Pursuing A More Habitable Space Module:

Using Impression Based Generative Design

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Abstract

Pursuing A More Habitable Space Module:
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The gravitational environment that we occupy is the formwork in which all buildings must be cast. Renzo Piano once said, “architects spend an entire life with this unreasonable idea that you can fight gravity”. Yet, in a time when science fiction is becoming science fact, architects may no longer need to fight gravity. A reemerging interest in space by the general public coupled with new economic opportunities has created numerous private companies set on pursuing space travel. With the development of this new sector architects and designers have the unique opportunity to re-examine the fundamental spatial principles that inform design. This thesis will explore a design methodology that is responsive to user input and apply that information to a space module in a zero-gravity environment.

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I: Introduction

The development of architecture through the evolution of humankind, while infinitely diverse has one constant factor, it must always consider gravity. Gravity has dictated our perception of space and wayfinding throughout human existence. This dependence on a gravitational constant will one day change when our descendants become an interplanetary species. In a time when Science fiction is becoming science fact, the norms that we have come to understand under terrestrial gravity will change. As terrestrial beings we have evolved over centuries to be accustomed to the gravity on earth. In this evolutionary journey gravity not only acts as the physical anchor that keeps us grounded, but it is also a critical factor in how we navigate and understand space.

As humanity is in its infancy in the realm of space design, we must attempt to understand how the change in directional navigation and orientation of a zero-gravity environment alters the architectural elements and spatial understanding we have come to know here on earth. With the advancement of rocket technologies, the commercialization and tourism of space is becoming a reality. As more people are sent into space the demand for models to house them will increase. With this demand for space habitation modules designers have the unique opportunity to redefine the methodologies used for spatial design.

This research seeks to develop a methodology that can be used when the gravitational constant designers have become accustom to is removed. To achieve this it will establish a base understanding of the terrestrial conditions of wayfinding, spatial perception, and terrestrial architecture elements. It will then discuss how current space modules are being designed and analyze possible methodologies that can be useful when designing in zero gravity. From this base of knowledge this thesis will develop and test a methodology that utilizes the input of a test group. This will then be used to design a space module. The module will consist of all the programmatic features necessary to sustain a small population of space travelers. The methodology produced will be a starting point for a conversation on how future designers and architects can design without the presence of a gravitational constant. In exploring this process this thesis looks to understand the true of nature spaces. As some imagine going to the stars as a freedom from the gravitational constraints of earth this freedom may in fact be a curse. Without gravity what can ground design when floating through the cosmos?

II: Theoretical Framework

Gravity

To understand the effects of gravity on wayfinding, perception, and architecture we must first establish an understanding of gravity. At a basic level gravity is the force of attraction between two bodies of mass.[1] The more mass an object has the larger the gravitational pull it will produce. Here on Earth the gravitational pull of our planet keeps us grounded to the surface at a force of 9.807 m/s^2. This is the velocity at which an object is pulled towards another object's gravitational center. The higher the number the stronger the effects of gravity while the lower the number the weaker the effects. Theoretically every object of mass has a gravitational pull, but the forces that are produced by objects of a small mass are imperceptible. Therefore, while occupying a vessel in space one perceives and experiences a state of gravity-less space.

Directionality

Under the influence of gravity humans have evolved to move through and understand space in a specialized way. The mere act of walking is a controlled fall in which an individual shifts their center of gravity forward and continues to catch themselves as they move through space.[2] This specialized way of moving has left human beings with a finite amount of ways to move through space. Under terrestrial conditions movement is restricted to rotational, and horizontal movements. In short, the body can travel anywhere if it is grounded to the Earth. In the case of zero gravity, the added directionality of up and down along with Axial movement is added (Figure 1). From a physical standpoint this is not something that the human body evolved to do, but it is still achievable. From a psychological standpoint this is something that can be taught and learned. Studies have shown that our directional understanding under earth's gravity is, in fact, not an innate occurrence.[3] It is instead a learned experience that can theoretically be relearned. The study found that children 4 months old understood a rolling ball cannot pass through an obstacle but do not understand that an unsupported ball will fall. At 5 months they can differentiate between upward and downward motion, and at 7 months they show awareness of gravity and sensitivity to a ball's "natural" acceleration in an upward or downward direction. What is important about this study is the fact that using observational methods children can learn the effect gravity has on an object. This observation of gravitational effects gives rise to an understanding of the relationship between gravity and directional navigation. If children learn directional understanding through observation, then perhaps there are methods to streamline the learning process of zero gravity directionality and orientation for adults.

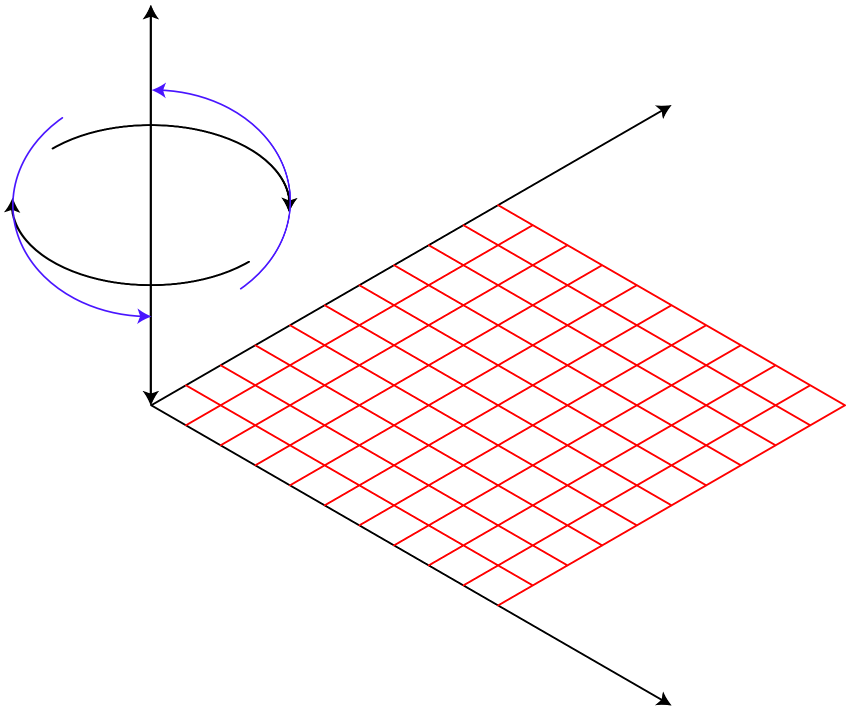


Figure 1: Zero-Gravity Movement (This diagram displays the movement potential of an individual while in a zero-gravity enviornment)

The Architecture of Confinment

What does it mean to be confined? At its root, to be confined means to be encapsulated within an entity. This can range from physical confinements such as being held in a cell to psychological and social confinements. This is inherently a very complex issue that has a tremendous number of variables. It is with this understanding that this thesis will only focus on the physical nature of confinement within a finite volume and briefly discuss the psychological impact these physical attributes have on individuals. It will not discuss the conditions that led individuals to be confined within a space, it will only test participant's exposure to test spaces. That being said it is very important to discuss the most extreme case, prisons. When one thinks of being confined architecturally speaking it is very easy to immediately associate this idea with a prison. Whether one likes it or not the concept of imprisonment is a reality of the society we live in, and this thesis will not discuss the agency or ethics of this architectural typology. What it will do is look at cases of finite architecture such as the international space station, and utilize its research to guide finite architecture to become more enjoyable for its occupants.

Architecture as a means of containment is something that has been practiced throughout the history of human evolution. From basic wooden fences used to define property lines and contain livestock to the complex design of a space capsule used to keep astronauts alive. Just as these examples state, there are degrees, scales, and specific intent behind contained spaces. Some are used for reasons seen as positive by society and others are negative. For the purpose of this thesis it will not be discussed whether confinement is good or bad for individuals. It will more importantly question when one is confined what forms, proportions, and scales are most appropriate for an individual or group of individuals.

The Elements of Architecture

When deigning in a zero-gravity environment the terrestrial elements of architecture must be understood. The elements of architecture can be many things, but for the purpose of this thesis they will be defined as the components of a standard building. While there are many elements that go into each piece of architecture for the purpose of wayfinding, we will only focus on six basic elements. (Figure 2) These will be the floor, walls, doors, windows, stairs, and ceiling. The defining of these elements will be done through the lens of Rob Krier's book "Elements of Architecture" (Figure 2). The floor is the plane in which we navigate through space.[4] While on a surface level it may seem like a rudimentary element its complexity can define a space. Grade, surface finish, and ornamentation are just a few factors that play a role in a floor's definition. The ceiling opposing the floor is the termination of space above our heads.[5] This element must resist the forces of gravity, insulate its occupants from the exterior, and act as a visual cue in defining a space. If the ceiling is the termination of space above our heads, then the wall is the confining of space on the horizontal plane.[6] It controls the flow through a space while defining it and resisting gravity. The door is defined as an occupiable void within a wall. A door is the transitional element between spaces.[7] A door gives a room its direction, and its appropriate meaning it prepares the occupant for an event to come.[8] The window like the door is a void within a wall but is not occupiable. It acts as a vessel for light and a medium to observe other spaces. The stair is a transitional element that allows an occupant to move from one level to another. It is a tool to oppose gravity and allow individuals to move up and down within a space.

What then happens to each of these elements in a zero-gravity condition? (Figure 3) When considering this question, it is also important to question how this change will alter wayfinding. How does redefining basic elements and cues alter how we perceive space? Taking what was previously learned from the directionality section of this thesis we understand now that axial and up/down movement will be added to a person's navigation abilities in zero-gravity. This added movement redefines floors, walls, and ceilings to "occupiable planes". In the case of a cubic space one would have no way of knowing which plane was defined as a wall, ceiling, or floor as there is no gravity to tell up from down. Therefore, the dependence on gravity for orientation must be shifted elsewhere. In terrestrial conditions each of these elements has visual, material, and tactile characteristics that help to define them. While there are infinite possible combinations of these element what is important is the ability to differentiate one from another.

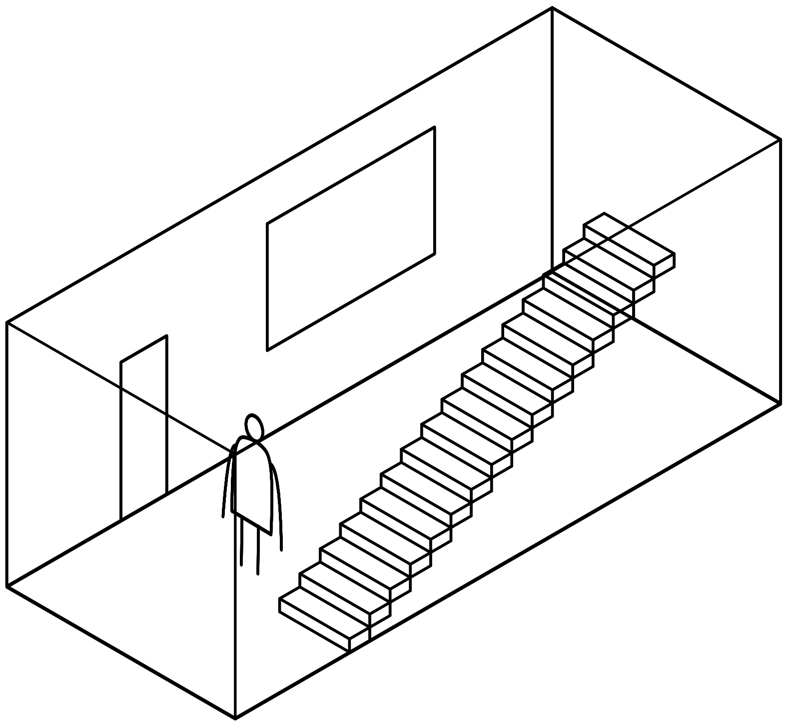


Figure 2: The Elements of Architecture (Floor, walls, cieling, door, windows and stairs all have their role in terrestrial gravity)

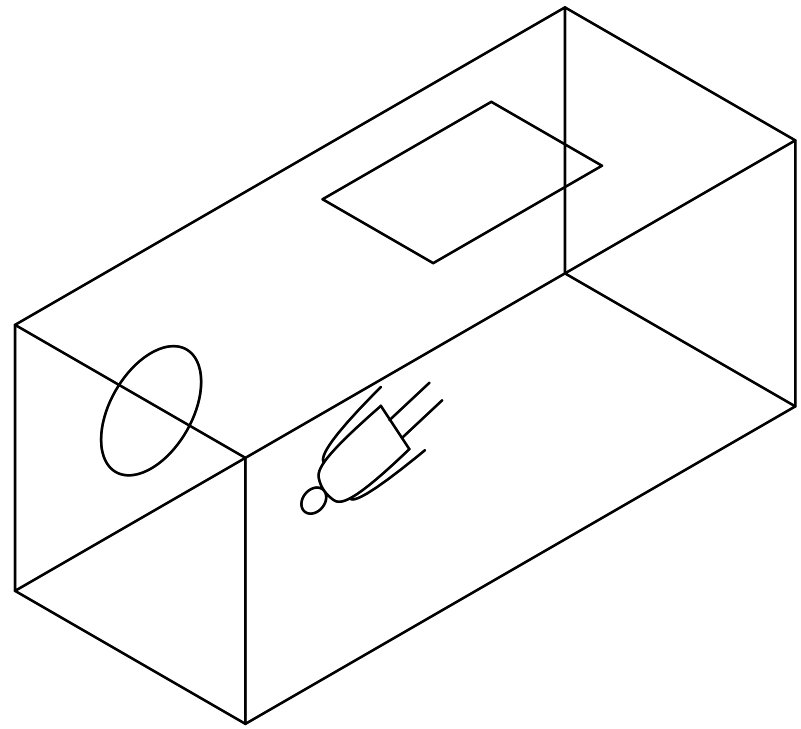


Figure 3: Zero-Gravity Elements of Architecture (The elements of architecture change when occupying a zero-gravity enviornment)

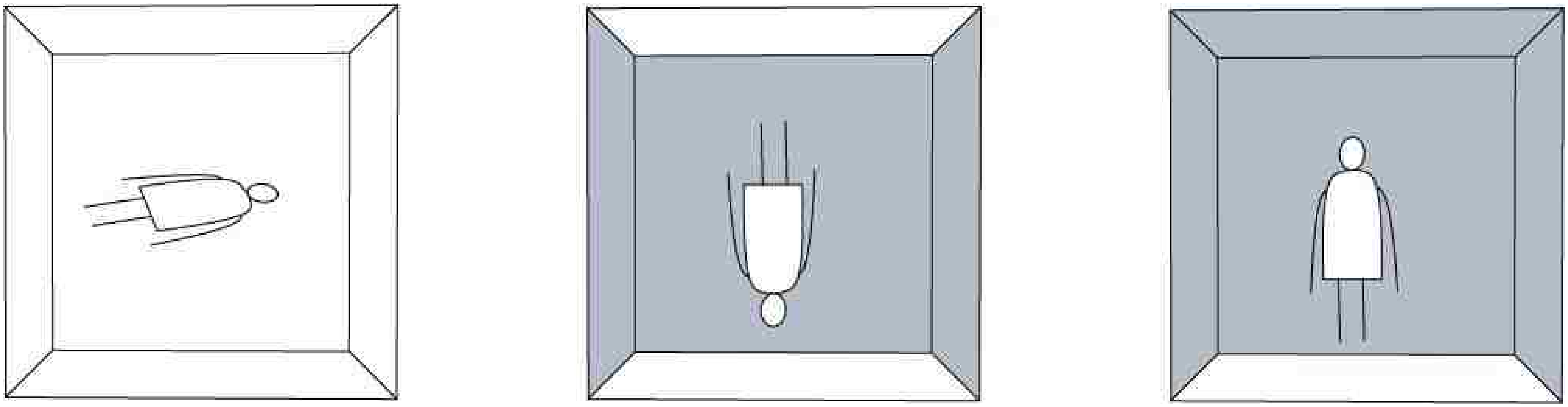


Figure 4: Establishing Orientation Using Differentiation (Color can be used as an element to differentiate directionality when occupying a zero-gravity enviornment)

As an example, if four sides to a cube are all a single color while two are another then one can visually differentiate between them and establish a up/down directionality. If five sides to a cube are a certain color then a frame of reference can be established to that plane promoting orientation (Figure 4). This is not limited to color, any manipulation of these planes can produce similar results such as the manipulation of scale, light, texture, material and form. Understanding this concept can help to design architecture that assists in orientation and wayfinding in zero-gravity. Looking to windows and doors their purpose remains relatively unchanged. However, their positioning can be completely altered. Doors can now occupy any plane while their form and size can change significantly. More importantly though, both windows and doors can be used to promote orientation and directionality. In the same way that color was used in the previous example the placement of doors on different planes can give a room directionality while the placement of windows can offer orientation. Utilizing these elements in their redefined nature is key to providing quality spaces in a zero-gravity environment.

Perception

Now that an understanding of architecture has been established an understanding of how occupants interact with their environment must be acquired. Perception is the process through which humans and other organisms become aware of the relative position of their own bodies and objects around them.[9] In the case of this research the discussion will focus on Spatial perception. Spatial perception is believed to have originated in an effort to "seek food and avoid injury".[10] An inability to perceive space would leave one with an inability to seek food, flee from danger, and form social connections. Thus, through evolution, and the adaptation of multiple sensory organs perception was obtained. Which allowed one to understand and survive in a given environment.

Perception at least in a terrestrial sense is a very specialized occurrence. Our perception as humans is highly dependent on the gravitational conditions established on earth. In order to understand how it is specialized we must first look at the sensory organs and how they provide cues to perception. At its basic level the body utilized its five sense to obtain information about its environment. These are as follows, touch, hearing, smell, sight, and taste. Touch is used in a number of ways to establish perception. The force of gravity on the body and the vestibular apparatus grants one the ability to differentiate up from down. The texture and sensations provided by the feet and hands when navigating relay the form and condition of a space. The skin informs the body of temperature and proximity. Hearing grants one the ability to reference their position. It can relay distance, materiality, and typology of an object or space. Smell tells one of proximity and position. Sight offers a sense of distance, trajectory, and orientation. What must also be understood is that each of these sensory cues do not work independently of one another. In fact they each work together to give one the most accurate perception of a space.

Perception: The Sensory Cues In Zero Gravity

What then happens to each of these sensory cues when they are placed in a zero-gravity environment? Starting with touch, the vestibular apparatus is disrupted in zero gravity since it utilized gravity to level itself. This in turn causes an inability for one to differentiate up from down. In addition, without gravity acting on the body a disruption in the proprioceptive system results in a temporary loss of feeling in the limbs that can last up to a week.[11] These paired with a general loss of kinesthetic coordination make initial exposure to zero gravity a disorienting perceptual experience. Hearing of all the sense is one that does not have significant changes due to the fact that a habitable zero gravity environment must be comprised of the same gas makeup that can be found here on earth. Sound waves will act as they do here on earth. The sensory organs that allow hearing remain relatively unchanged as well. Yet, the manner in which sound is given off will be similar to an enclosed space that produces echoes and reverberation making it difficult to trace a sounds origin. Smell takes on an interesting character in zero gravity. On earth smell is dependent on its mass and composition. If it is lighter than air it will float away, if there is a current of wind it will be blown away, in short, its distribution is highly dependent on its environment and its properties. In zero gravity smell will remain stagnant until it is acted upon by another force. It will disperse itself from an origin point until the particulates are no longer pushing one another.[12] This can create lasting "pockets" of smell throughout a given space instead of smell trails which can be experience in terrestrial gravity. Sight will be interrupted directly for up to a week when in zero gravity. Temporary blindness may occur upon initial exposure to zero gravity and can last up to one week. This is caused by a surplus of blood in the upper torso as the body no longer needs to fight the effects of gravity to pump blood to the eyes and brain. Aside from the physical change, sight-based cues in zero gravity may initially be disorienting. The unusual trajectory of objects and lack of orienting ques may cause confusion and anxiety in individuals.

Case Study: International Space Station

Out the few examples of occupiable architecture in zero gravity the international space station is by far the most renown. Approximately 400km above the surface it revolves around the earth once every 90 minutes. In terms of habitable space, it is measured by volume, of which it has 43,000 cubic feet. This is roughly equivalent to the interior volume of a 747-jumbo jet.[13] Aside from its basic facts it is important to observe how the space station tackles the issues associated with wayfinding, orientation and acclimation to zero gravity. Unfortunately, due to the relatively small size of the station it is somewhat difficult to make an argument for the "wayfinding" portion of this research. Instead this research will look at how this station addresses the shift in each person's sensory cues and tries to either negate the negative effects or ease them through design.

Starting with touch the space station was designed so that individuals will always have a given surface to grab hold of while occupying the space. The largest module attached to the station the Kibo Module measures in at 37 feet long by 14ft wide. Although this does leave room for astronauts to become "stranded" a line is run down the middle of the module to prevent this from occurring. This accompanied with various types of handles spaced throughout the station make certain that individuals will always have a surface to keep them oriented and grounded.

Figure 5: International Space Station (Handles placed throughout the station allow for astronauts to grip and orient themselves to any surface)

Case Study:Autodesk MARs Office

In an effort to find a methodology that can assist in the design of future space modules the MARs Autodesk office by The Living can act as a precedent. It utilizes an innovative way of designing space. This example was created using the Generative design method. This is a process in which a set of constraints is used to generate an evolving set of spaces. These spaces are then evaluated and evolved over the course of hundreds to thousands of simulations run by a computational software. Following this a set of spaces are generated that represent the optimum conditions based on the applied parameters. These spaces are what designers carry forward in the development of the project. This methodology is an effective way of generating spaces that need to meet or exceed

Figure 5: Generative Design Method (A daylight evaluation done during the generative design process used to create the Autodesk MARs office)

a set of requirements of a specific set of parameters. Due to the specific nature of this design method it can be useful in creation of a new design method for designing in a zero gravity environment.

Conclusion

As seen throughout this research designing in a zero-gravity environment adds a level of complexity to what is currently known about design. Complex issues often require complex solutions and if designers are to be effective in creating habitable spaces for people to occupy, they cannot use methodologies optimized for designing on earth. With change and hardship comes the opportunity to reimagine the current methodologies in place. It is up to the design community to push the boundaries of how people think about and produce designs.

III: Methodology

Introduction

With the absence of gravity and with it the conventional methods through which architecture is designed and built it is difficult to define what factors will be guiding principles when designing in space. All architectural spaces on earth were designed to obey the laws of gravity and those that refuse are doomed to failure. Gravity is the formwork that all designs must be cast into, and if designers are now forced to ignore gravity, what can they depend on to achieve their designs? The methodology proposed in this thesis is one of the infinite alternatives that can offer a potential logic to designing in a zero-gravity environment. It proposes establishing the visual preferences and aversions of a test group towards spaces that were generated using Rob Krier's Elements of architecture.

The Test

The methodology in this thesis is formatted under the generative design model that was discussed in the MARs AutoDesk office section of this document. This model involves a set of constraints that are used to generate a design. This design is then put though a computational software in which it is continuously evaluated and evolved. The evaluation/evolution phase can be run numerous times until a desirable outcome is produced. The product then enters the exploration phase in which designers can modify it into a final product (Figure 6). This thesis proposes a modified form of this generative design model. The constraints are replaced with form, scale, proportion, portal, aperture, and light. The computational software is replaced with a test group, and the medium in which they interpret the space is through virtual reality (Figure 7). This methodology then gauges each individual's preference or aversion towards a space they are experiencing. The goal of this test is to gain a greater understanding of individuals preferences and aversions when occupying a space in a zero gravity enviornment for an extended period of time.

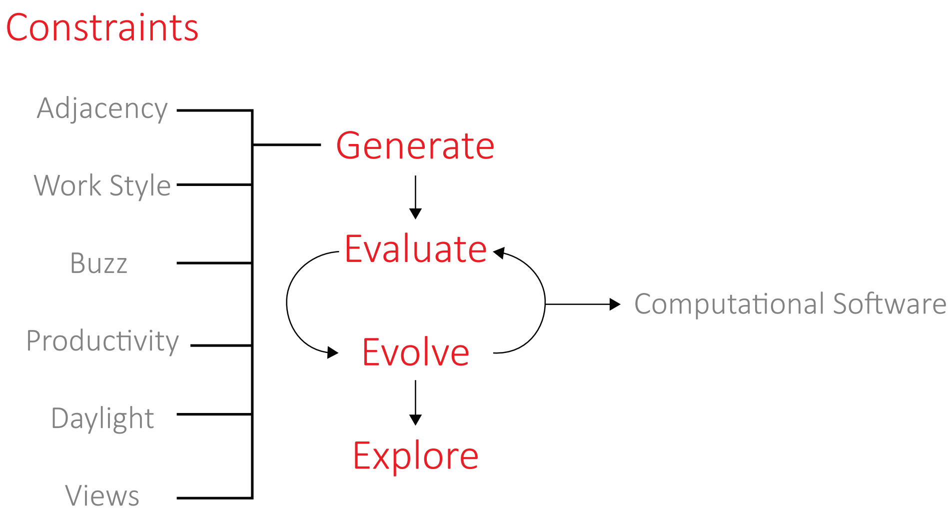


Figure 6: Standard Generative Design Method

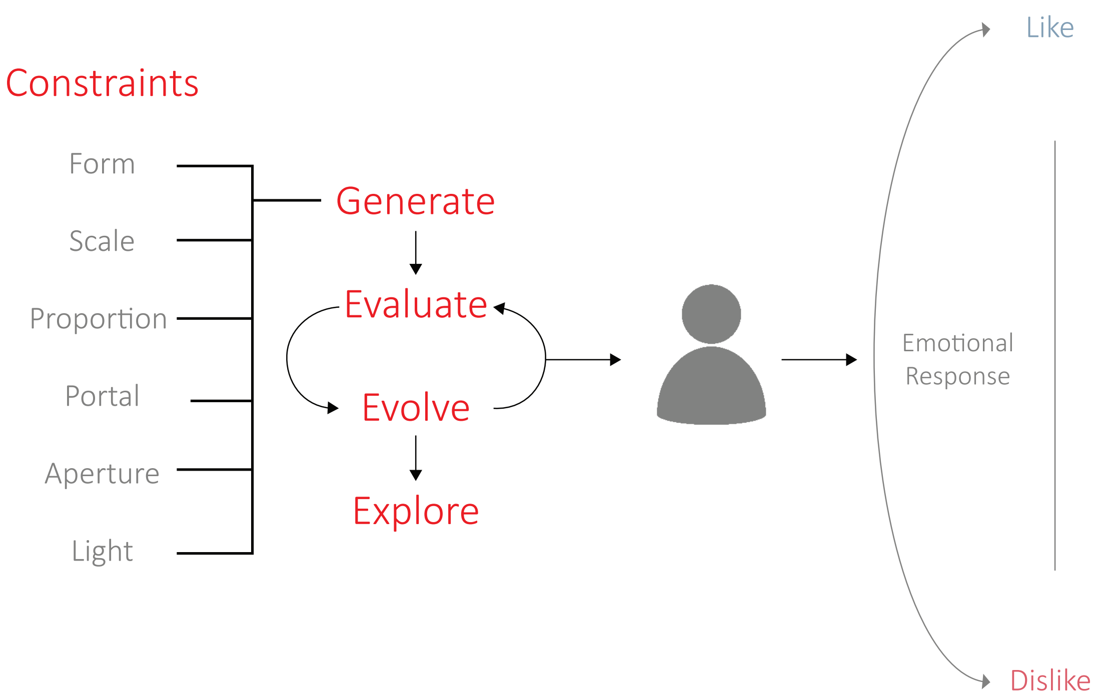


Figure 7: Proposed Generative Design Method

Process

The proposed test was done using a sample of 50 students at the University of Washington's College of Built Environments. The sample size included individuals under the age of 35 and was composed entirely of students studying architecture. Prior to the test students were briefed individually on the following conditions: they would be occupying this space for 1 year, this would be a shared space, and the space would be in zero gravity. Following this briefing each participant was placed in a chair that allowed them to rotate freely without standing. This was done for safety and consistency reasons, as all participants would be entering the VR environment under the same conditions. They were then asked to put on a Samsung Gear VR headset 2018 model (Figure 8). Upon putting on this headset a preloaded set of 360 jpeg images would appear for the students to view. Each of these spaces was modeled using Rhino 6 software and rendered in Lumion. The nature of this method and technological limitations meant that test participants were limited to experiencing the space from a fixed location. In addition to the fixed location test participants were limited to a fixed orientation. This meant that individuals would be in the center of a space and could look in any direction, but not tilt their view or move their position.

Once entering these VR spaces participants were instructed to select one of the five spaces that they preferred, and one of the five spaces that they disliked. They were then asked to give a brief explanation on what attributes made that space feel either desirable or undesirable to be occupied. There was no minimum or maximum time set on how long each participant could occupy a space, and they could freely navigate between each space as they wished. This process was repeated for each of the architectural elements being tested form, scale, proportion, portal, aperture, and light. Each test took ten to twenty minutes to complete and the tests took place over a two-week period in November 2019. The results were then recorded in an excel spreadsheet and used for the exploration phase of this thesis.

Figure 8: Samsung Gear VR Headset 2018 Year Model

Metrics and Form Generation

The metrics that were gathered from this test are based on a logic of duality. The dualities in this test were generated from the elements being tested. Form; was tested for orthogonal and circular spaces; scale; was tested for large and small spaces; proportion; was tested for tall and short spaces; Portal; was tested for the form and proportion of an opening; aperture; tested for the size and placement of an opening; and light was tested for central or peripheral lighting. Testing under the theoretical framework of dualities allowed for tangible and clear data to be produced. While it is clear that each of these elements are more complex than the dualities proposed, this test is merely a starting point for understanding the types of spatial characteristics people prefer when occupying a zero-gravity environment.

As stated earlier the metrics for each element in the test are based on a logic of dualities. The test spaces created followed this logic. A 10ft cubed space was used as the control when testing elements that are applied to a surface, which in the case of this thesis were the elements of portal, aperture, and light. Each space was tinted a light gray, and in situations where a reference of scale was important a scale figure was added along with grid lines on the surface of the test environment. (Figure 9) This occurred in the elements of form, scale, and proportion.

Each of the tested elements had five variations ranging from one of the duality parameters to the other (Figure 10). Form had on one end, a cubic space and on the other a spherical space with three hybrid forms between them. Scale had spaces ranging in size from 8 ft cubed to 25 ft. cubed. Proportion spaces were scaled varying from tall and narrow to short and wide. Portal spaces had an opening placed on the center of one surface within the test form. This opening varied between circular and orthogonal and was either symmetrical, or asymmetrical vertically. Aperture created openings that varied in size and location on a single wall. Spaces that tested light had either direct or indirect lighting of the space.

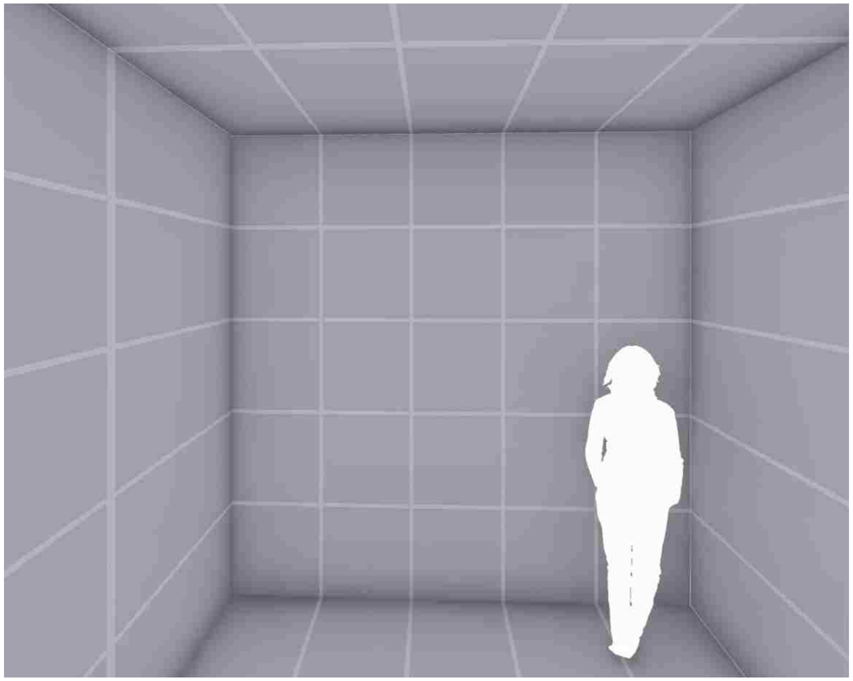


Figure 9: Test Environment (The test environment consisted of a scale person and gridlines on the walls)

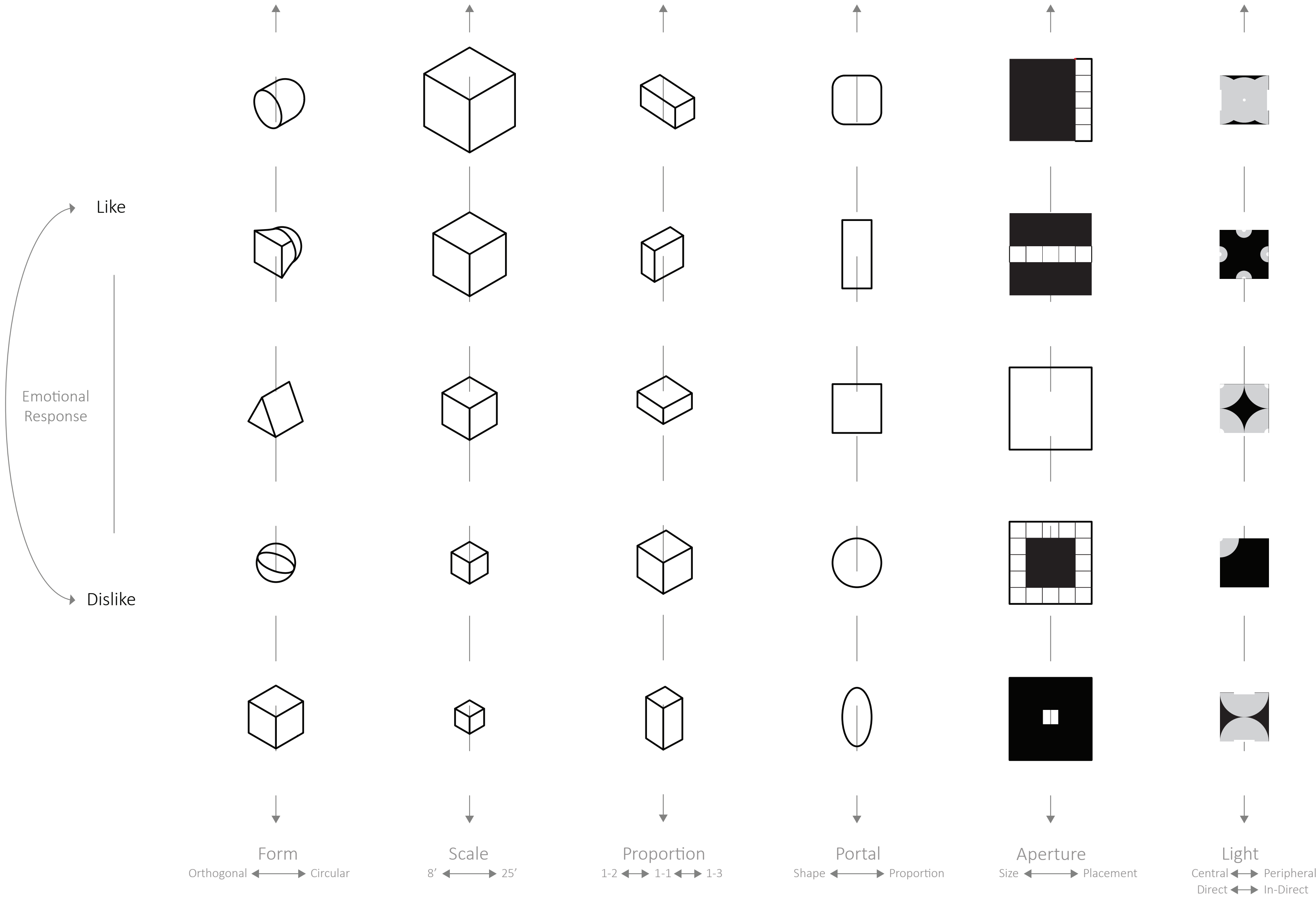


Figure 10: Test Parameters (The test consisted of 6 element categories, and a total of 30 unique spaces)

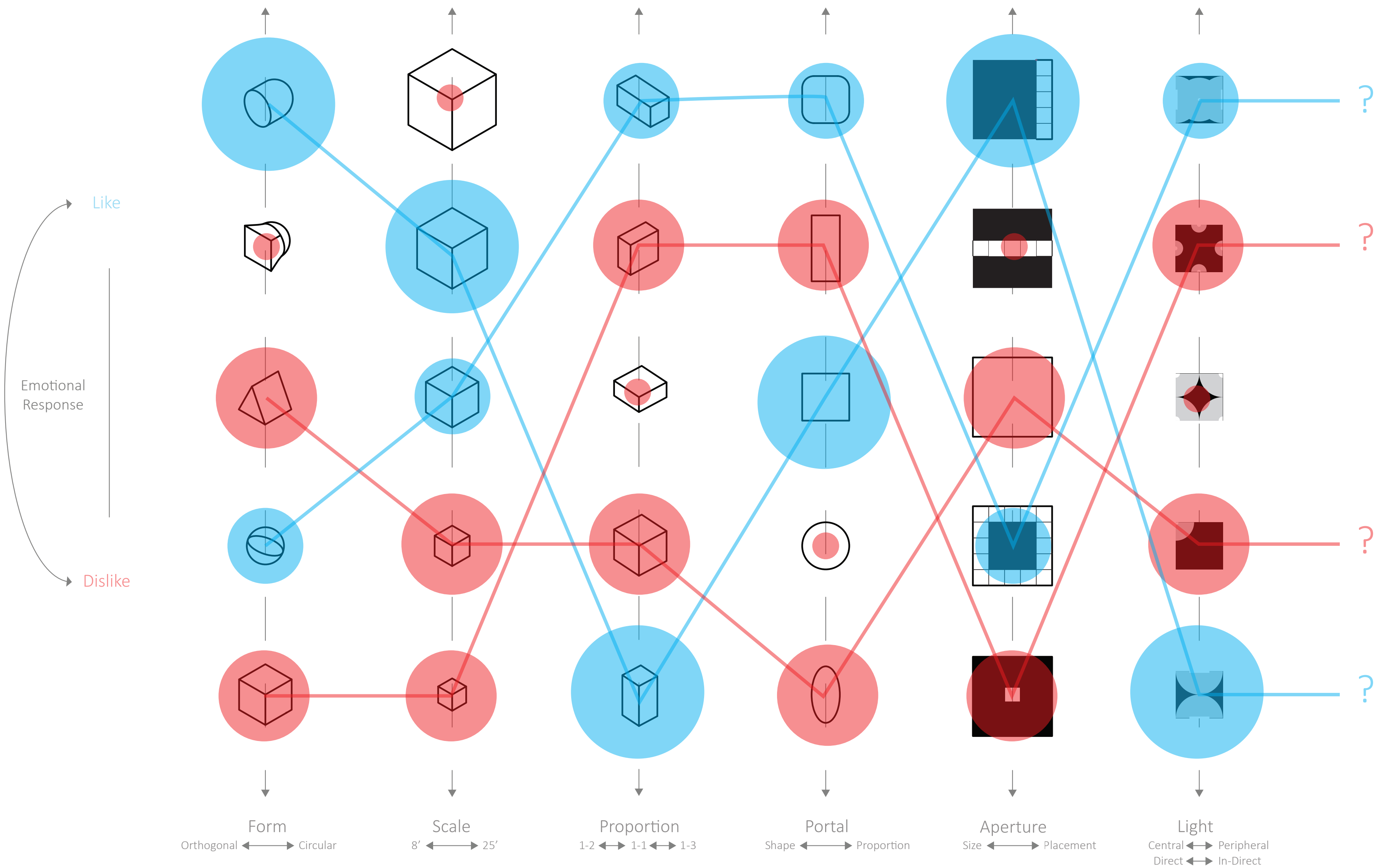


Figure 11: Combination of Attributes (this diagram shows the proposed method of combining attributes that individuals had preferences and aversions to)

Evolve and Evaluate

Following the results of the tests, this thesis worked to garner meaning from the information gathered. To achieve this, it combined the two most liked and two most disliked architectural attributes from each test category and generated four architectural spaces. These spaces were then tested amongst the original test participants to confirm if the combination of these attributes creates spaces that mirror the preferences and aversions of their individual elements (Figure11).

Explore

The explore portion of this thesis worked similarly to that of the generative design method used to create the MARs AutoDesk office. The resulting architectural form generated from the most desirable characteristics of each architectural element tested was be carried into this phase. Based on the variables being tested the program for the explore phase of this thesis was a common social space surrounded by individual sleeping modules. Utilizing the information gathered from the research portion of this thesis the space was developed into a module that can be attached to an existing space station. It must be understood that the purpose for the generation and development of this space is to test if the methodology proposed can produce a space that is seen as desirable by the original participants in the test. In addition, this test was only focused on understanding the visual characteristic individuals like and dislike in a space. Therefore, factors such as life-support systems, scientific equipment, and other elements of a space module were omitted from the design. This research is intended to be used as a base guideline for what visual architectural elements should be pursued and avoided in the development of a space module.

Conclusion

The previous section has demonstrated the potential of a hybrid generative design methodology that can be used to create a more habitable space module. It utilizes a modified version of the generative design method as proposed by the Autodesk MARS office. While this methodology is not fully refined at this point in the research it can, in fact bring to light an individual's preferences and aversion towards certain types of architectural elements. In the following section of this document this methodology was run on a sample size of 50 students in exercising this process this thesis seeks to understand if this methodology can generate a set of designs that individuals prefer and dislike.

IV: Findings

Test Results

After conducting the test these were the responses received from the test group. For references on the spaces tested and a key to what category theses spaces fell into please refer to the image reference key on page 38. The first factor tested in this thesis was form. This tested a set of spaces ranging from orthogonal in form to circular. The responses showed F1 had a total of 8 individuals that dislike that space and nobody who liked it. F2 had 30 individuals dislike that space and 5 who liked it. F3 had 0 dislike responses and 17 like responses. F4 had 12 dislike responses and 0 like responses. And F5 had 0 dislike responses and 33 like responses. The most desirable space within this group of parameters was F5 which was a hybrid form with one spherical end and one flat circular end. Participants reported that the mix of non-orthogonal, and orthogonal spaces made them feel comfortable. The most dislikes space from this category was F2 which was a sphere. Participants reported this space having no frame of reference they also noted it was confusing and uncomfortable to occupy.

The second factor tested what size of space individuals preferred. It tested a cubic form ranging in scale from 8 ft. cubed to 25 ft. cubed. S1 the smallest of the spaces had 42 dislike responses and 0 like responses. S2 the had 0 dislike responses, and 6 like

The second factor tested what size of space individuals preferred. It tested a cubic form ranging in scale from 8 ft cubed to 25 ft. cubed. S1 the smallest of the spaces had 42 dislike responses and 0 like responses. S2 the had 0 dislike responses, and 6 like responses. S3 had 0 dislike responses and 15 like responses. S4 had 8 dislike responses and 29 like responses. And S5 had no dislike or like responses. In this category individuals appeared to prefer spaces that were between 12ft cubed and 20 ft cubed. The participants strongly disliked spaces that were smaller that 10 ft cubed. Participants reported feelings of claustrophobia and discomfort when occupying spaces of this scale.

The third factor tested was proportion this compared forms ranging from tall narrow spaces to short wide spaces. P1 received 0 dislike responses and 6 like responses. P2 received 5 dislike responses and 20 like responses. P3 received 37 dislike responses, and 6 like responses. P4 received 8 dislike responses and 29 like responses. P5 received 0 dislike responses and 15 like responses. Participants tended to prefer forms that were closer to a perfectly symmetrical cubic form. They reported that spaces that were either too tall or too short made them feel uncomfortable. The fourth factor tested was Portal this tested the shape and proportion individuals preferred for an occupiable opening. The tested elements ranged from a standard door to circular and orthogonal forms. PO1 received 7 dislikes and 0 like responses. PO2 received 0 dislikes and 16 like responses. PO3 received 0 dislike responses and 14 like responses. PO4 received 43 dislike responses and 4 like responses. PO5 received 0 dislike response and 14 like responses. Participants strongly disliked the standard door and tended to prefer circular openings with rounded edges.

The fifth factor tested was aperture which consisted of testing the size and placement of visual openings on a single wall of a cubic form. A1 Received 0 dislikes and likes. A2 received 22 dislike responses and revived 10 like responses. A3 Received 0 dislikes responses and received 40 like responses. A4 received 10 dislikes and 0 likes. A5 received 18 dislike responses and 0 likes. Participants noted that larger apertures were more desirable and apertures that were along a corner brought them feelings of discomfort. The sixth and final factor tested was light. This test involved direct or indirect lighting either centered in a room or along the peripherals of a space. L1 received 0 dislike and like responses. L2 received 22 dislike responses and 10 like responses. L3 received 19 dislike responses and 7 like responses. L4 received 0 dislike responses and 43 like responses. L5 received 18 dislike responses and 0 like responses. Participants expressed interest in lighting situation where the light was peripherally located on the walls of a space and direct in orientation.

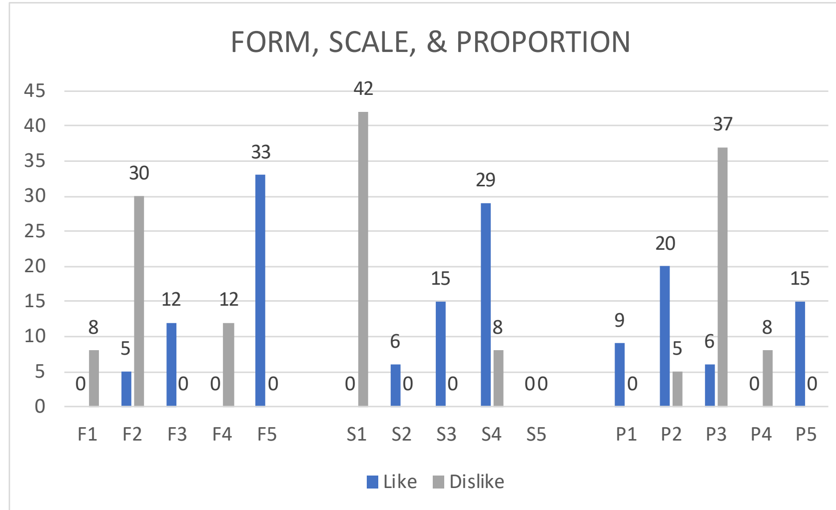


Figure 12: Form, Scale, & Proportion Results (the following chart displays the results of the first three elements tested in this thesis.

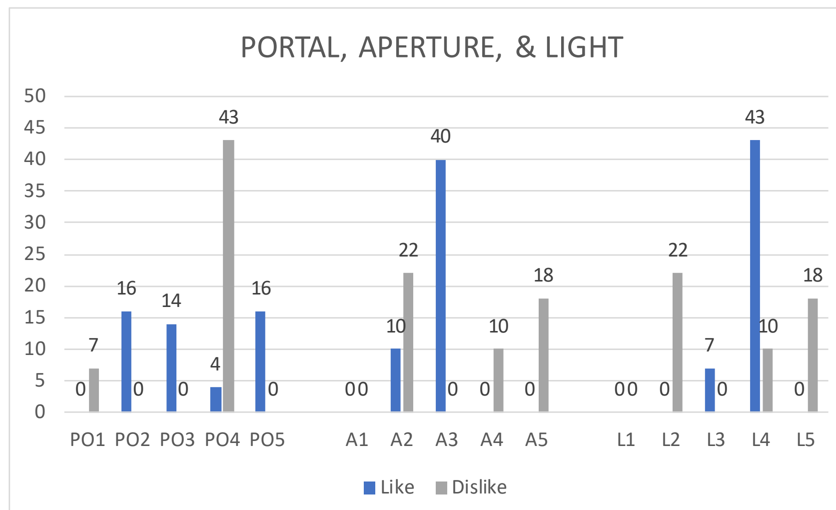


Figure 13: Portal, Aperture, & Light Results (the following chart displays the results of the second set of elements tested in this thesis)

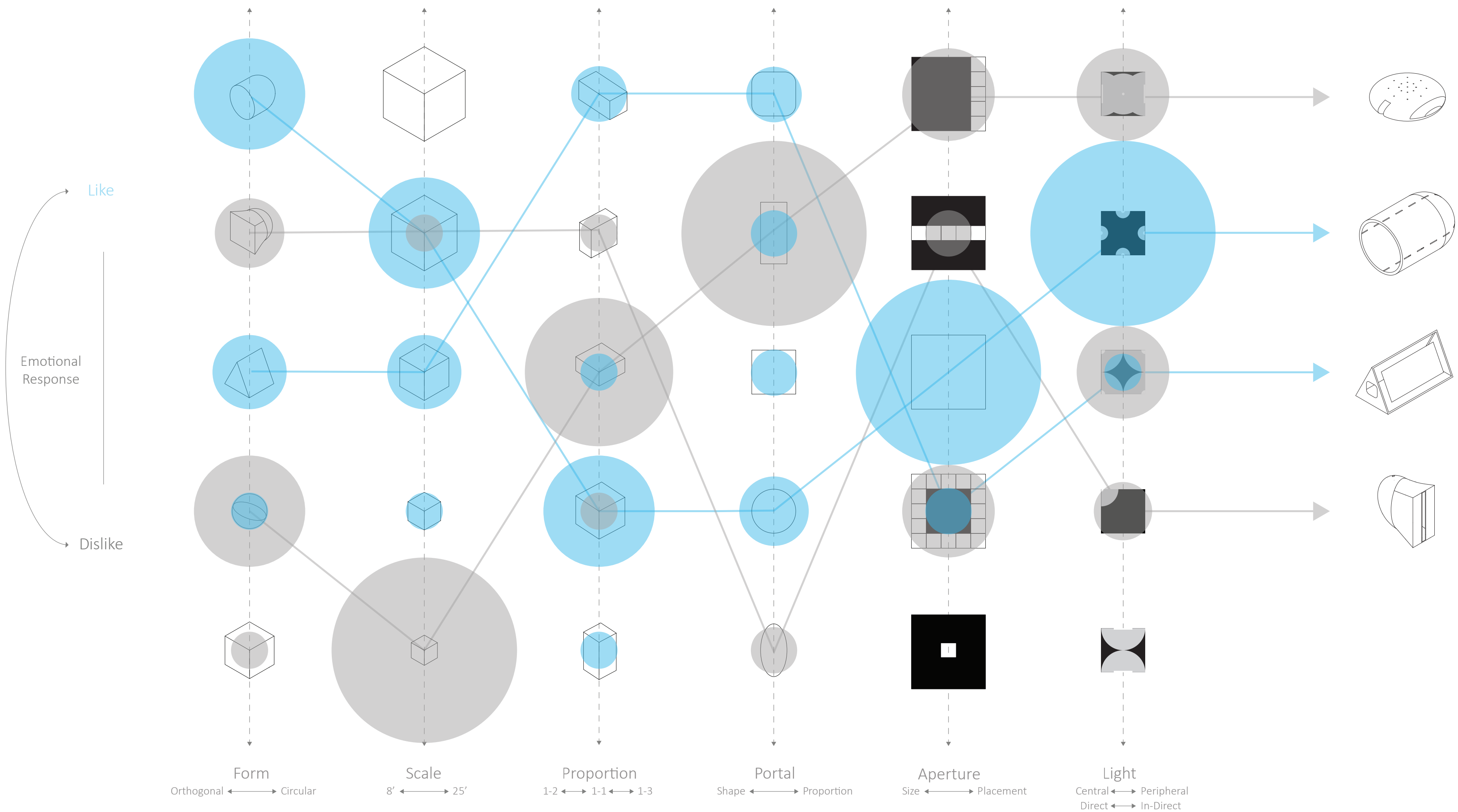


Figure 14: Combination of Test Results (this diagram shows the combined attributes that individuals had preferences and aversions. This combination of elements created the four forms seen above)

Desired Traits

Following the results of the test, the data was used to distill what types of characteristics individuals dislike when occupying a space. The characteristics individuals had a preference for were cylindrical or triangular forms with at least one flat plane. Spaces ranging in size from 3,375 to 8,000 cubic feet. A proportional form that is near that of a perfectly symmetrical cube. A portal shape that is either a circle or a square with rounded edges. The largest aperture possible, and peripheral lighting that is either direct or indirect. The following images represent the type of space these characteristics would create.

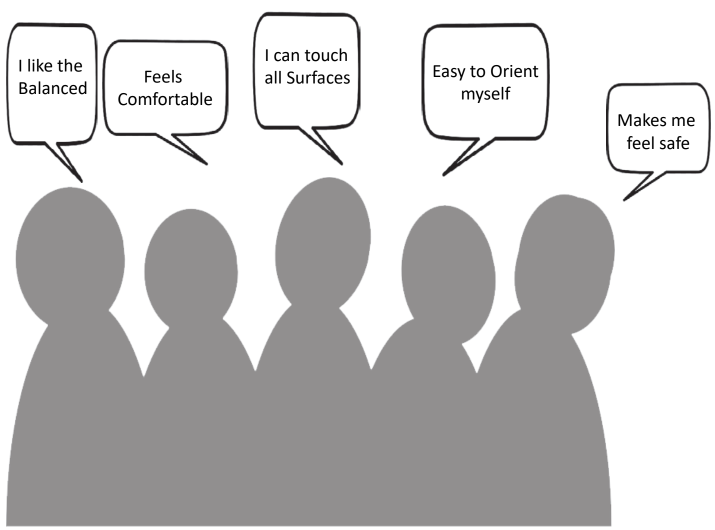


Figure 15: Participant Comments

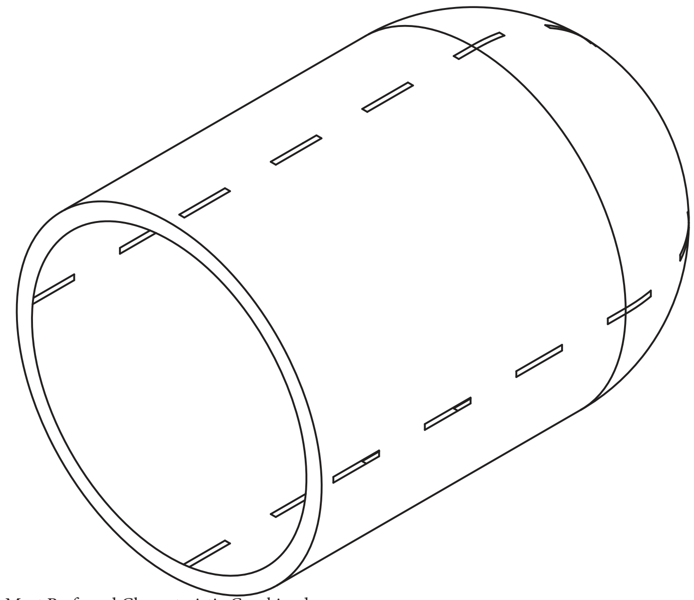


Figure 16: Most Preferred Characteristic Combined

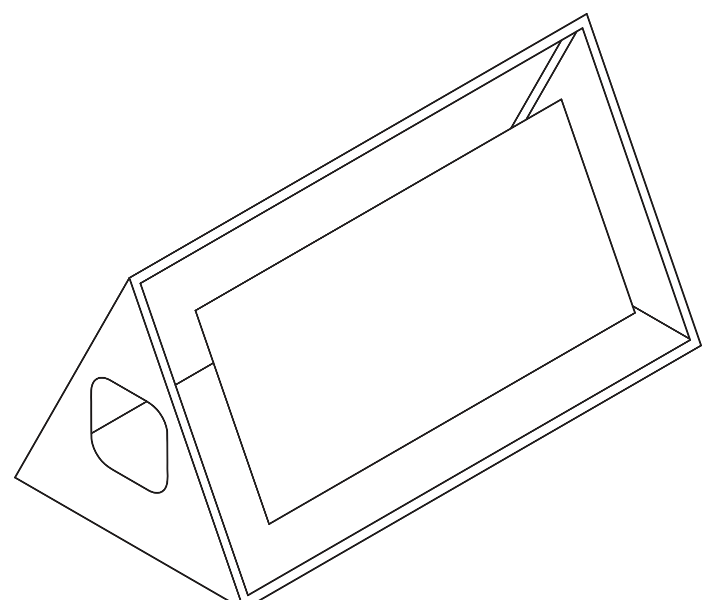


Figure 17: Second Most Preferred Characteristic Combined

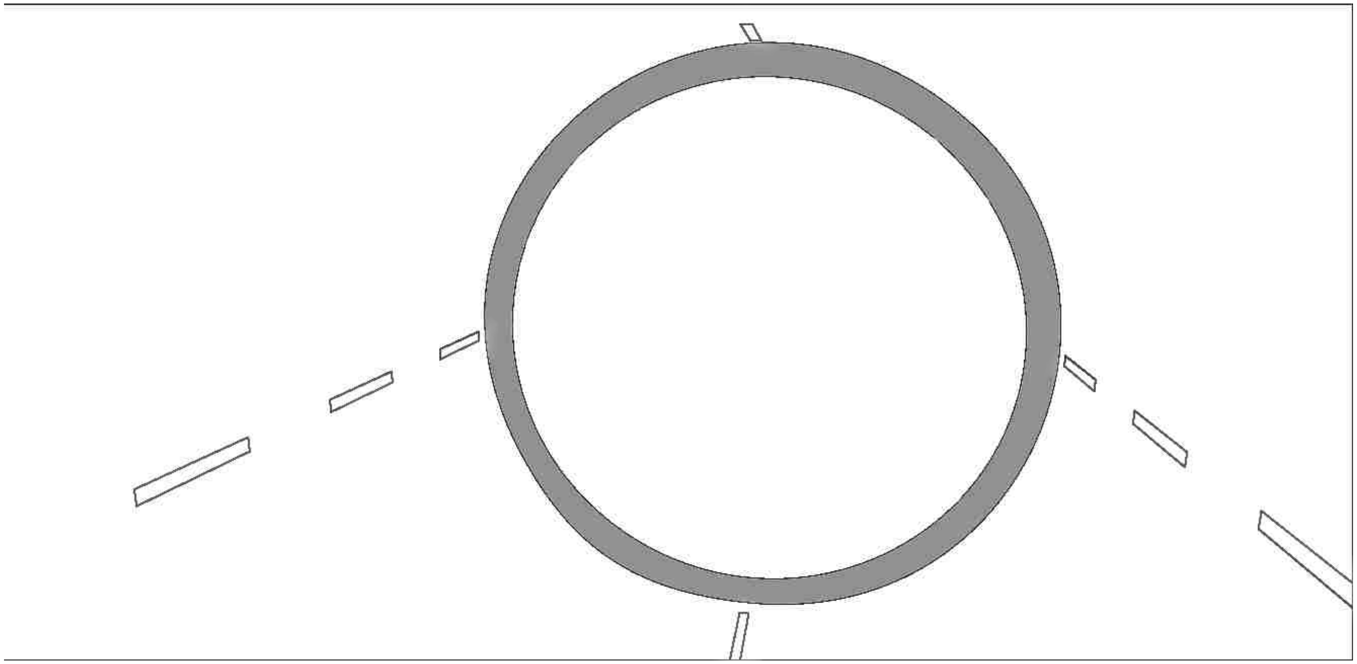


Figure 18: Most Preferred Characteristic Perspective

Figure 19: Second Most Preferred Characteristic Perspective

Undesirable Traits

Traits that participants had an aversion to were any circular form that has no flat areas or forms that had an abrupt transition from circular to orthogonal. Any space smaller that 512 cubic feet, any form that is disproportionately tall or wide. Portals that are either too tall or wide regardless of the shape and participants viewed shard edges as undesirable. Any aperture that is banded across a space in the direct center of a surface of offset to a single corner, and lighting that is centrally located and direct in orientation. The following images represent the type of space these characteristics would create.

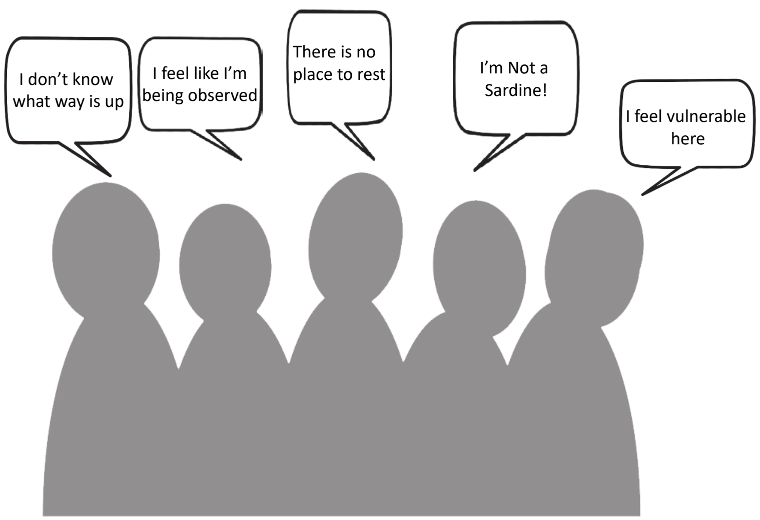


Figure 20: Participant Comments

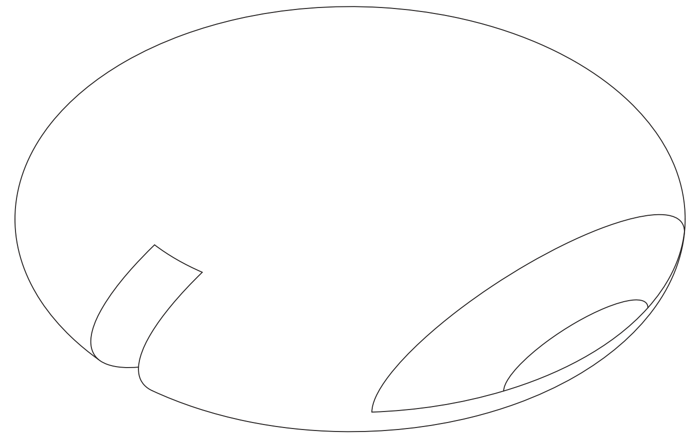


Figure 21: Most Disliked Characteristic Combined

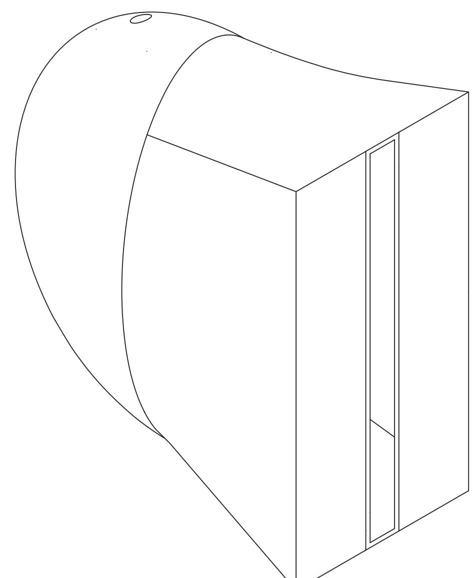


Figure 22: Second Most Disliked Characteristic Combined

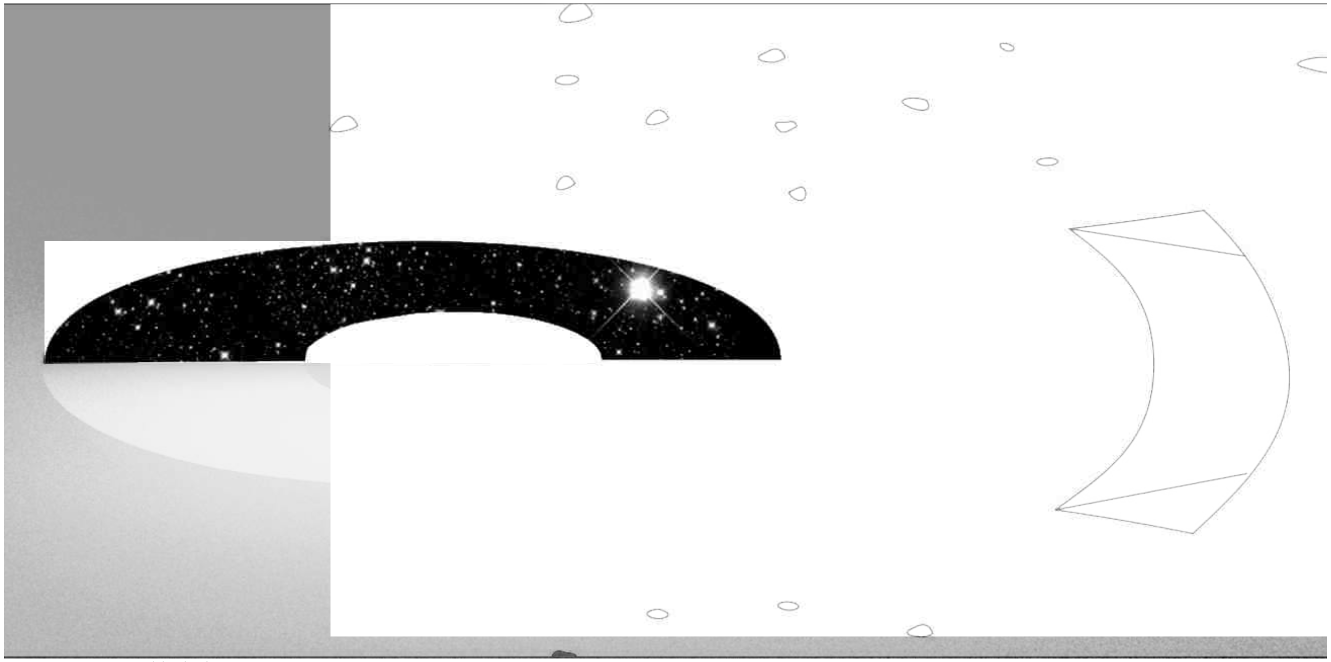


Figure 23: Most Disliked Characteristic Perspective

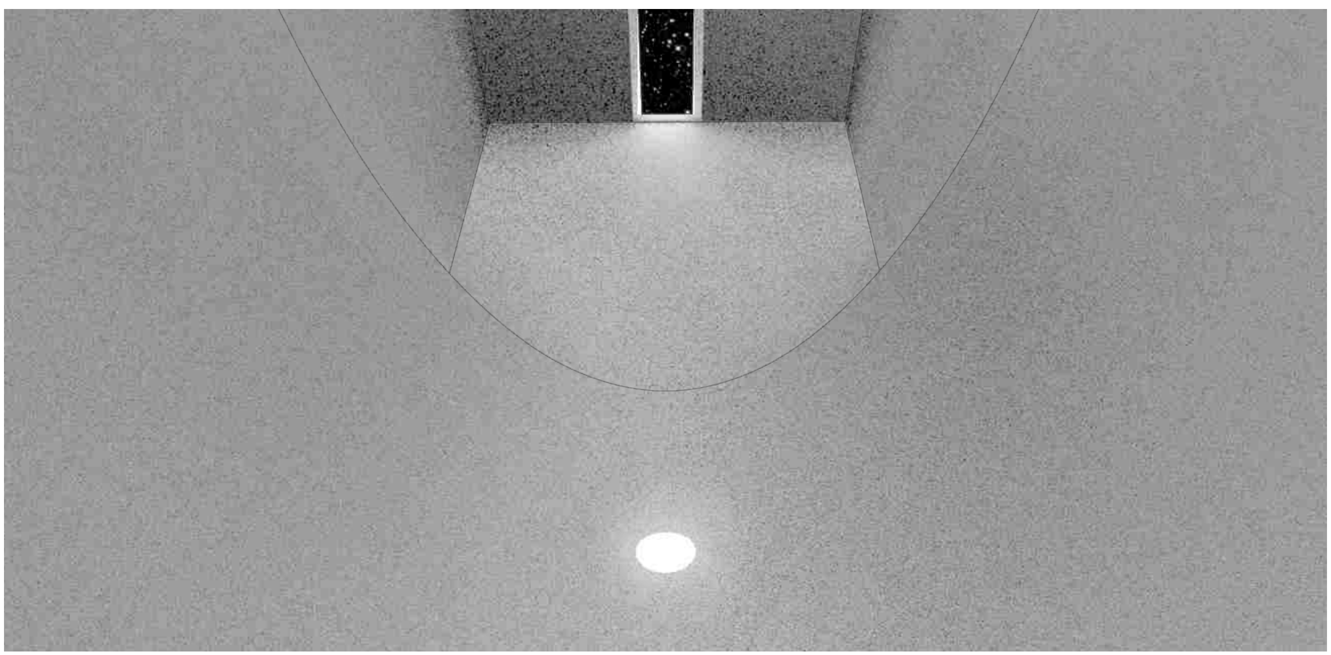


Figure 24: Second Most Disliked Characteristic Perspective

The Design

For the exploration phase of this thesis the elements that were seen as most preferred were added together to create the form seen in Figure 25. These Elements are a cylinder form with a spherical end. A volume of 4,100 cubic feet, a symmetrical 1/1/1 proportion. A circular portal, a large aperture, and a peripheral direct lighting condition. Using the research gathered earlier in this thesis this design was developed to serve as a communal space surrounded by 16 sleeping pods. This module is meant to be attached to a larger station that is pending development. It serves only to house individuals for sleeping and leisure activities and is not meant to be a self-sustaining station.

Entering the space is a circular portal that is 4 ft. in diameter this allows for two individuals to pass by one another when trying to get in or out of this module. The circular portal was one of the preferred elements by participants and was integrated for this purpose. Upon entering one is greeted with a large aperture at the opposite end of the habitation module (Figure 27). This opening spans 14 ft. in diameter and offers occupants stunning views and natural light. Flanking this opening is four standing stations. These are flat workstations that allow occupants to work on a flat surface through foot handles located at the base of each of these tables. Foot handles are currently used in existing space modules and are present in the international space station.

Turning back and looking towards the portal shows 16 doors offset from the midpoint of the module these doors are designed with rounded edges, and open to each occupant's sleeping quarters (Figure 26). The sleeping quarters offers 300 cubic feet of personal sleeping space. Lining the walls of the Habitation module are bands of light that illuminate the space from four directions. These are placed symmetrically for optimum lighting and as discussed in the perception portion of this paper help to promote orientation. Along the spherical portion of the habitation module is a padded rest area where occupants can strap themselves down and enjoy stationary leisure time (Figure 26). The habitation module produced is by no means a finished product it is a rough estimation of what could potentially emerge from the methodology proposed in this thesis. It does not take into consideration many of the equipment and systems that allow for a module like this to exist. It does, however, reflect the spatial conditions that participants preferred. This is only one synthesis of the data gathered and offers a suggestion to what might be a more habitable space module.

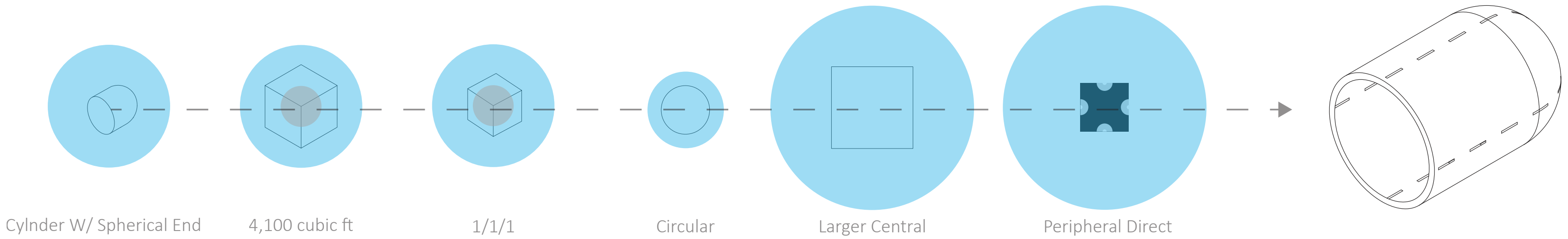


Figure 25: Most Preferred Characteristic For Design Synthesis

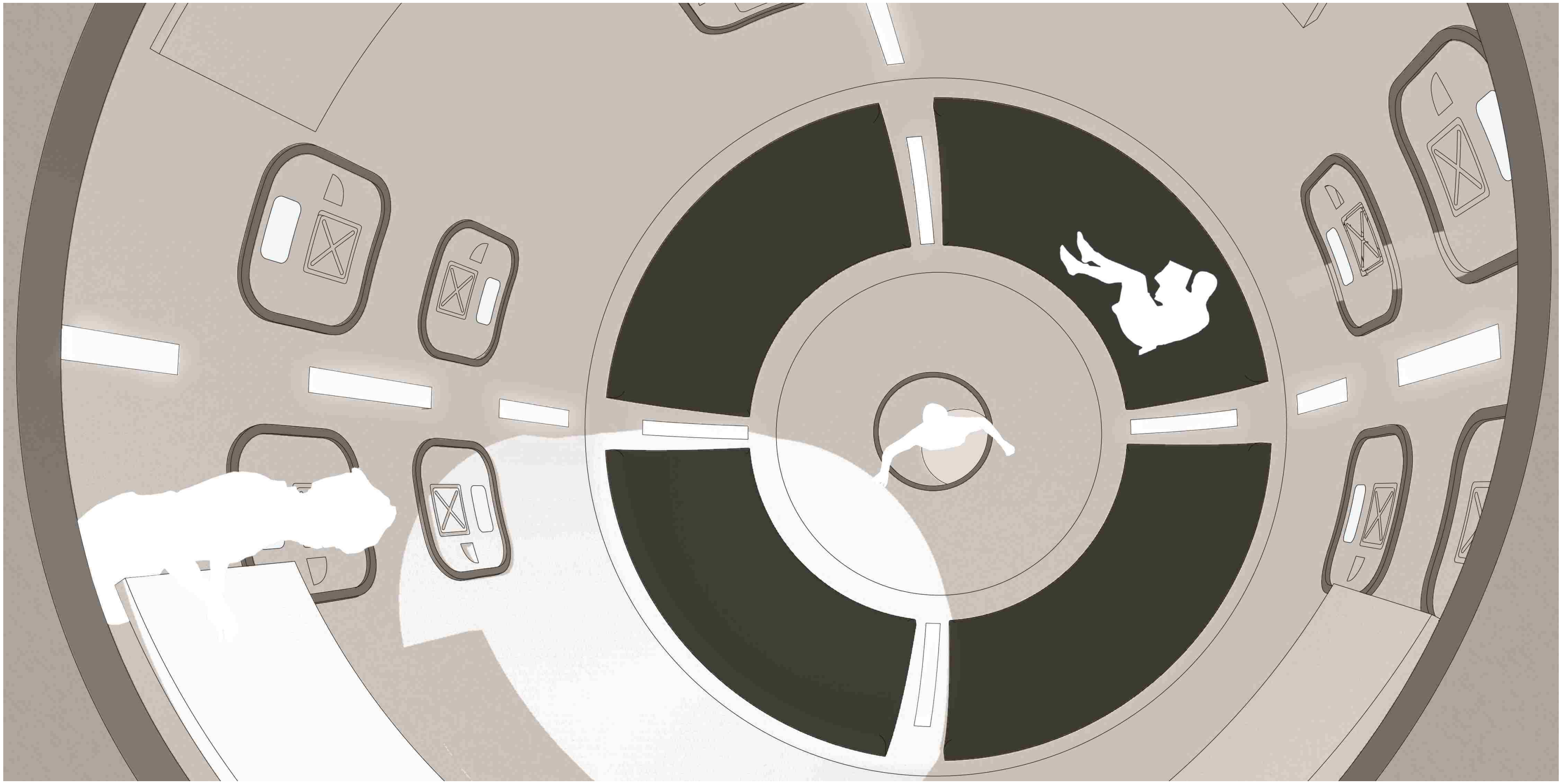


Figure 26: Interior Perspective of Space Module (This image is looking towards entrance portal)

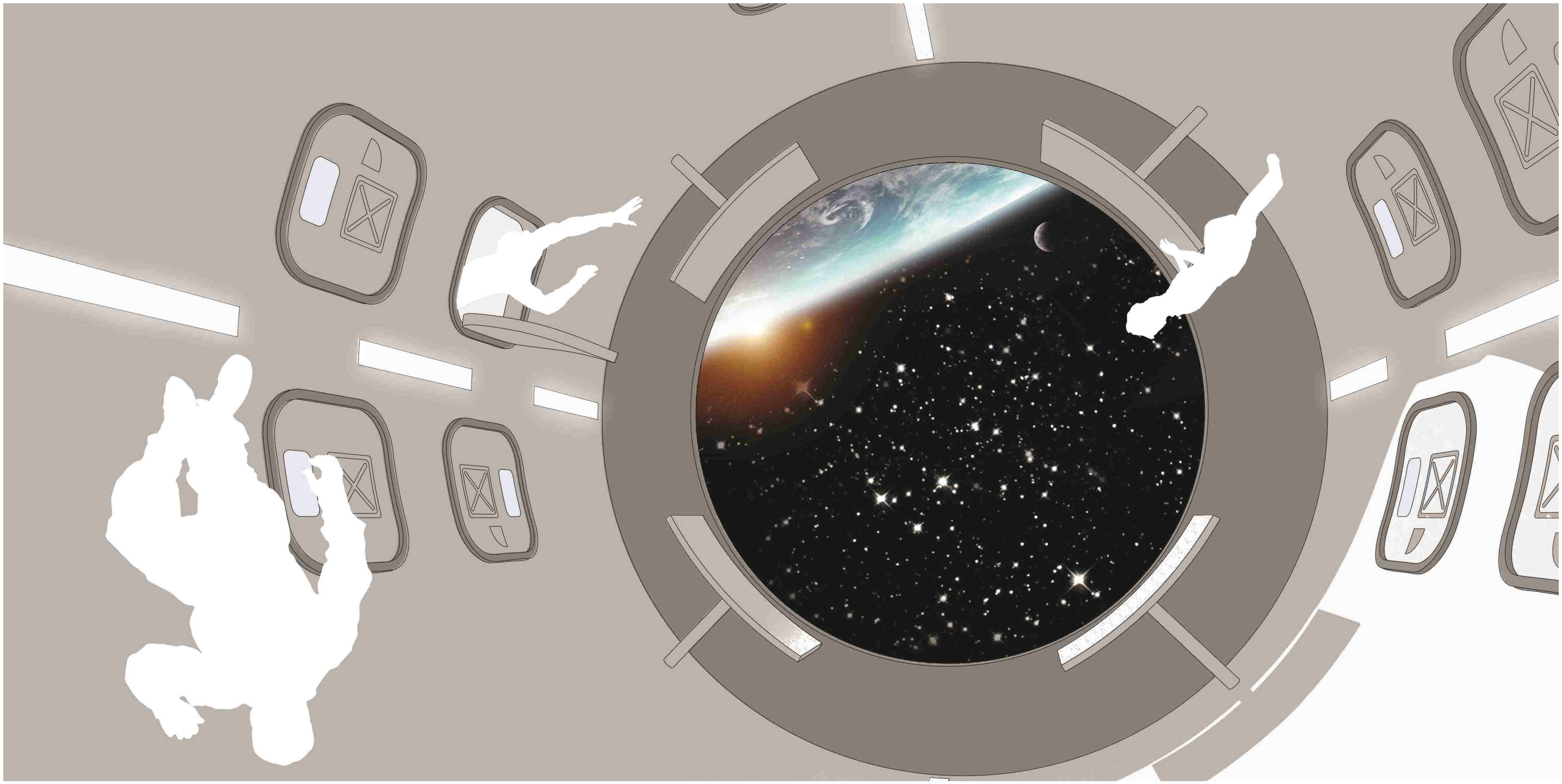


Figure 27: Interior Perspective of Space Module II (This image is looking towards the large aperture)

V: Conclusions & Reccomendations

It can be said that in order to find the right answer you must first ask the right question. This thesis attempted to question if the development of a new methodology for design could provide the basis for designing in a zero-gravity environment. It used the development of a more habitable space module as the vehicle to achieve that goal. It proposed a methodology that took the elements of architecture as discussed by Rib Krier and plugged them into a modified version of the generative design methodology used by The Living in their Autodesk MARs office. This methodology utilized a group of 50 participants to use virtual reality to establish their preferences, and aversion to 6 different elements and a total of 30 spatial conditions. The results were then taken and used to produce 4 distinct spaces. Two of these spaces were composed of the most preferred characteristics and two were composed of the disliked characteristics. Out of the four spaces the condition that most participants preferred was taken forward for development. The design was developed using the research gathered at the beginning of this paper and using the results of the test conducted. The space generated was ultimately created as a common space for a habitation module.

Upon completion of the first attempt of a methodology for design in zero gravity it has become obvious. that the testing methods need a more rigorous basis. The dualities used for the first three variables of Form, Scale, and proportion have an understandable duality logic, while the next three portal, aperture, and light, do not. Instead of testing a true duality they try to measure multiple dualities at once, which invalidates the data. If the test were to be run again, these elements would be altered to measure a true duality. Another change would be the addition of more conditions within the tested elements. The test only consisted of 5 variations of each element tested. This limited range of experence of spaces meant that participants could only like object in three categories. They could choose between two extremes or a hybrid. A revised version of this test might consider adding more variables or considering a gradient method of a morphing space instead. This would involve participants occupying an element that starts off in one extreme of the duality being tested and slowly morphs into the other. It would allow participants to stop in the morphing sequence when they have reached their most preferred version of the space. A test like this could offer a gradient of results that would be more indicative of how people actually feel about a space. This test was also limited due to the fact that it only tested the visual nature of space. A more developed version of this test would find a way to integrate more of the sensations associated with occupying a space. A test integrating the senses of touch, smell, and sound could be added in order to focus on a more precise design. Technology was one of the most pronounced limitations of this test. The VR headset used, along with the rendering method only allowed for participants to occupy a fixed position in the center of each of tested element. In addition to this, they were locked into a horizontal orientation and could not rotate on axis to give the perceived feeling of zero gravity. An ideal setup would involve a VR headset and environment that would allow for individuals to roam the tested element freely and rotate on an axis. The variables set in place by this test were also vague. The information given to participants of occupying the space for one year, and it being in zero gravity could have been more specific depending on what the test desired to achieve. The last change to the test would be adding more participants of a more diverse background. A group of 50 architecture students presents a homogenous test pool. Including more individuals of varying background could help gain a greater understanding of what participants prefer in a zero- gravity environment.

While this test was not by any means a perfect or properly functioning example of a methodology that may one day be adopted. It did provide an opportunity to question if designers actually design for what people want. What can be gathered from this process is that creating a methodology that takes into account the desires, wants, and needs, of many people is an extremely difficult task to achieve. People are complex and the issues associated with designing in a completely new environment is also complex. Pairing the two together creates a problem with a magnitude that not one person or methodology can solve. What can be said though is when gravity ceases to ground us we must find something else to inform our designs.

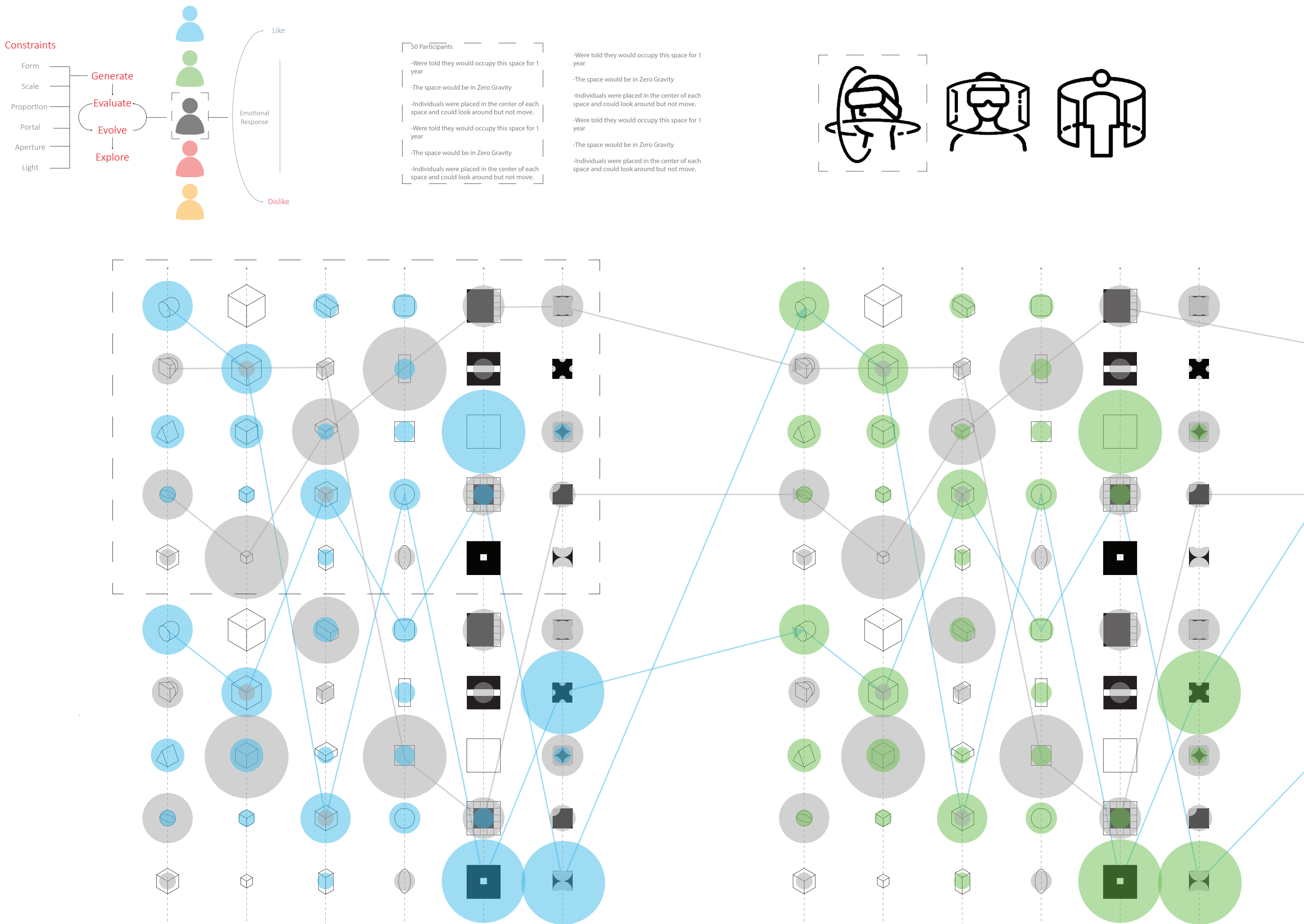
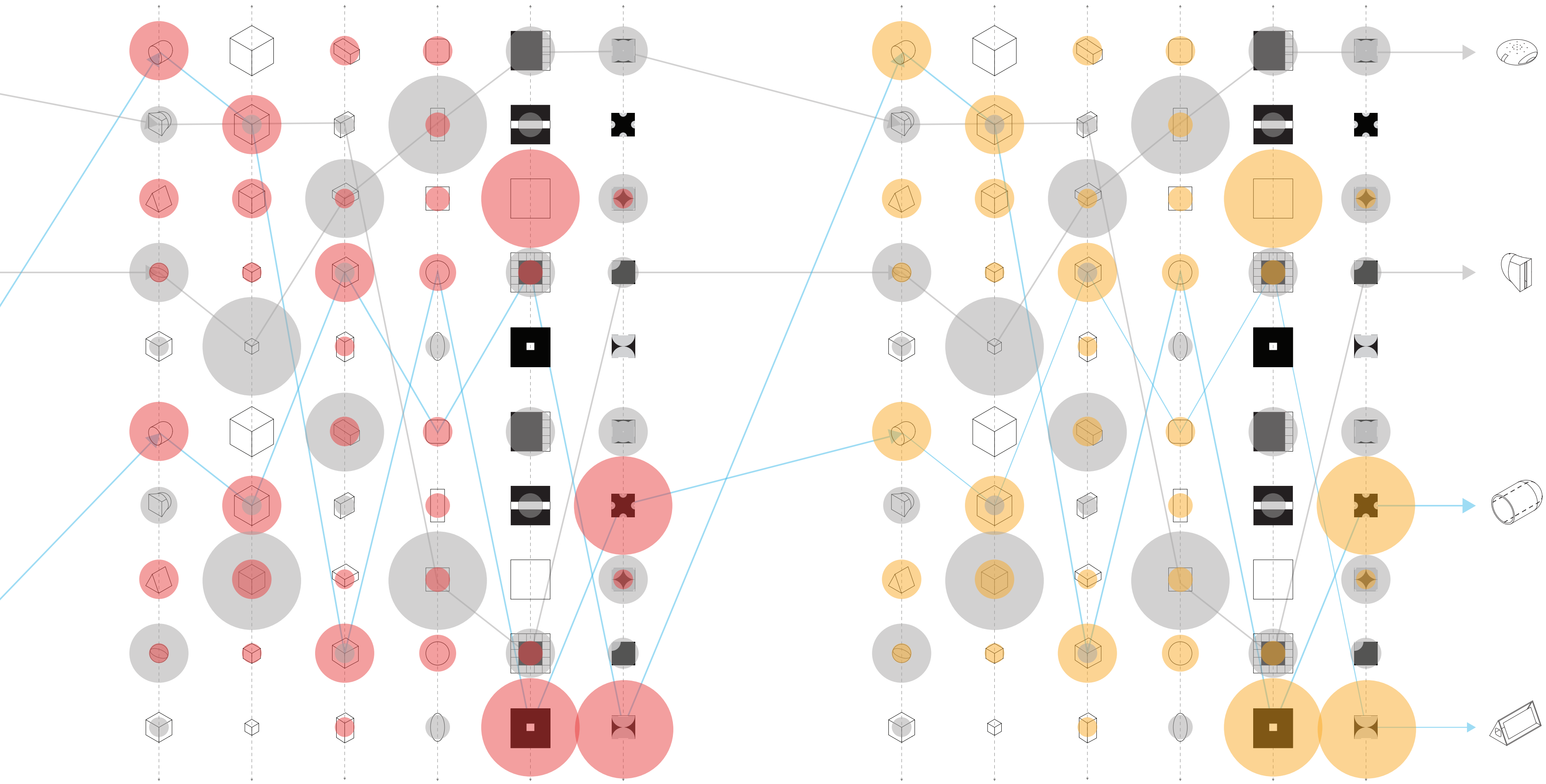


Figure 28: Visualization for Future Test (the following image is a visual representation of what a more complete test may encompass. The elements in this image that were part of the current test are enclosed in a dashed box)



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6)Ibid.

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8)Ibid.

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10)Ibid.

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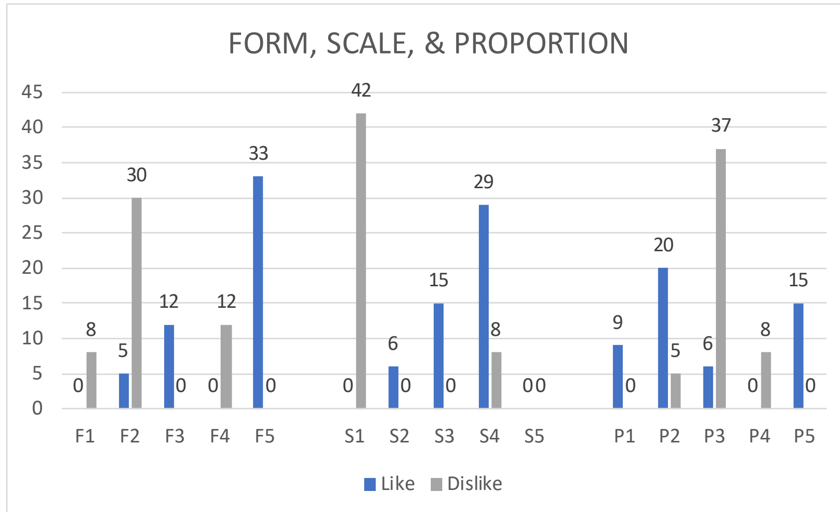


Figure 29: Form, Scale, & Proportion Results (the following chart displays the results of the first three elements tested in this thesis.

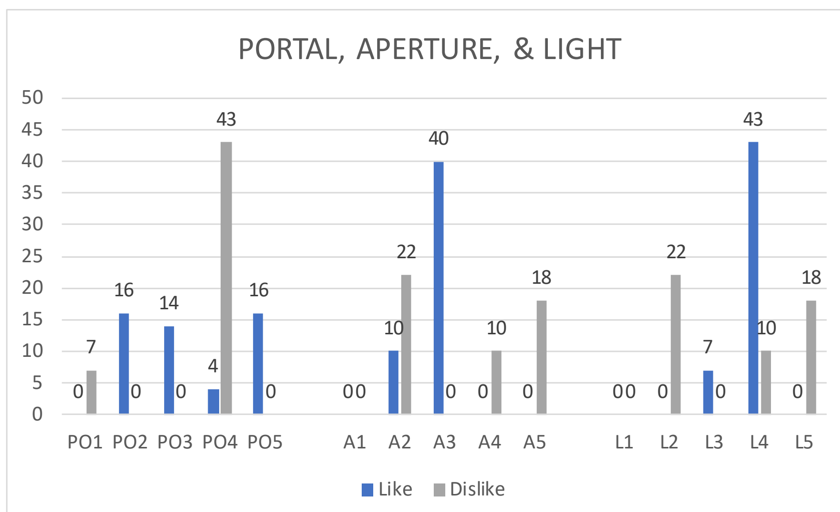


Figure 30: Portal, Aperture, & Light Results (the following chart displays the results of the second set of elements tested in this thesis)

Image Reference Key

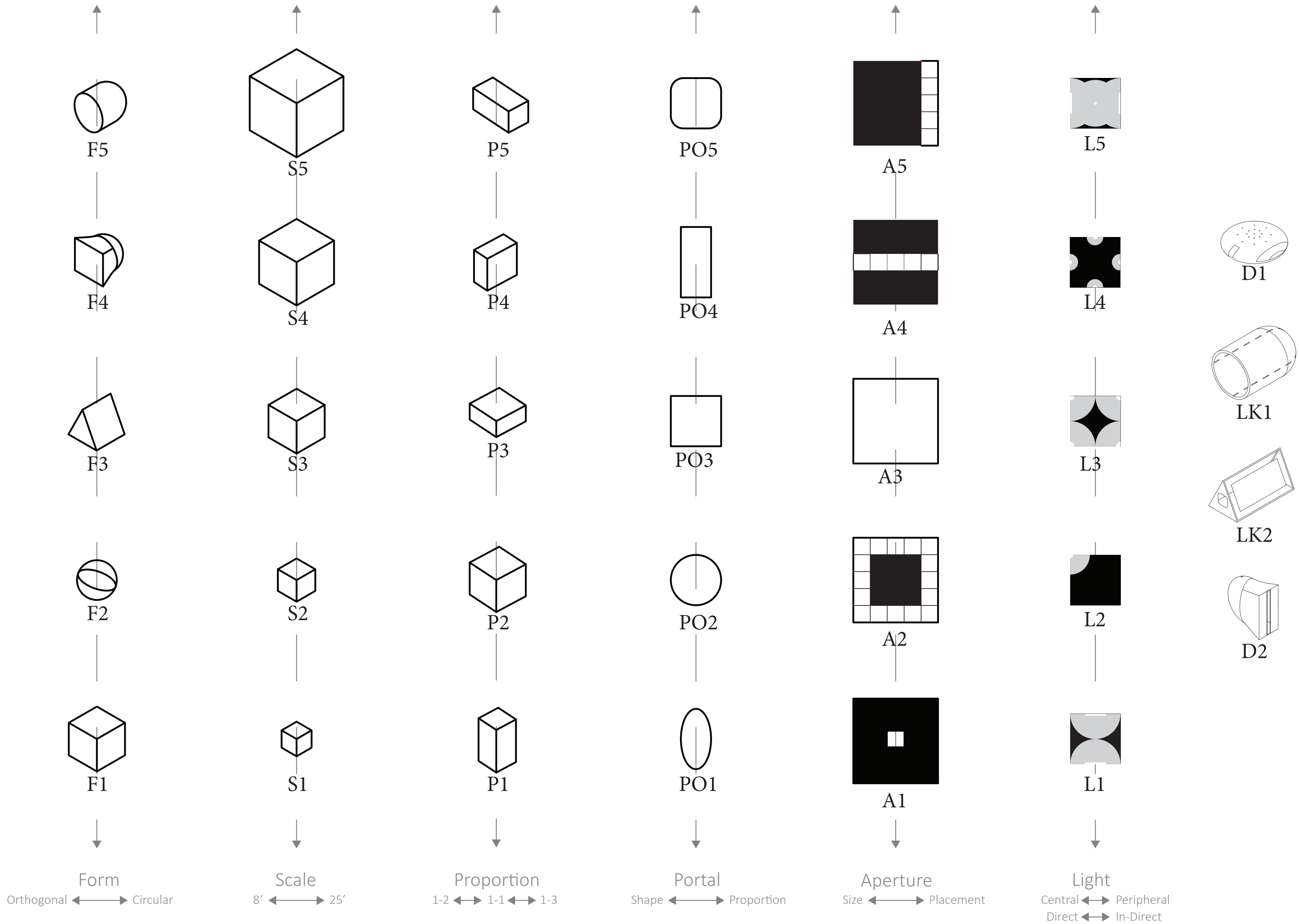
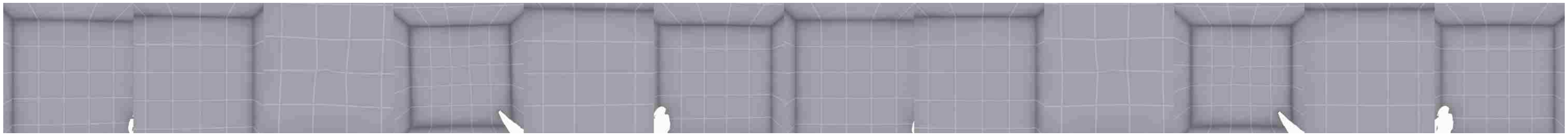
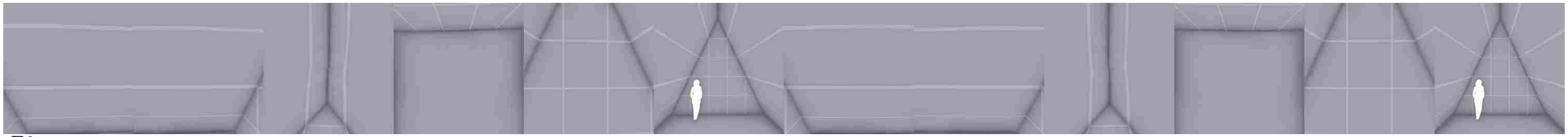


Figure 31: Image Reference Key

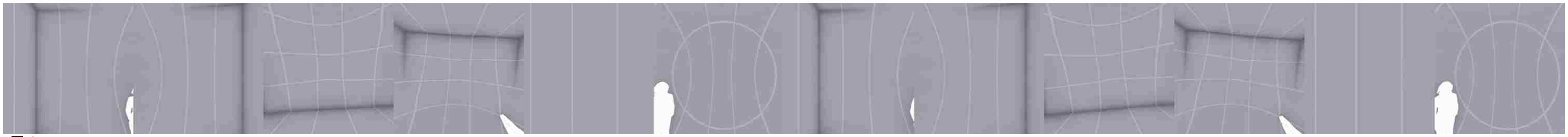


F1 Figure 32: Form 1 Cube

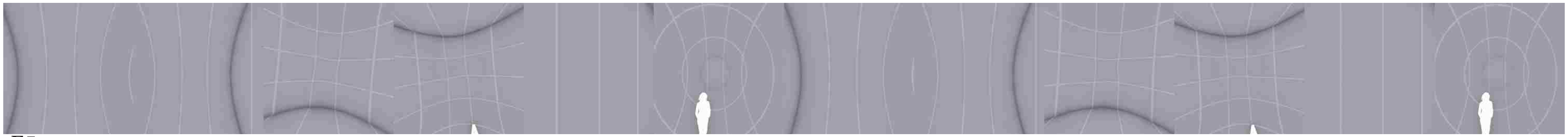
F2 Figure 33: Form 2 Sphere



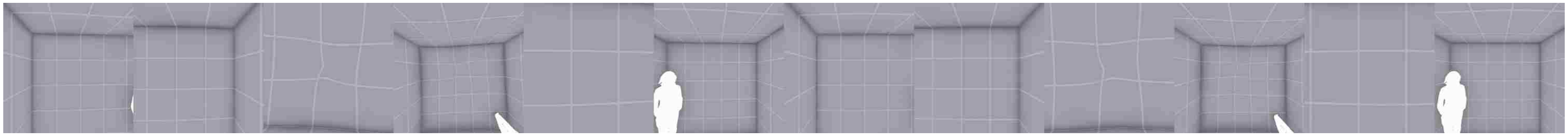
F3 Figure 34: Form 3 Triangular Prism



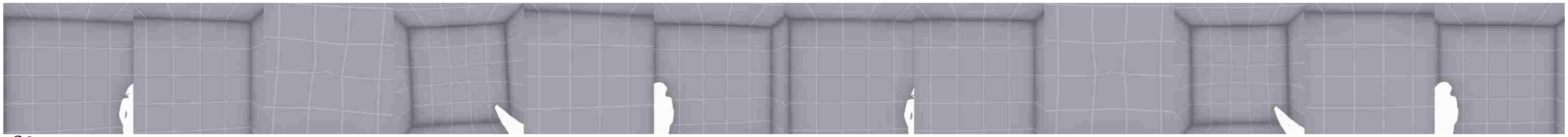
F4 Figure 35: Form 4 Hybrid



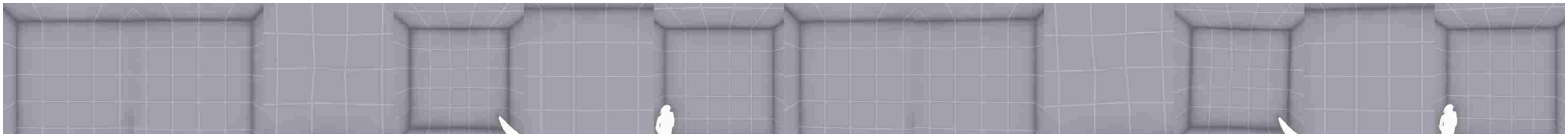
F5 Figure 36: Form 5 Hybrid



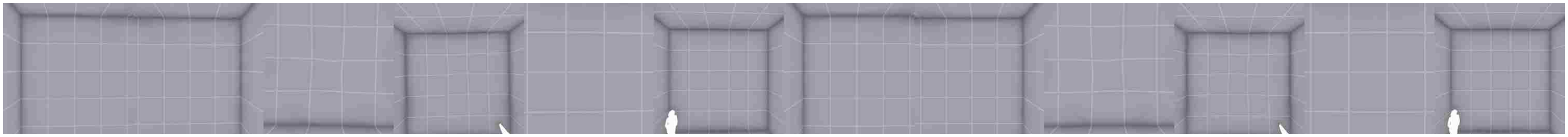
S1 Figure 37: Scale 1 8 ft. cubed



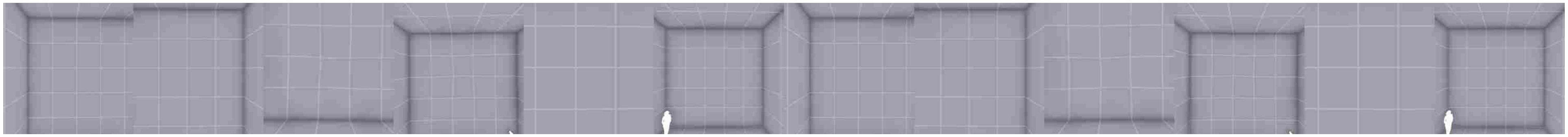
S2 Figure 38: Scale 2 12 ft. cubed



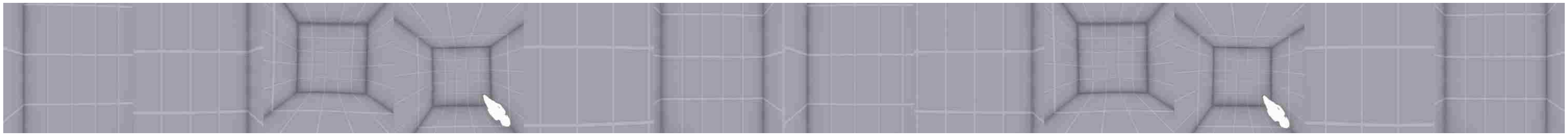
S3 Figure 39: Scale 3 16 ft. cubed



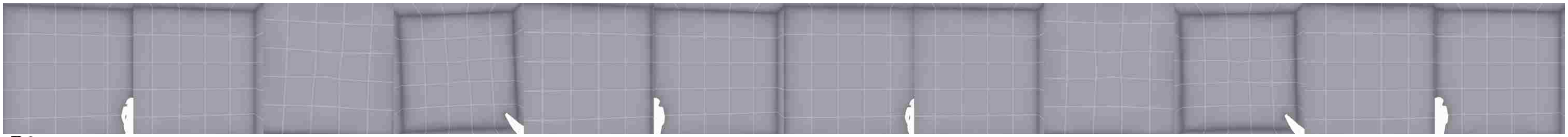
S4 Figure 40: Scale 4 20 ft. cubed



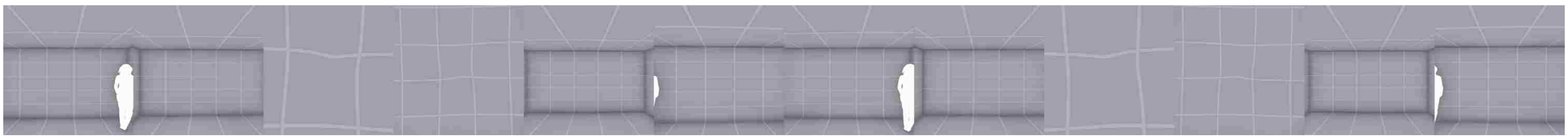
S5 Figure 41: Scale 5 25 ft. cubed



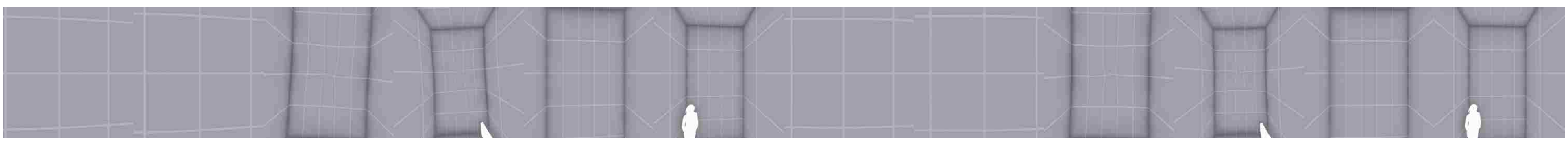
P1 Figure 42: Proportion 1



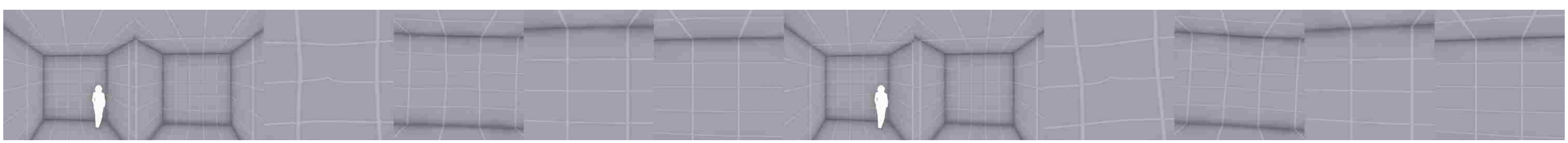
P2 Figure 43: Proportion 2



P3 Figure 44: Proportion 3



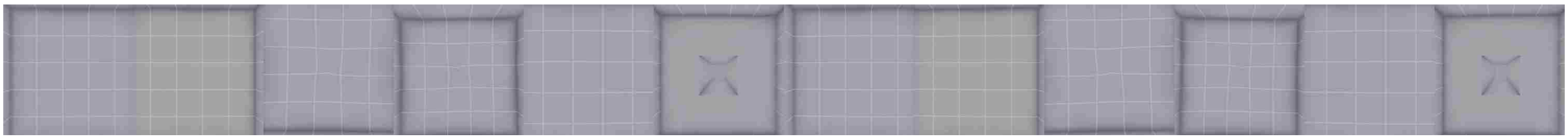
P4 Figure 45: Proportion 4



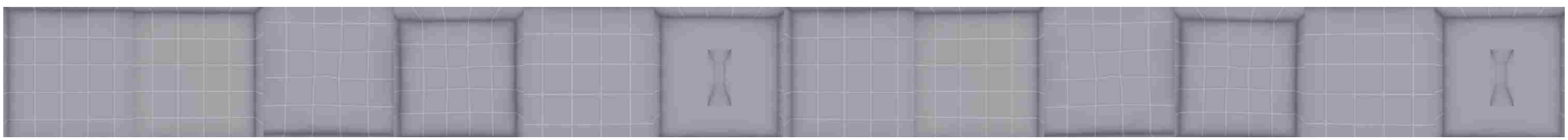
P5 Figure 46: Proportion 5

PO1 Figure 47: Portal 1

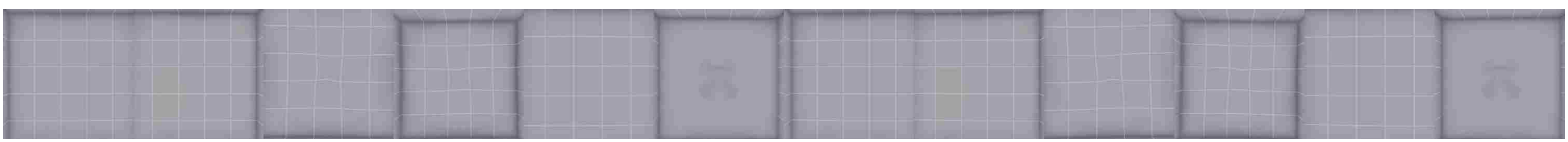
PO2 Figure 48: Portal 2



PO3 Figure 49: Portal 3

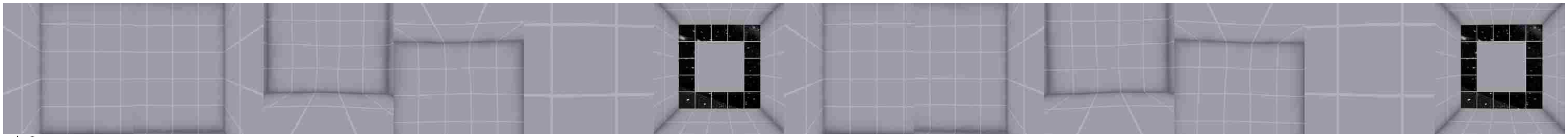


PO4 Figure 50: Portal 4



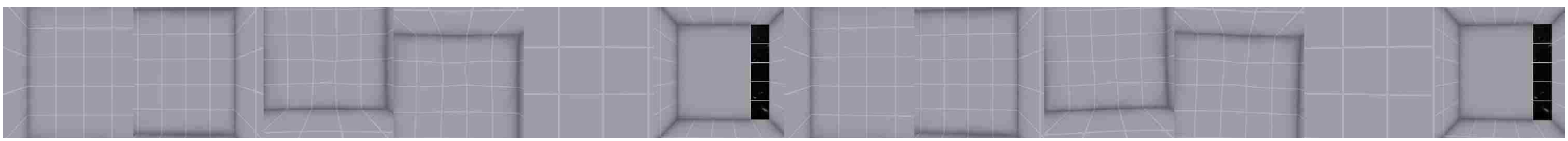
PO5 Figure 51: Portal 5

A1 Figure 52: Aperture 1

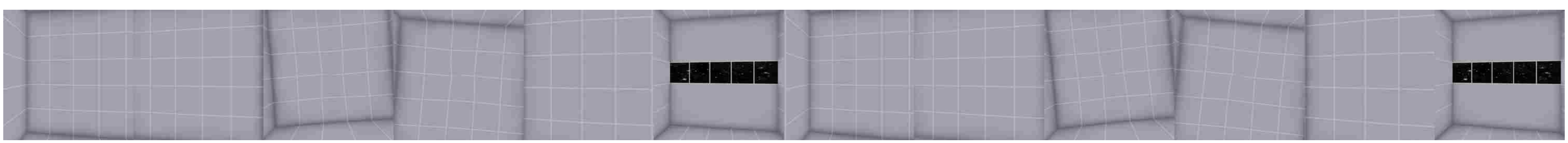


A2 Figure 53: Aperture 2

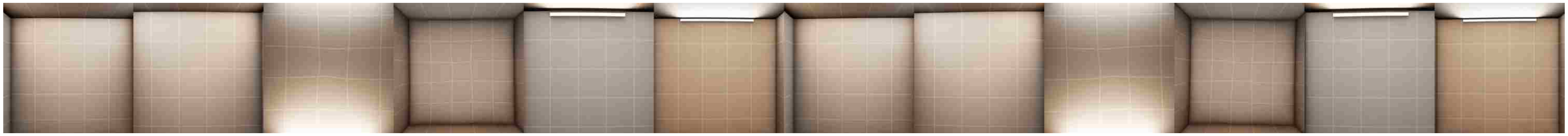
A3 Figure 54: Aperture 3



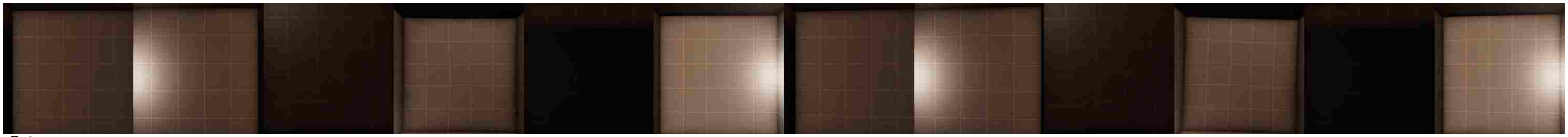
A4 Figure 55: Aperture 4



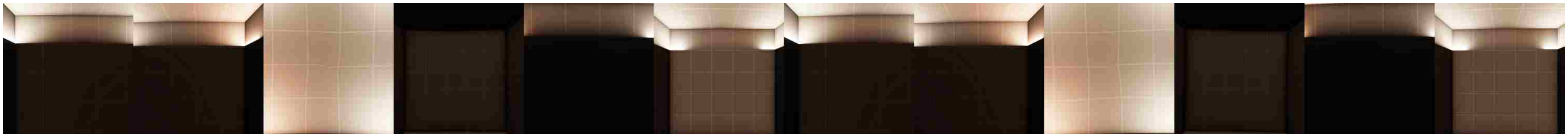
A5 Figure 56: Aperture 5



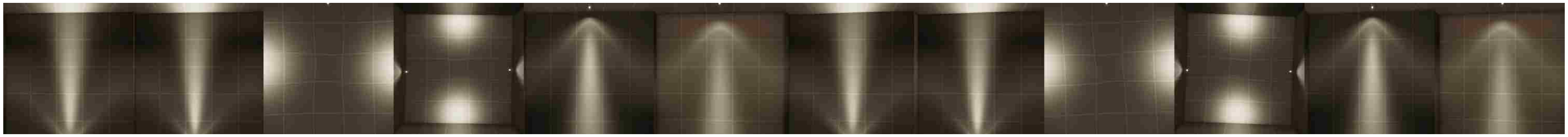
L1 Figure 57: Light 1



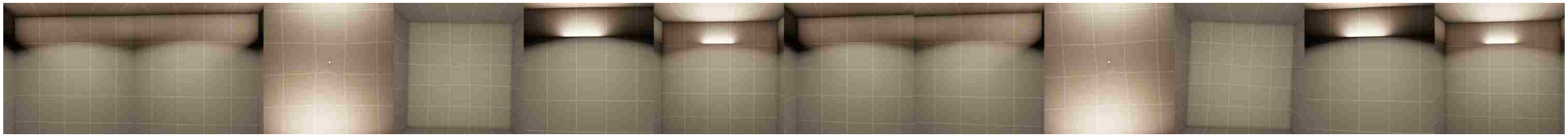
L2 Figure 58: Light 2



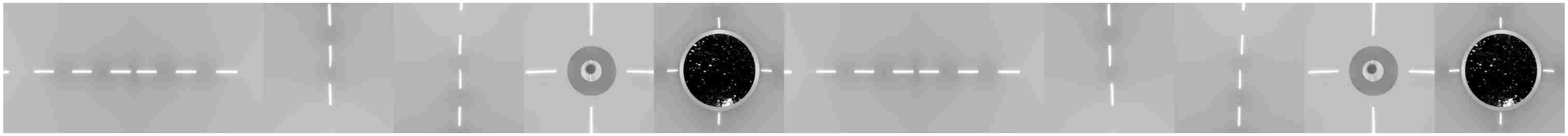
L3 Figure 59: Light 3



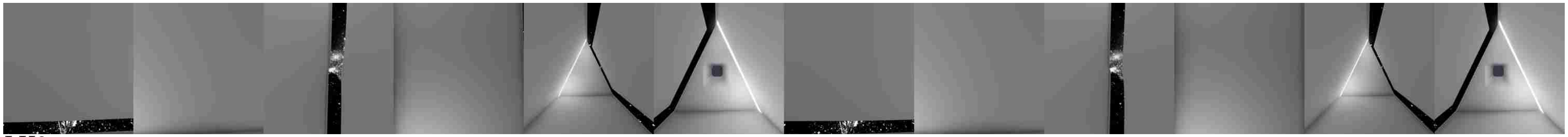
L4 Figure 60: Light 4



L5 Figure 61: Light 5

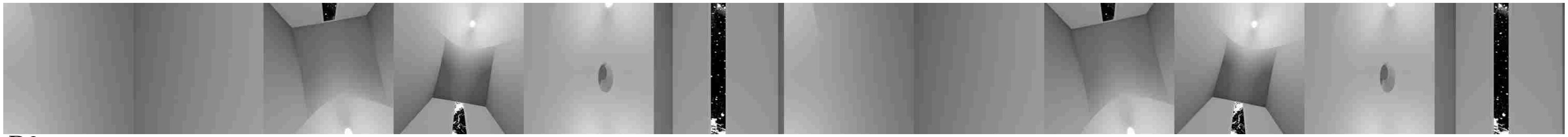


LK1 Figure 62: Most Preferred Characteristic 1



LK2 Figure 63: Most Preferred Characteristic 2

D1 Figure 64: Most Disliked Characteristic 1



D2 Figure 65: Most Disliked Characteristic 2

VII: List of Figures