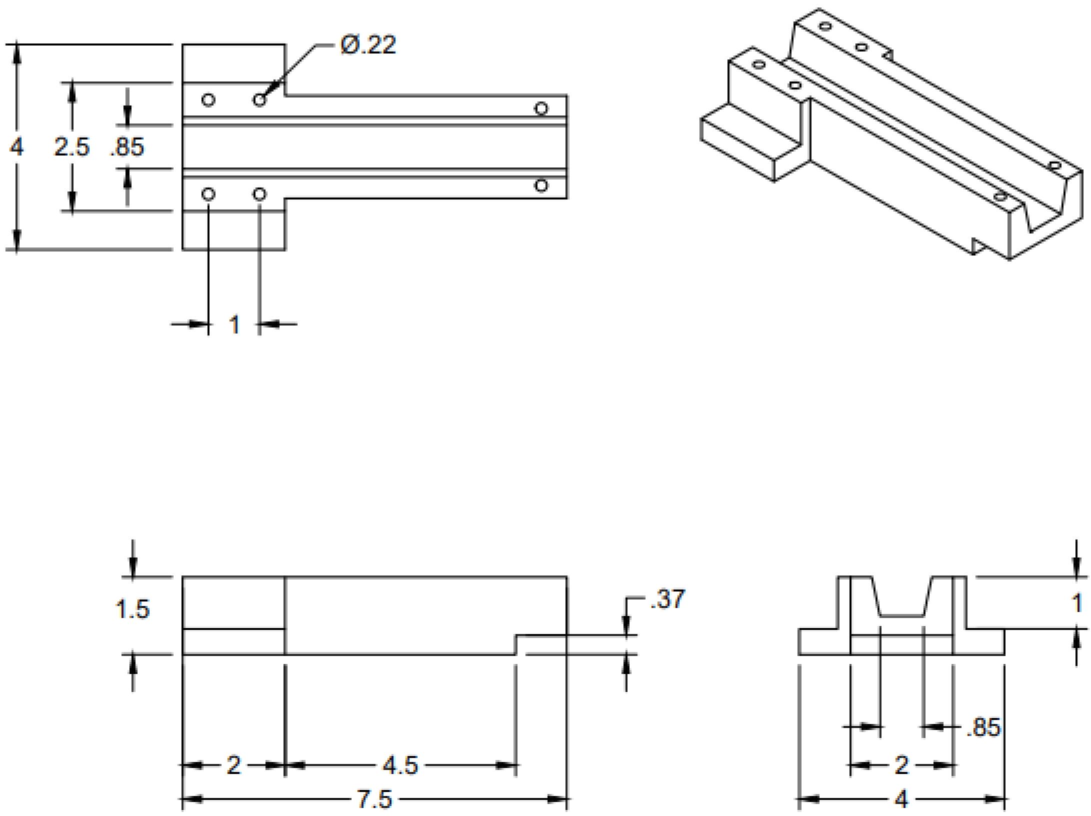
Figure B2. Wiring Diagram for Motor Controllers. Provided by manufacturer.

Appendix C: Poster for Advertisement

Appendix D: Custom Mount Parts - CAD Drawing Plans



WPI	PROJECT MQP23 Built Environment				
	TITLE Bracket Mount [SMALL]				
APPROVED	SIZE A	CODE	DWG NO		REV
CHECKED					
DRAWN Sebastian Villacorta 4/25/2023	SCALE 1:3		WEIGHT	SHEET 1/1	

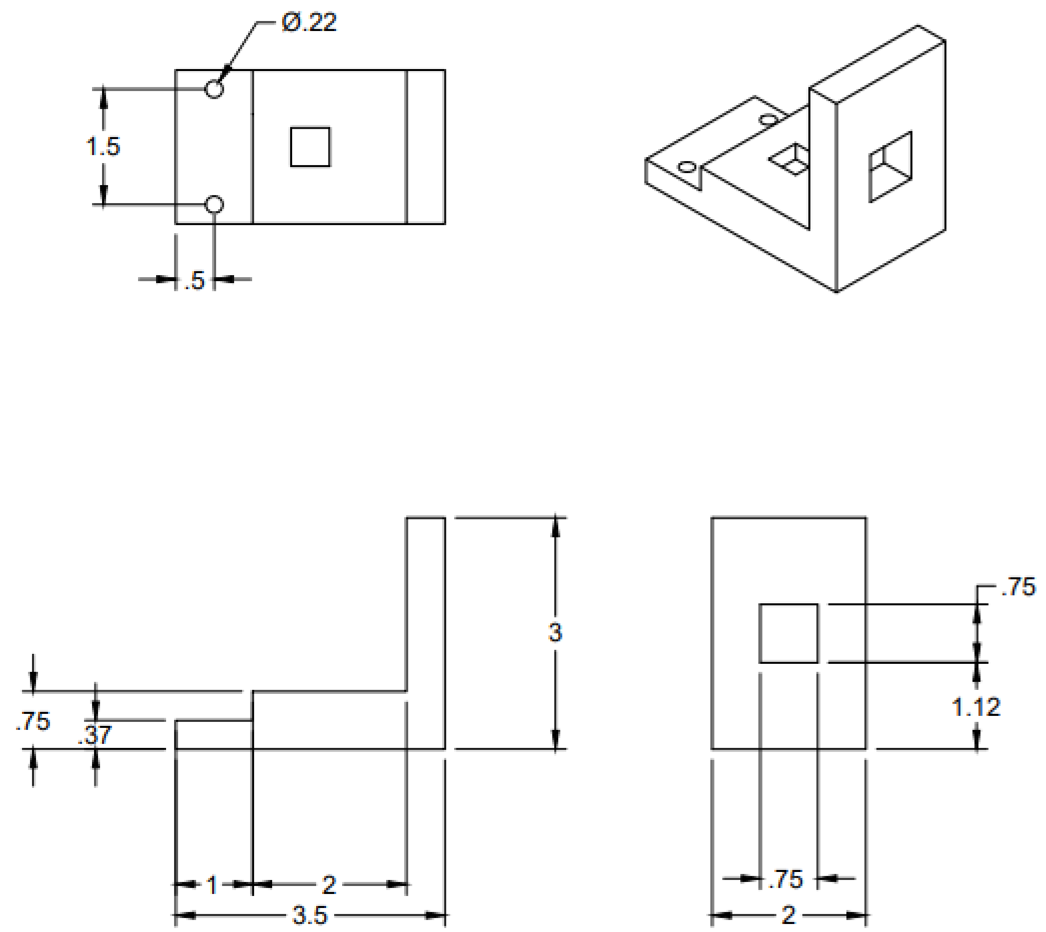


WPI

PROJECT
MQP23 Built Environment

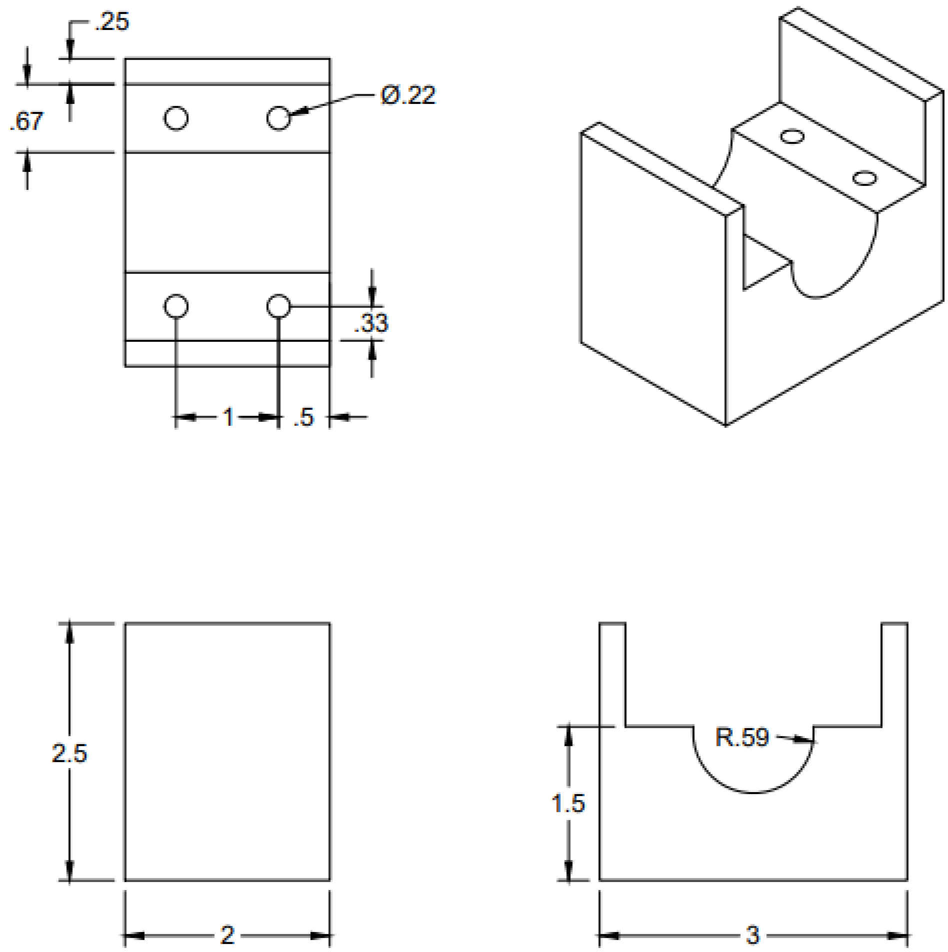
TITLE
Extruded Bracket Mount [LARGE]

APPROVED	SIZE	CODE	DWG NO	REV
CHECKED	A			
DRAWN Sebastian Villacorta 4/25/2023	SCALE 1:3	WEIGHT	SHEET 1/1	



WPI

PROJECT: MQP23 Built Environment				
TITLE: Back Brace For [LARGE] Mount				
APPROVED	SIZE: A	CODE	DWG NO	REV
CHECKED				
DRAWN: Sebastian Villacorta 4/25/2023	SCALE: 1:2	WEIGHT	SHEET: 1/1	

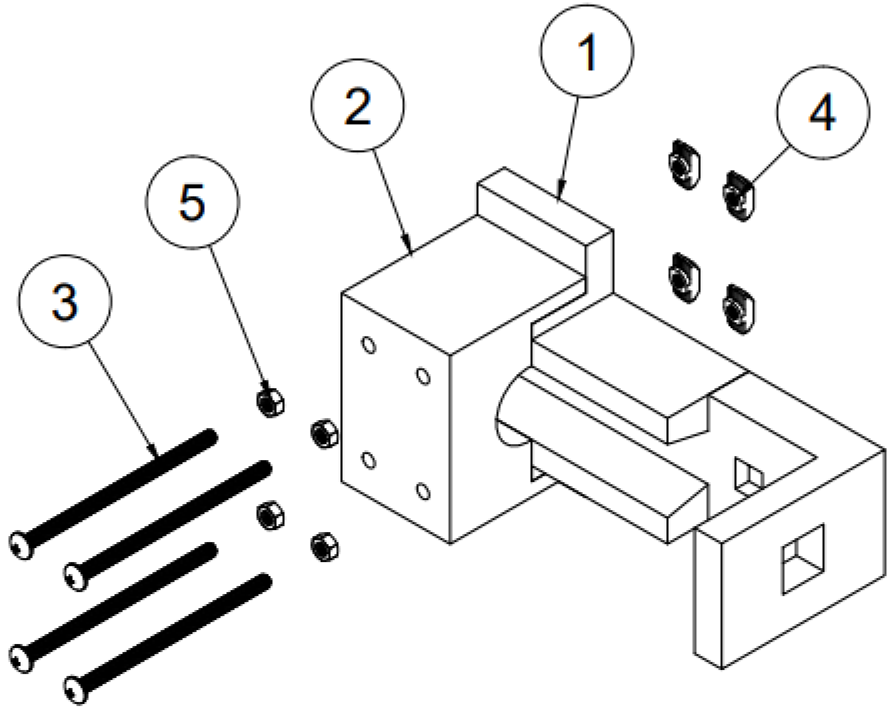


WPI

PROJECT
MQP23 Built Environment

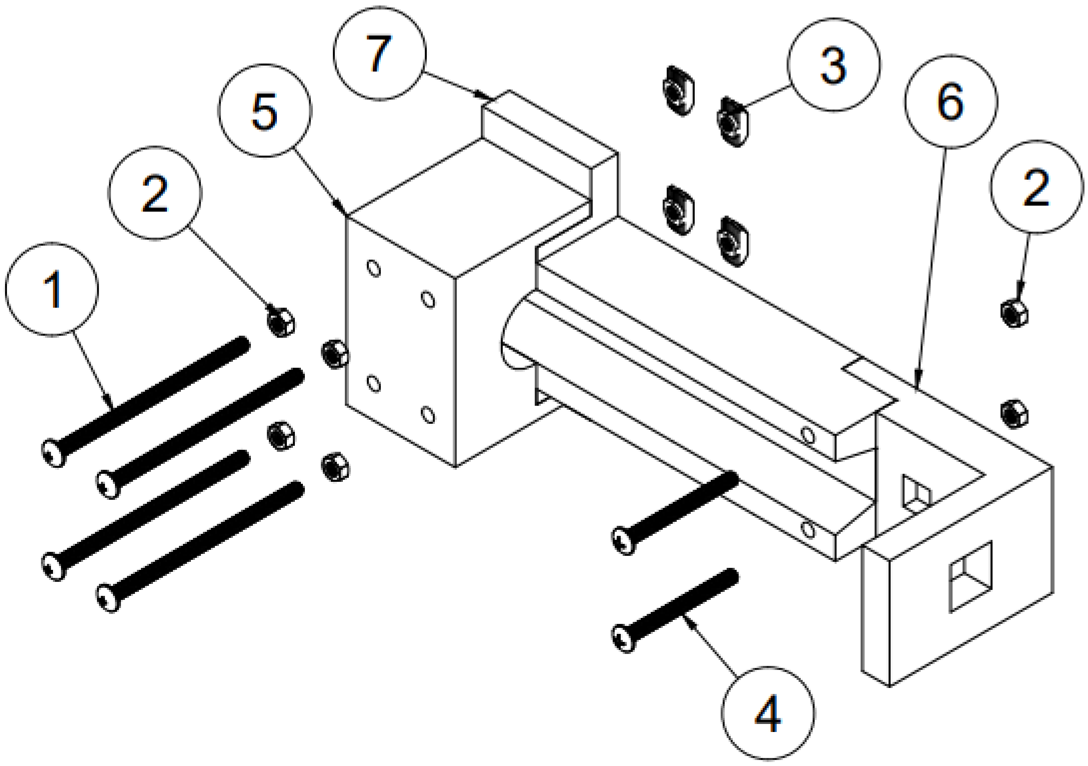
TITLE
Clamp

APPROVED	SIZE	CODE	DWG NO	REV
CHECKED	A			
DRAWN Sebastian Villacorta 4/25/2023	SCALE 1:2	WEIGHT	SHEET 1/1	



PARTS LIST			
ITEM	QTY	PART	MATERIAL
1	1	Bracket Mount [SMALL]	PLA
2	1	Clamp	PLA
3	4	3-1/2" Steel Pan Head Machine Screw #10-32 Thread Size	STEEL
4	4	80/20 10 & 25 Series 10-32 Standard Drop-in T-Nut	STEEL
5	4	Machine Screw Hex Nuts, #10-32, Grade 18-8 Stainless Steel	STEEL

WPI	PROJECT: MQP23 Built Environment			
	TITLE: Motor Mount Assembly [SMALL]			
APPROVED	SIZE: A	CODE	DWG NO	REV
CHECKED				
DRAWN Sebastian Villacorta 4/24/2023	SCALE 1:4	WEIGHT	SHEET 1/1	



PARTS LIST		
ITEM	QTY	PART
1	4	3-1/2" Steel Pan Head Machine Screw #10-32 Thread Size
2	6	Machine Screw Hex Nuts, #10-32, Grade 18-8 Stainless Steel
3	4	80/20 10 & 25 Series 10-32 Standard Drop-in T-Nut
4	2	2" Passivated 18-8 Stainless Steel Pan Head Phillips Screw 10-32 Thread
5	1	Clamp
6	1	Back Brace
7	1	Bracket Mount [LARGE]

WPI	PROJECT: MQP23 Built Environment			
	TITLE: Motor Mount Assembly [LARGE]			
APPROVED	SIZE	CODE	DWG NO	REV
CHECKED	A			
DRAWN Sebastian Villacorta 4/25/2023	SCALE 1:4	WEIGHT	SHEET 1/1	

Appendix E: 80/20 Plans

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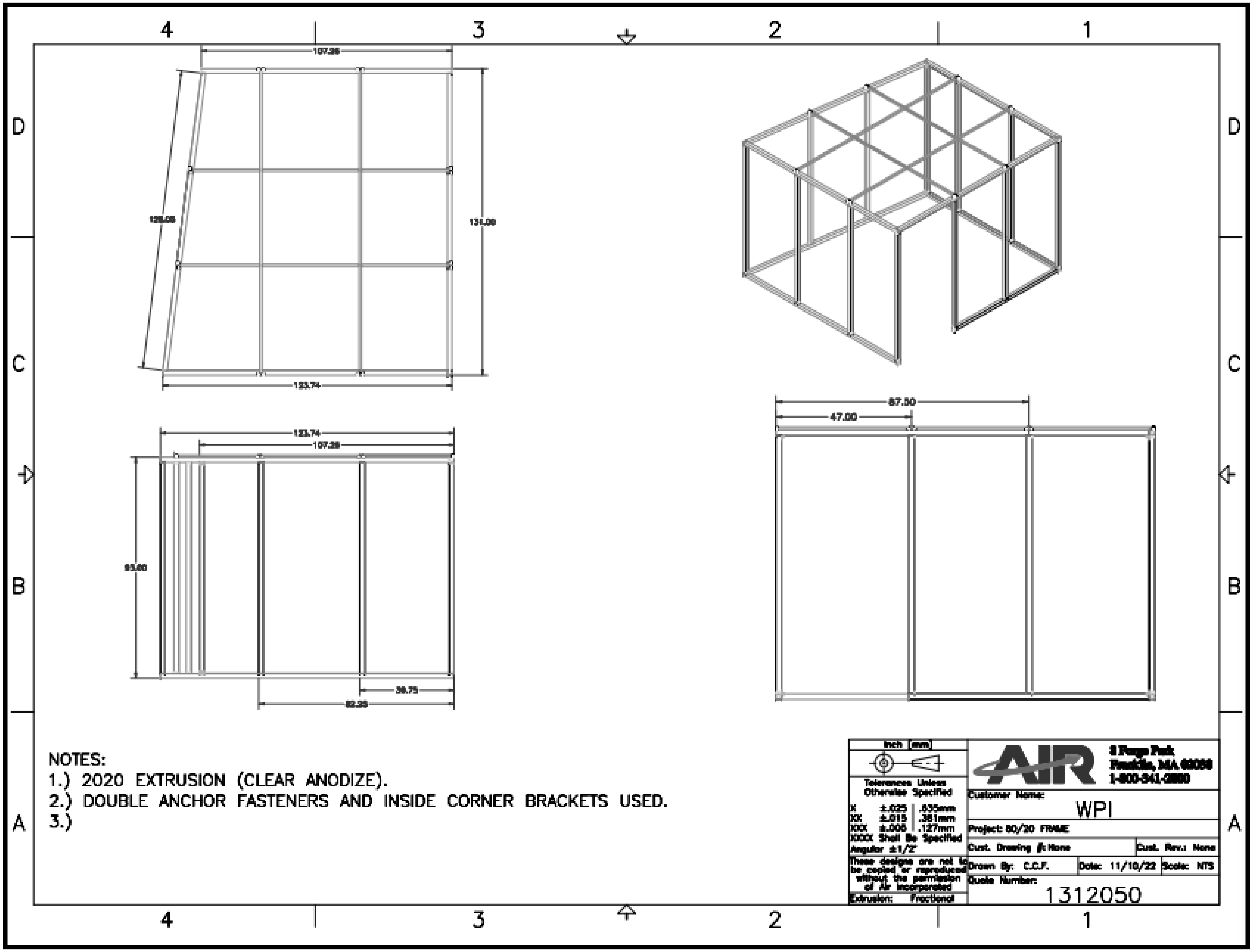
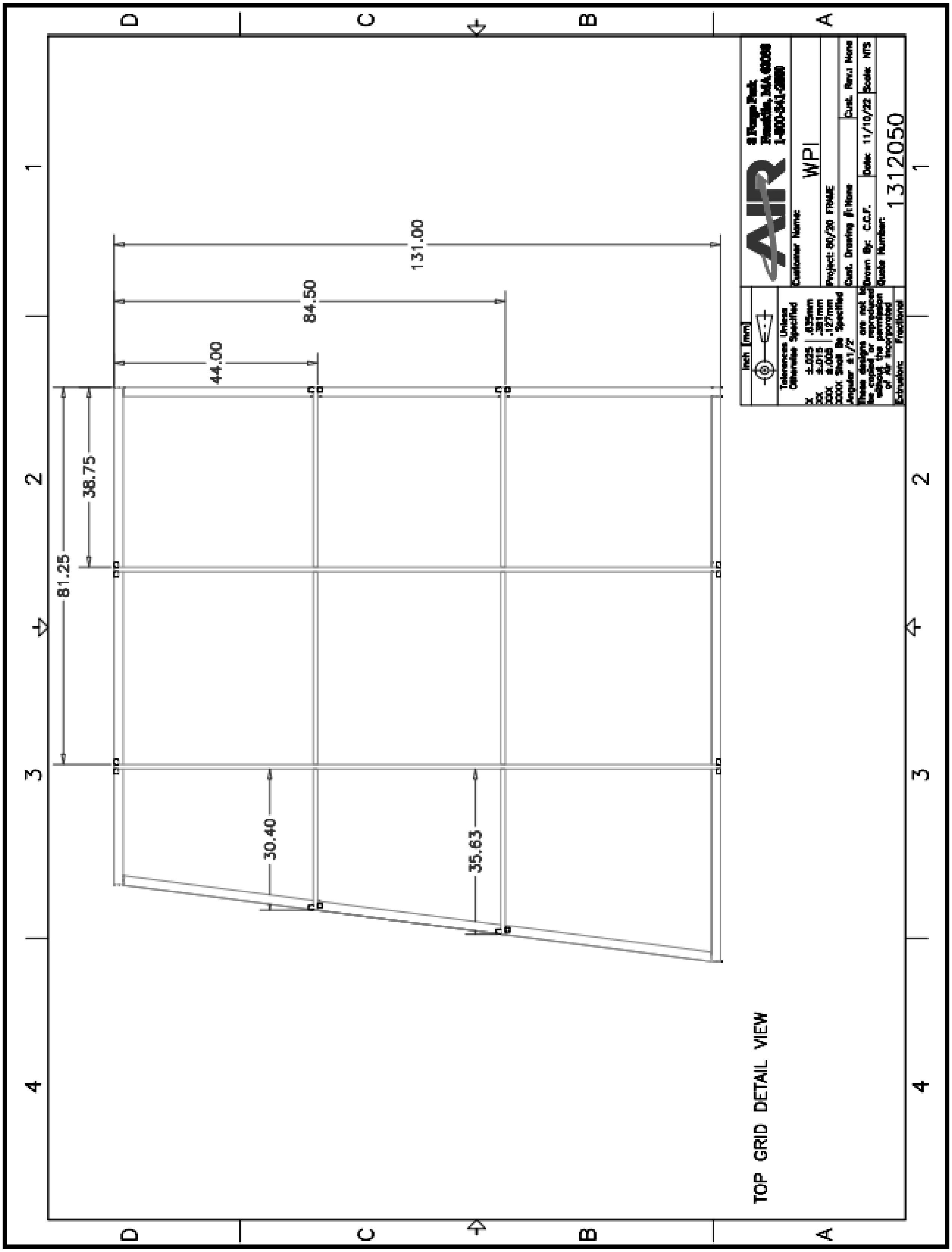

NOTES:
1.) 2020 EXTRUSION (CLEAR ANODIZE).
2.) DOUBLE ANCHOR FASTENERS AND INSIDE CORNER BRACKETS USED.
3.)
AIR
Customer Name:
WPI
Project: 80/20 FRAME
Cust. Drawing #: None
Cust. Rev.: None
Drawn By: C.C.F.
Date: 11/10/22
Scale: NTS
Quote Number:
1312050
Inch [mm]
Tolerances Unless Otherwise Specified
X ±.025 | .635mm
XX ±.015 | .381mm
XXX ±.005 | .127mm
XXXX Shall Be Specified
Angular ±1/2°
These designs are not to be copied or reproduced without the permission of Air Incorporated
Extrusion: Fractional


TOP GRID DETAIL VIEW
131.00
84.50
44.00
38.75
81.25
30.40
35.63
Customer Name:
WPI
Project: 80/20 FRAME
Drawn By: C.C.F.
Date: 11/10/22
Scale: NTS
Quote Number:
1312050

HARDWARE

	PN: 7413	Qty: 1	– YOUR ORDER IS TAGGED PER YOUR BOM AT NO EXTRA CHARGE
CUSTOM JOINING PLATES	PN: 3321	Qty: 16	– 1/4-20 X 1/2" FBHSCS & ECON T- NUT
DOUBLE ANCHORS	PN: 3092	Qty: 50	– 10 S 10-32 DOUBLE ANCHOR T-NUT LONG ASSEMBLY
2 HOLE JOINING PLATES	PN: 3321	Qty: 32	– 1/4-20 X 1/2" FBHSCS & ECON T- NUT
SINGLE ANCHOR FASTENERS	PN: 3395	Qty: 8	– 10 S ANCHOR FASTENER ASSEMBLY

Inch [mm]

Tolerances Unless Otherwise Specified
X ±.025 | .635mm
XX ±.015 | .381mm
XXX ±.005 | .127mm
XXXX Shall Be Specified
Angular ±1/2°
These designs are not to be copied or reproduced without the permission of Air Incorporated
Extrusion: Fractional

AIR

Customer Name: WPI
Project: 80/20 FRAME
Cust. Drawing #: None
Cust. Rev.: None
Drawn By: C.C.F.
Date: 11/10/22
Scale: NTS
Quote Number: 1312050

Appendix F: Experiment Manual

	Setup						Main Experiment	Exit Check	
Time (min)	0	2	3	5	2	3	12	3	
Elapsed Time	0	2	5	10	12	15	27	30	30
Participant Task	Participant Enters Space	Informed Consent	Fit-Out with EEG and O2 Ring (Time 0)	Onboarding Survey + PANAS Questionnaire (iPad)	Study Instructions	Mindfulness Exercise	Free Choice Activities: Legos, magazines, play dough, sudoku, coloring pages, coffee table books	PANAS Questionnaire (iPad)	Participant exits space
Operator Task						Final Equipment Check	Monitor Equipment (EEG, O2, Video Footage)		
Light	Normal						L1S1/L1S2/L2S1/L2S2		
Sound	Normal								
Data Phases	Phase 0 (Pre data collection)			Phase 1 (During onboarding)		Phase 2 (Mindfulness ex.)	Phase 3 (With Independent Changes)		

Figure 5.1 Experiment layout

Max time if things go wrong:

Time(T) In Minutes:

Before Session:
Instructions:

TBefore: Set up IPAD with an informed consent file and qualtrics links and room for specific variables on hand. Open up Open Signals to be ready to connect and ensure O2 is charged. Ensure the participant is connected to WPI's internet. Set Volume for 66.
(links on how to set up IPAD)
T0: Ask the Participant to enter the Room and have the participant to Informed Consent signing

T2: Begin Timer and Camera:

Setting up the camera

T5: Begin Putting On and Setting Up EEG and O2 Ring.

Setting up EEG   Setting up O2 ring

- Tell the participant they can sit in the chair if they'd like while you are setting up the software
- Set Up Software for EEG and O2 ring

T10: Direct Participant to the Onboarding Survey On Panas

- There is a link to the panas survey on the computer you just have to click it
- Start a new lap on the timer before they start the Panas
- EEG, O2, and Camera should be running at this time

T12: Go Over Study Instructions/ Agenda

(study instructions go here)

T15: Go over mindfulness exercise

- You should start a new lap on the timer before they begin the exercise

Instructions on Mindfulness Exercise

T27: Have Light and Sound Variables turned on.

- Turn on room variables and step out of the room
- Start a new lap on the timer after you leave the room
- Monitor Equipment

T30: Have participants take Out PANAS and Survey?

- Take off participants' Pandas and EEG.
- Stop EEG's Open Signal On Desktop

T33: Guide the Participant out of Room and stop the timer.

TAfter: Upload Files and Wipe the Room

- Save and upload EEG's open signal files to (TBD)
- Save files from O2 software to (TBD)
- Wipe down the area with Disinfectant Wipes
- Check the battery of the equipment and take notes

Setting up the EEG:

- Confirm that each permanent node has a new detachable wet node on the end
- Have participant put their hair back or in some way move it out of the way, if applicable
- Set up nodes behind the participants ear in the same way as shown in the picture below:
    - The black node is behind the upper part of the ear
    - The red node is behind the lobe of the ear
    - And the white node is below both of those on the neck of the participant
- Confirm that the nodes are plugged into channel one of the console and turn it on. (Confirm it is on by checking for the power button to be blinking green)

Setting up the O2 ring

- Participant cannot wear any finger jewelry on the finger the O2 ring is on
- Set it up on the middle or ring finger (whichever they prefer) of the participant's nondominant hand. The ring must go all the way to their knuckles
- Confirm its on by waiting for the screen to light up with numbers

Setting up the EEG Software: OpenSignals

- OpenSignals is downloaded on the desktop.
- If the green light is on. The screen should look like below:
- Make sure to check out continuous variables

- Next step is pressing the **Red Dot** to begin recording. Take note of what time in timer this is pressed.

-in order to ensure good data recording there should be a moving line graph.
-To stop the recording at the end of the study press the red dot again.

Uploading the Data from EEG

- Click on the fourth icon from the right with the arrow pointing down
- …

Instructions on Mindfulness Exercise

Repeat Exercise 5 times:

4-7-8 Breathing

1. Place the tip of your tongue against the ridge of tissue behind your upper front teeth. You'll keep it there for the entire exercise.
2. Completely exhale through your mouth, making a "whoosh" sound.
3. Close your mouth and inhale quietly through your nose as you mentally count to four.
4. Hold your breath for a count of seven.
5. Exhale completely through your mouth, making another "whoosh" sound to a count of eight

Setting up the camera

1. Confirm that webcam is plugged in and that power symbol on the right side of the lens is red
2. Find bandicam app on desktop click on it
3. Click start recording
4. We can should have a glowing green light to the left of the camera lens
5. Right click on head and click hide

Appendix G: Data Pipeline Code

The following Content is from a python file called experiment.py:

```
import csv
import sys,os
from matplotlib import pyplot as plt

import pandas as pd
import numpy as np
import h5py
from bokeh.plotting import figure
from jinja2.utils import markupsafe
from markupsafe import Markup
from bokeh.io import output_file, show
from numpy import nan, average
from numpy import random
from numpy import array
import biosignalsnotebooks as bsnb



class Experiment:
    def __init__(self, idNum, o2csv, eeg, panas1, panas2, info):
        self.idNum = idNum
        self.o2csv = o2csv
        self.eeg = eeg
        self.panas1 = panas1
        self.panas2 = panas2
        self.info = info

def createExperiment():
    idNum = sys.argv[1]
    folder_path = sys.argv[2] #--> Where the folder is located

    #ASk questions about - Who ran the experiment & Start and end time
& brief report and put into text file

    #idNum = 1856 #hardcoded for now
```

```
    #folder_path =
'/Users/nwhalen/Developer/MQP/BuildEnvDataPipeline/sebastian 11-18'
    #target_path =
'/Users/nwhalen/Developer/MQP/BuildEnvDataPipeline/EMILY'
    panasCount = 0


    target_path = os.path.join(folder_path, "Result" + str(idNum))

    if not os.path.exists(target_path):
        os.mkdir(target_path)
    textFilePath = target_path + "/report.txt"
    writeReport(textFilePath)
    for file in os.listdir(folder_path):
        f = os.path.join(folder_path, file)
        if os.path.isfile(f):
            #print(os.path.basename(f))
            if  'O2' in os.path.basename(f):
                #Process o2 data Todo
                readInO2ring(f, target_path)
                #target = target_path + "/O2.csv"
                #os.rename(data, target)
                #print(os.path.basename(f))
            elif 'h5' in os.path.basename(f):
                #Process eeg data
                readEeg(f, target_path)
                #print(os.path.basename (f))
            elif 'PANAS' in os.path.basename(f):
                    #Process panas data
                if(panasCount < 2):
                    #data =
getPanasScores("/Users/nwhalen/Developer/MQP/BuildEnvDataPipeline/CSV/
test/CSVTEST_PANAS.csv", idNum)
                    data = getPanasScores(f, idNum)
                    panasCount = panasCount + 1
                    target = target_path + '/' + 'PANAS' +
str(panasCount) +'.csv'
                    pd.DataFrame(data).to_csv(target, index_label="i",
header=['Time/Date','PANAS_PA','PANAS_NA','PANAS_SN','ID'])




def getPanasScores(target, idNum):
    csv_file = csv.reader(open(target, "r"), delimiter=",")
```

```
    array = []

    for row in csv_file:
        strId = str(idNum)
        # if current rows 2nd value is equal to input, print that row
        if strId == row[4]:
            #print(row)
            array.append(row)
    #print(array)
    result = np.asarray(array)
    return result

#Reading in O2
rows = []
heartRate = []
clock = []
def readInO2ring(fileName, targetPath):

    ave = []
    with open(fileName, 'r') as file:
        csvreader = csv.reader(file)
        header = next(csvreader)
        for row in csvreader:
            rows.append(row)
    #print(header)

    # Way to specify which column we are using
    mean = 0
    count = 0
    watch = 0
    lastbmp = 0
    # Check for motion
    time = 0
    sp02 =1
    pulse =2
    motion =3
    sp02reminder =4
    pulseReminder = 5
    for i in range(len(rows)):
        # Turn each row into a list of each thing in row
    # print (time, sp02, pulse, motion, sp02reminder, pulseReminder)
        if int(rows[i][pulse]) > 60 and int(rows[i][pulse]) < 100:
            # if int(pulse)<= lastbmp+7 and int(pulse)>=lastbmp-7 or
lastbmp == 0:
           # print(watch, pulse)
```

```
            mean += int(rows[i][pulse])
            count += 1
            heartRate.append(int(rows[i][pulse]))
            clock.append(watch)
            rows[i][time] = watch
            # else:
            #   heartRate.append(np.nan)
            #  clock.append(watch)
        else:
            heartRate.append(np.nan)
            rows[i][pulse] = np.nan
            clock.append(watch)
            rows[i][time] = watch
        watch += 4
       # lastbmp = int(pulse)

    #  paresedRow = row.split(",")
        # print(row)
    ave = int(mean/count)
    makeGraph(heartRate,clock,ave)
    writeO2Data(fileName, targetPath)

def writeO2Data(fileName, targetPath):
    with open(targetPath + "/02.csv", 'w') as cleaned:
        fieldnames = ['time','O2','heart
rate','motion','02reminder','pulsereminder']
        writer = csv.DictWriter(cleaned, fieldnames = fieldnames)
        writer.writeheader()
        writer = csv.writer(cleaned, delimiter=',')
        for row in rows:
            writer.writerow(row)
        #return cleaned

def makeGraph(pulse,time, mean):
    plt.axhline(y=mean,color='r',linestyle = 'dashed',label =
'Average')
    plt.xlabel('time(secs)')
    plt.ylabel('heartrate')
    plt.plot(time,pulse, label='Pulse Over Time')
    plt.show()



def writeReport(filePath):
```

```
    names = input("Please enter the names of the people who ran the
experiment.\n")
    summary = input("Please provide a brief summary of the
experiment\n")
    data = [names, summary]
    with open(filePath, "w") as txt_file:
        for line in data:
            txt_file.write("".join(line) + "\n")



#### EEG COODE
def readEeg(filePath, targetPath):
    markupsafe.Markup()
    Markup('')

    output_file(targetPath + "/eegVis.html")

    file_folder = ""
    #file_path
="/Users/nwhalen/Developer/MQP/BuildEnvDataPipeline/sebastian
11-18/experiemtData-11-18.h5"

    h5_object = h5py.File(filePath)
    a_group_key = list(h5_object.keys())[0]

    #grid = gridplot()

    # get the object type for a_group_key: usually group or dataset
    print(type(h5_object[a_group_key]))

    print("Keys: %s" % h5_object.keys())


    # Keys list (.h5 hierarchy ground level)
    list(h5_object.keys())


    #h5_group = h5_object.get('00:07:80:3B:46:61')
    #h5_group = h5_object.get('00:07:80:4B:18:75')
    h5_group = h5_object.get(a_group_key)
    print ("Second hierarchy level: " + str(list(h5_group)))

    print ("Metadata of h5_group: \n" +
str(list(h5_group.attrs.keys())))
```

```
    sampling_rate = h5_group.attrs.get("sampling rate")
    print ("Sampling Rate: " + str(sampling_rate))

    h5_sub_group = h5_group.get("raw")
    print("Third hierarchy level: " + str(list(h5_sub_group)))

    h5_data = h5_sub_group.get("channel_1")

    # Conversion of a nested list to a flatten list by
list-comprehension
    # The following line is equivalent to:
    # for sublist in h5_data:
    #    for item in sublist:
    #        flat_list.append(item)
    data_list = [item for sublist in h5_data for item in sublist]
    time = bsnb.generate_time(data_list, sampling_rate)


    # Signal data samples values and graphical representation.
    # print (array([item for sublist in h5_data for item in sublist]))
    # bsnb.plot([time], [data_list], x_axis_label="Time (s)",
y_axis_label="Raw Data", show_plot=False, save_plot=True)

    data = np.array([time, data_list]).transpose()
    df = pd.DataFrame(data)
    df.to_csv(targetPath + "/eeg.csv", header= ["Time", "Data"],
index_label="i")


#http://notebooks.pluxbiosignals.com/notebooks/Categories/Visualise/pl
ot_acquired_data_single_rev.html

    data, header = bsnb.load(filePath, get_header=True)
    print("\033[1mHeader:\n\033[0m" + str(header) +
"\n\033[1mData:\033[0m\n" + str(data))
    signal = data["CH1"]
    time = bsnb.generate_time(signal, header["sampling rate"])
    baseline = average(signal)
    baseline_shift = 0.50 * baseline
    data_noise = signal + random.normal(0, 1000, len(signal)) +
baseline_shift
    bokeh_figure = figure(x_axis_label='Time (s)', y_axis_label='Raw
Data')
    bokeh_figure.line(time, signal, legend_label="Original Data")
```

```
    bokeh_figure.line(time, data_noise, legend_label="Noisy Data")
    #show(bokeh_figure)
    bsnb.plot([time, time], [signal, data_noise],
legend_label=["Original Data", "Noisy Data"],
              y_axis_label=["Raw Data", "Raw Data"],
x_axis_label="Time (s)")
    #data.transpose()
    # with open(filePath, 'w', newline='') as file:
    #     writer = csv.writer(file)
    #     # for length of list
    #     writer.writerow(["time", "data"])
    #     print(type(data_list))
    #     for line in data:
    #         print(line)
    #         writer.writerow([line.time, line.data_list])

if __name__ == '__main__':
    createExperiment()
```

For an updated version and previous iterations see BuildEnvDataPipeline on github.