Cognitive Performance Improvement

in a Workstation Design by

Applying Biophilia and an Immersive Environment

by

Claude M. Reyes

Thesis

Submitted to the University of Houston

In partial fulfillment of the requirements

for the degree of

Master of Science in Industrial Design

2018

Thesis Committee:

George K. Chow (Advisor/Chair)

Gordon Vos, PhD

Olga Bannova, PhD

Jorge Dorribo Camba, PhD

Cognitive Performance Improvement

in a Workstation Design by

Applying Biophilia and an Immersive Environment

____
(Claude M. Reyes)

Approved by
Committee Members:

____
Chair of the Committee
George K. Chow, Assistant Professor,
Industrial Design, Gerald D. Hines College of Architecture and Design

____
Dr. Gordon A. Vos, Adjunct Faculty,
Industrial Design, Gerald D. Hines College of Architecture and Design

____
Dr. Olga Bannova, Research Associate Professor,
Director of SICSA Mechanical Engineering, Cullen College of Engineering

____
Dr. Jorge Dorribo Camba, Associate Professor,
Dept of Computer Graphics Technology, Purdue University

ABSTRACT

An isolated and confined environment, which can be categorized as low, moderate, and extreme risk, is detrimental to the physiological and psychosocial well-being from office workers to space crewmembers. Countermeasures in mitigating the detrimental effects of sensory deprivation and social isolation in an office setting can potentially be applied to long-duration space missions. Moreover, despite the vast amount of research on detrimental effects, little is known on the effects of a wind or air somatosensorial feedback in an immersive virtual environment. A novel office workstation solution, which integrated a biophilic immersive environment and wind feedback, was designed and built. Other workstation design factors included a simple market research, construction & assembly, and ergonomics. The experiment was comprised of comparing 4 environmental conditions. An iPad mini app-based typing (keyboarding) test, Stroop Effect, and a cognitively demanding game (Mastermind) assessments were administered to quantitively measure task-oriented performance in the workstation. The study results were evaluated on the usefulness of the workstation countermeasures, and future development of solutions. Lastly, this study is part of a growing body of research about sensory and socially deprived environments.

Keywords: Isolated and confined environments, sensory deprivation, social isolation, biophilia, workstation, office worker, Stroop Effect

Dedication

To my amazing and loving fiancé, Yeonjin,

who has been enormously supportive of my journey…

I couldn’t have done this without you.

Table of Contents

CHAPTER 1: INTRODUCTION

Extreme environments push the limits of human survival by exposing humans to a plethora of stressors. Specifically, many researchers have investigated how stressors affect humans in sensory deprived and socially isolated setting ranging from space missions, hospital patient care, and ordinary office interactions (Bachman, Otto, & Leveton, 2012; Biner, Butler, Lovegrove, & Burns, 1993). Sensory deprivation is one stressor, and it is defined as the lack or declining of stimuli on the physiological senses (Bachman et al., 2012) (Kubzansky, 1961). The second stressor is social isolation, and it is the lack of contact with other individuals (Cacioppo & Patrick, 2008). Sensory deprivation and social isolation are two important problems observed in an isolated and confined environment (ICE). Both have detrimental effects and result in decremental work performance levels. The negative effect pathway of an ICE is through human physiological senses. There are many more physiological senses, but the following are the five main traditional ones: vision, audition, gustation, olfaction, and somatosensorial**.**

Effects between human interactions and the environment, through our physiological senses, can vary with the exposures of environmental stimulation. People have been accustomed to and are constantly subjected to environmental stimuli and have evolved to respond accordingly, whether there is a lack of stimulus (hypo-stimulation) or too much stimulus (hyper-stimulation). Repetitive, tedious, and menial work-related tasks are common examples in an isolated and confined office environment that often leads to boredom and monotony. Moreover, it is evident that sensory deprivation activates the physiological senses including visual, olfactory (smell), somatic (touch), auditory, gustatory (taste), and others such as kinesthetic, proprioception, balance, and pain (Bachman et al., 2012). Secondly, social isolation is a growing concern in an ICE. Space researchers are currently concerned with problems associated with crew interactions during a long-duration mission to Mars that will have a higher level of social isolation compared to orbital space missions (Manzey, 2004). Likewise, social isolation exists in office settings. Employees in office settings who are often assigned to small and single occupancy rooms can also experience this stressor. A prevalent solution in alleviating this specific office environment is an open-space layout. However, this solution does have its own shortfalls. An open-space office design can be unproductive or worse for employees (Nagy, 2016). Both sensory deprivation and social isolation have a profound human impact as they contribute to overall stress and have shown negative behavioral and cognitive performance consequences. I grouped ICE conditions into three categories; extreme, moderate, and low risk. Understanding ICE by grouping them into categories may reveal appropriate actions in mitigating sensory deprivation and social isolation (figure 01).

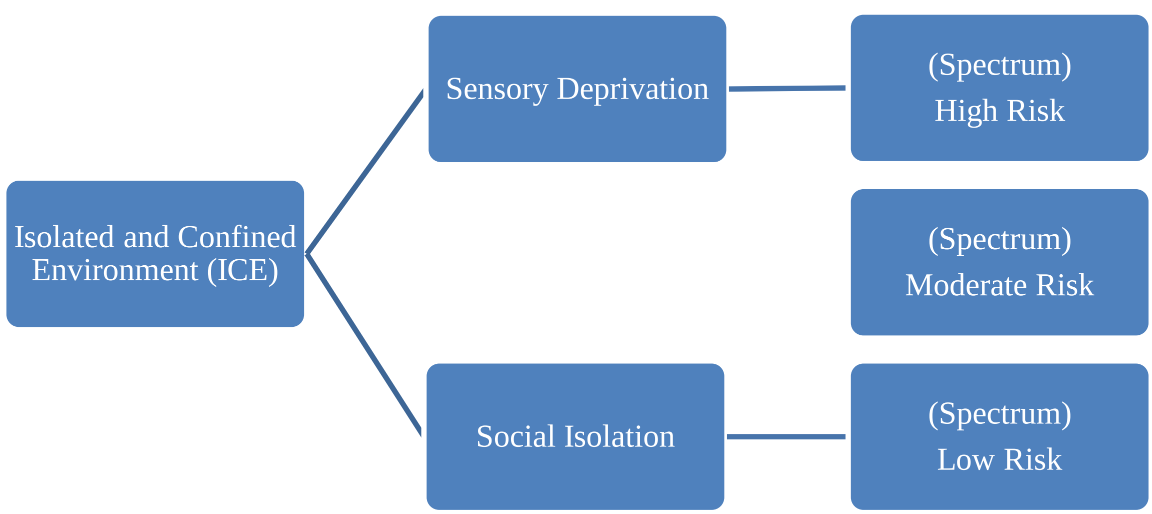


Fig. 01: ICE and the associated stressors chart

One way it has been suggested to mitigate the detrimental effects is by introducing biophilia in an environment. Incorporating biophilic design provides passive, cognitive, and psychological supportive countermeasures (S. Bishop, HÄuplik-Meusburger, Guined, & Peldszuz, 2016) Additionally, an implementation of an immersive virtual environment (IVE) addresses detrimental effects, though the primary focus of researchers was a solution through visual and auditory perception stimulation (Loomis, Blascovich, & Beall, 1999).

There is more to understand about which appropriate mitigating techniques that apply to counteract the negative effects caused by sensory deprivation and social isolation. This paper proposes an alternative solution through a combination of both the visual-somatosensorial (wind simulation) feedback, and a heuristic biophilic design approach being implemented in a workstation. Knowledge gained from this solution may be applied to an extreme ICE where an analogous experiment may be difficult or cost prohibitive, like a space mission. Overall, the potential solution could further improve our understanding of the importance between human interaction and an ICE.

CHAPTER 2: LITERATURE REVIEW

2.1 SENSORY DEPRIVATION AND SOCIAL ISOLATION

Two negative human-environmental interactions that are attributable to a confined and isolated environment are sensory deprivation and social isolation. Consequently, both stressors cause decrement in work or task-oriented performance amongst office workers and space crew members. In an ICE, a person is dissociated from a more preferred and appealing environment, but it is not unusual that a person is sometimes placed in an environment out of their control. For example, employees such as accountants who are self-driven and self-directed may find an open-space office distracting because their job does not involve frequent colleague interactions. In this case, an employee's job does not involve frequent colleague interactions. On the other hand, employees in the marketing field may find an open-space layout conducive to collaboration because their job requires creative work and constant teamwork. Therefore, it is important to address the congruency of the work responsibilities with the work environment.

A mismatch of work responsibilities and environment setting can be exacerbated further by an unstimulating environment, such as a windowless office space (Heerwagen & Orians, 1986). In most office settings, it is almost impossible to accommodate each employee for the type of work they do with an appropriate office design. Smaller companies may not be able to afford redesigning their office space or relocating to a better office environment, while a more established company may need to justify the return of investment of a well-designed office. This example of a mismatched worker-office environment displays a dynamic problem between sensory deprivation and social isolation. This is an inherent ICE issue. Sensory deprivation and social isolation can be addressed individually or as a combination of the two (Bachman et al., 2012).

Stressors are also evident in an open-space and partitioned workspace office layout. It is often construed that an open-space layout increases productivity amongst employees as opposed to a closed or confined office environment which decreases productivity and focus amongst employees. With no barriers, it increases communication amongst employees and subsequently collaboration (Kaufmann-Buhler, 2016a). The benefit of an open-space layout is that there is less exposure to sensory deprivation and social isolation compared to an enclosed room, although an enclosed working space provides privacy and focus amongst employees. An open space layout increases distraction from unwanted noise such as conversations with other people (Haynes, Suckley, & Nunnington, 2017). The negative effects in an open-layout office may not be of the same intensity on the onset, but with longer duration and constant exposure, it will have a long-lasting, detrimental effect comparable to an extreme environment (figure 02).

Fig. 02: Example of an open-layout office.

Image Source: Photo by [Alex Kotliarskyi](https://unsplash.com/photos/QBpZGqEMsKg). (https://unsplash.com/photos/QBpZGqEMsKg)

Secondly, a space habitat is restrained from having a large allocated *livable* volume to crew members. Spacecraft design is restrictive because of the overall weight consideration and the associated cost of launching a heavy spacecraft. Providing a larger and a more comfortable room for the crew members, especially with long-duration human Mars exploration, is a design limiting factor. Astronauts need to be accustomed to a very confined environment for a duration of time. It has also been shown that the extreme and demanding nature of space exploration contributes to a decline in work performance (Bachman et al., 2012). NASA's Human Integration Design Handbook makes recommendation of body volumes with the associated operations (figure 03). The volumetric suggestions of a given operation (i.e. sleeping, eating, donning, doffing etc.) for an astronaut does not provide a *comfortable* accommodation. For perspective, the national average in space per worker in 2011 is between 180 to 220 square feet, and the desk area is continually trending lower since (Miller, 2012). The area of a recommended general workstation in a space craft is only 23.814 ft^2 (3.78ft length by 6.53ft width). This is significant even though the type of work required for space missions is different from an office environment. Furthermore, the confinement exposure is constant throughout a space mission.

	Recommended Sleeping, eating, personal office etc.	Recommended Donning/Doffing, Grooming	Recommended General Workstation	Space Shuttle - Leisure	Skylab Private Quarters
Height	2.06m	2.16m	2.06m	1.9m	1.98m
Length	1.06m	0.88m	1.06m	1.9m	0.91m
Width	1.23m	1.23m	1.99m	1.9m	0.91m
Volume	2.69m^3	2.34m^3	4.34m^3	6.81m^3	1.65m^3

Fig. 03: Source: *NASA Human Integration Design Handbook 2004.*

The importance of broadening our understanding of prolonged isolation and confinement (Solignac & Kuntz, 2015) such as space habitats for long duration space missions (Jørgensen & Bannova, 2006) and introducing physiological sensory stimulus in a windowless office work environment (Heerwagen & Orians, 1986), provides a novel solution to counter act the negative effects.

There are many more situations or environmental settings in which social isolation and sensory deprivation exists (Bachman et al., 2012). It is therefore suitable to define, evaluate, and categorize these environments into three levels of risk or exposure as extreme, moderate, and low.

ICE can be thought of as a *spectrum* of risk. Additionally, a criterion of associated risks can be established. These criteria's can be modeled on what is imposed on a person in an ICE such as exposure of isolation, confinement, sensory stimuli, danger, noise, opportunities for variety and change, and dependence on machine-human environment (Bishop, 2010).

2.2 ICE SPECTRUM

Sensory deprivation and social isolation affect humans in an ICE as evident with extreme environment space mission, and likewise, in a less dangerous circumstances of an open-layout office plan. Hospital settings, for example, can be categorized as a moderate risk environment. Low risk ICE situations are those in which an individual is more prone to exposure on a daily basis. There are many more examples of a low risk environment within the spectrum of ICE, but a common example that has been provided is an office setting.

In an ICE, whether it is extreme, moderate, or low-risk, sensory deprivation occurs as a relationship between the duration of the exposure and inherent dangers of the environment. The longer the duration or consistency of the exposure, the more impactful the adverse effects. It can also be inferred that an inherently dangerous environment is where a person is required to have protection from the elements of nature. Consequently, countermeasures in mitigating isolation and confinement stressors become progressively crucial from a low risk environment to an extreme risk environment. In a moderate or low-risk ICE condition, mitigating the detrimental effects is essential in improving the psychosocial and physiological functioning, management or reversing negative consequences. For example, an individual has a choice to break oneself from monotonous or repetitive work such as an office workspace. The ability of an individual to easily detach from such a condition is a unique opportunity, which is not available in an extreme ICE situation. Moreover, the negative effect of noise is increased significantly that increases concentration difficulties and coping strategies (Kaarlela-Tuomaala et. al., 2009). An individual can lessen the length of time of exposure by taking a walk, as a coping strategy, during a 5-minute break in an office environment, diminishing the associated negative consequences.

2.2.1 EXTREME RISK ENVIRONMENT

In an extreme environment, humans have little to no opportunity to change the environmental circumstances. Examples of an extreme environment circumstance include being confined in a space mission capsule, polar research arctic bases, military submarine operations, and bed rest studies (Bishop, 2012). Again, space exploration is a great example of an extreme ICE because exposure in this environment makes it impossible to detach oneself from a cramped space habitat. Furthermore, astronauts in outer space are exposed to an unforgiving environment. The thought of aborting a spacecraft while in outer space if a disaster strikes is less than a favorable option because the contemplation of this kind of predicament can add to their anxiety. The astronaut's safety in space is paramount; their survivability depends on the constant reliance of electronics and technology. On the other hand, ground control team members are monitoring the mission progression in the relatively safer *office* environment. This is a glaring juxtaposition of circumstances. It is also evident that the environment in space habitats are devoid of sensory stimuli which range from white or neutral wall paddings, to electronic humming sounds, to limited food choices; sensory deprivation is the imposed monotony of the spacecraft (Bachman et al., 2012). The astronauts cannot easily eliminate the drowning sounds inside a space habitat, are limited to choices on the types of food they eat, and large natural environment such as trees are non-existent. Although a reprieve from this social isolation and sensory deprivation is a small window looking out to outer space and observing the earth, moon, and other astronomical bodies. It is a stimulus rooted in the biophilia concept; the tendency to be close to nature.

Social isolation from families and friends can take a toll on the astronaut's performance and task-oriented objectives. The lack of real-time communication contributes to added stress for astronauts. It will be much harder to have constant communication with family and friends on earth. It has been shown that social isolation is a predictor of mood disorders including depression and anxiety, which can cause poor performance, lack of motivation, and attention during operation of a spacecraft (IJsselsteijn, et. al., 2008; Sandal, 2007). With continued desire to travel further and longer missions in pursuit of human explorations, the communication barrier only increases. Deeper space flights will require automation and the extreme distances will eventually lead to a phenomenon known as the Earth-out-of-view phenomenon (Kanas et al., 2008; Manzey, 2000); which is an experience described as the distance between an astronaut and earth growing larger, as the view of the Earth becomes smaller. This phenomenon can intensify stress and anxiety. Although this phenomenon has not been fully replicated such as a long duration trip to Mars~~.~~ This phenomenon is a hazardous precedent although it has not been fully investigated, such as a long duration trip to Mars. Improvements in engineering and technology has made the trip to mars possible, but the psychosocial human health and well-being has not made improvements since the earliest days of space travel (S. L. Bishop, 2010).

Another extreme environment study example is polar explorations (Jørgensen & Bannova, 2006). Polar explorers or researchers are exposed to dangerous, unfavorable, and frigid weather. Polar exploration environments are inhospitable and the people in those situations are usually confined in a facility protected from weather. Polar researchers are also confined for long periods of time, which has contributed to experiencing greater cognitive exhaustion as seen in space missions (Basner et al., 2014). Polar researchers cannot easily be evacuated from their research facility in a situation that needs evacuation but have a better chance of survivability than being in outer space. Communication may not be reliable or instantaneous to the other research team members outside of an arctic region. Also, it may be difficult to connect with their family and friends with a reliable real-time communication. This imperfect communication system with family members is found to be similar to space missions and is a stressor for the individual and team (Landon, et. al., 2017). The social isolation from people, other than the researcher themselves, will make them feel disconnected, eventually affecting their well-being. Moreover, confinement in a small environment or crew quarters is a stressor to an individual, and can contribute to crew member conflicts (Sandal, 2007). The opportunity for environment and change is limited to the outside of the facility and the interior of the facility. For example, there is no option to view large, lush greenery environment during polar explorations. These polar researchers also carry enough supplies and food rations with them for the entire research period but may require a re-supply shipment. This uncertainty may pose anxiety. Social isolation and sensory deprivation in an arctic research environment pose comparable and detrimental effects as space missions with individuals.

Natural	**Man-made**	**Simulated Environments**
Polar Expeditions	Operational Antarctica Bases	Bed Rest Studies
Deep Caving Teams	Submarines	Mock EVA simulations
Saturation diving		Mars Society Habitats
		Concordia Antarctic Research Facility

Fig. 04: Examples of other analog extreme environments (Bishop, 2010).

2.2.2 MODERATE RISK ENVIRONMENT

In the middle of the spectrum is the moderate-risk condition or environment. In a moderate-risk condition environment, an individual is not in any immediate or imminent danger. Instead, the individual is being relegated to a situation out of their control or choice. For example, a patient after surgery will be in a post-surgery recovery room in which they may not be able to stand up or walk outside their recovery room. However, patients are not entirely devoid of social contact. Hospital caretakers are present and tend to their needs. Some patients can have family and friends visit them as much as a hospital policy allows. Patients are also exposed to the hospital's visually monotonous surrounding, without the option of configuring or decorating their room.

There are also situations in which a patient may share a room with another patient, and one of them may not have access to a window. Having a windowless room is a sensory deprivation stressor. Evidence suggests that habitat interiors might be designed to assist emotional, cognitive, and perceptual processes for stress reduction and personal emotional management (Bachman et al., 2012.)

Hospital patients are not the only ones affected by sensory deprivation and social isolation in a hospital setting; hospital employees are equally exposed to these stressors. Interior hospital environments are visually monotonous. They are traditionally painted with white or neutral colors. It has been cross-culturally acknowledged that white denotes cleanliness, but this perception is only based on the acceptance of a longstanding practice. It is also anecdotally noticeable that most health care worker uniforms (i.e. scrubs) are blue and that lab coats are white. This may be an added stressor, because it creates a monotonous interior environment (figure 05). Also, some healthcare workers have minimal access to windows or views of the outside of the facility. Visual monotony is a hidden occupational hazard that merits further sensory deprivation research.

Fig. 05: Example of a monotonous hospital environment.

Image Source: Photo by Hush Naidoo. (https://unsplash.com/photos/ZCO_5Y29s8k)

2.2.3 LOW RISK ENVIRONMENT

At the low end of the ICE spectrum is the low-risk condition or environment. This environment is considered to have minimal ICE danger to an individual. Although exposure to this environment does not diminish any of the detrimental effects of sensory deprivation, individuals have the ability or willpower to leave their environment to reduce their exposure to an ICE. For example, if an office worker is feeling an undue stress and it is affecting their concentration or focus level, the office worker can simply walk away from their desk and take a break. Once the office worker has a sense that they have alleviate their stress, they can return to their desk. The office worker's workspace, workstation, desk, or the room can contribute to their work-related stress.

Social isolation from other employees is sometimes beneficial in a more enclosed workstation or office, as it allows an employee to focus and avoid distractions. An open-space office design, on the other hand, provides unfiltered distractions. Anecdotally, it is observed that employees who share a space or desk tend to wear over-the-ear or in-ear headphones (Hills & Levy, 2014). This helps them concentrate with their work by filtering ambient office noise passively. Human-borne noise such as co-worker's speech in an office environment produces the strongest dissatisfaction in open-plan offices (Kaarlela-Tuomaala et al., 2009). However, the type of music the office workers listen to can invigorate their mood and consequently their concentration and focus. While this provides a reprieve through the auditory perception, it may not be an effective distraction filter for the other physiological senses. For instance, people walking around can be visually distracting, a colder office climate can be uncomfortable through the somatosensorial sense (in conjunction with another physiological sense, *thermoception*), or the feeling of hunger. The other senses are always engaged even though auditory distractions can be isolated. So, fatigue may result when a person tries to compensate for any unwanted noise and other extraneous distractions (Kaarlela-Tuomaala et al., 2009), such as wearing a hoodie over the head or tilting their seating position away from distractions.

Usually, people do not realize the fatigue is due to sensory deprivation. Though people instinctively know they are fatigued by their environment. Individuals in a low-risk ICE are not completely inhibited by the circumstances of the setting. For example, employees in an office setting are less isolated from other people. Individuals who work in co-working spaces share amenities and services are also less isolated. In a co-working space, individuals are paying members that can work in an office environment. These individuals use a co-working space because business amenities and services are less costly than a traditional office setting. While other co-working space tenants opt to have a dedicated desk or a small personal office, it is not unusual to see people working on a communal desk in a co-working space. Most of the assigned desks are partially enclosed or not enclosed at all. It is beneficial when people are surrounded by other people. When individuals are isolated from others, either physically or mentally, they suffer from performance decrement and a compromised well-being (IJsselsteijn et al., 2008). This may be in part because humans are social animals and commonly want to be part of a community. Working in groups effectively is an evolutionary advantage that has favored individuals (Bachman et al., 2012). For example, some freelancers or solo-entrepreneurs work alone but may use a co-working space to be surrounded with other people; working at home alone is socially isolating.

2.3 DETRIMENTAL EFFECTS

As discussed in the previous sections, sensory deprivation and social isolation are two stressors caused by an isolated and confined environments ICE, which exhibits detrimental effects (Loomis et al., 1999). Detrimental effects include, but are not limited to, boredom, monotony, decrement in cognitive performance, lack of stimuli or over familiarity with the surroundings, prolonged periods of low work schedules, minimal activity, repetitive tasks, and restricted social contacts all undermine the performance and psychosocial functioning of an individual (Bishop, 2010; Zuckerman, et.al., 1968b). These detrimental effects do not happen often on an individual singularly; rather, it is common that it works in combination (boredom-monotony, cognitive performance-isolation). In an ICE, factors such as the use of colors on interior hospital walls, volume of a physical space, lighting conditions, settings that are conducive to sociability, or sounds that prompt the human physiological perception, in particular, the visual and auditory senses predominantly. Mitigating the detrimental effects are becoming more relevant because in recent years, the effects have become more noticeable in an open-space layout office setting (Kaufmann-Buhler, 2016). Countermeasures of the detrimental effects can be applied to extreme and moderate-risk conditions because the underlying stressors are the same.

Detrimental effect of a sensory deprived and socially isolated setting is boredom and monotony. It has been proposed that boredom and monotony is involved in stress related activities such as long periods of minimal workload and the lack of stimulation of the physiological senses (S. L. Bishop, 2010). Additionally, boredom and monotony can be described as a deprivation or the lack of cognitive performance stimuli, specifically in an ICE. Thus, it is the lack or absence of sensory stimuli having a deleterious effect on our cognition (Bachman et al., 2012). Stress is commonly understood to be manifested in an extensive and high-pressured performance task. This may include conducting non-stop experiments during space missions or being involved in an office project in which the deadline is fast-approaching. Although stress can likewise be seen in minimal workload and hypo-stimulated circumstances. Stress can also be observed in a period of low to no workload, unchallenging task-oriented work, or repetitive and mundane work. Evidence from long-duration missions and analog environments, the lack of meaningful and productive task produces many of the symptoms associated with overwork (Palinkas, 2007). It has been suggested to address the issue during the first mission quarter as a coping strategy from low workload during space missions (Basner et al., 2014).

Social isolation, also known as social deprivation or social monotony, can cause boredom and monotony. It is described as having minimal or restricted contact with other individuals such as family and friends. Social connectedness can be categorized to have increased contacts with family and close friends (figure 06). Immediate relatives are the closest social contact in the level of social connectedness, while the greater society is the furthest.

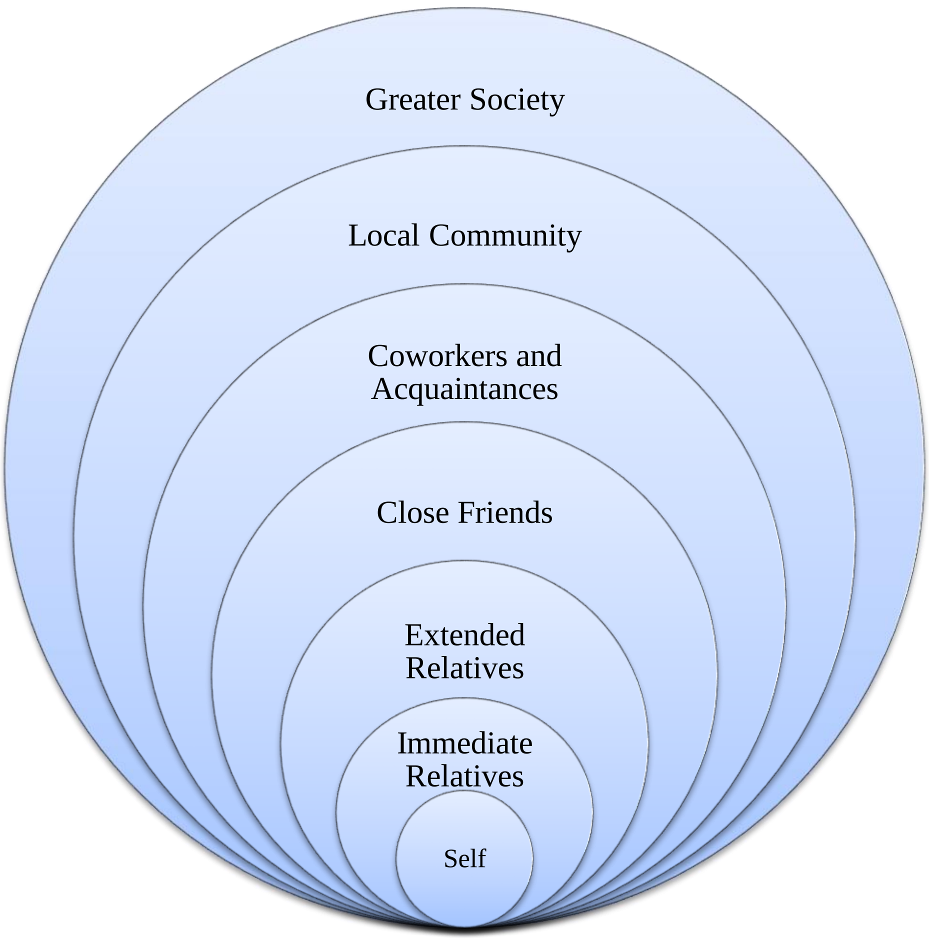


Fig. 06: Level of social interconnectedness (Otto et. al., 2012).

Psychological problems become increasingly more visible in a hypo-active and hypo-stimulated space missions when astronauts are isolated from family and friends, restricted communications within the social contacts, small crews (Manzey, 2004). In other situations, contact with the same individuals for long periods of time can have the same effect of social isolation. This can cause a rift and team cooperation. In an ICE, a coping style that is meaning-based may be more useful, and some forms of coping such as seeking social support may not be as normative nor adaptive as in ordinary environments (Ihle, Ritsher, & Kanas, 2006).

Social isolation does not only suggest the separation of an individual from familiar surroundings, but it also refers to the lack of contact with other individuals (Ott et al., 2016). A confined environment is conducive to be socially isolated. Long periods of social isolation have a negative effect on performance, memory, engagement, and social skills (Jørgensen & Bannova, 2006). Evidence suggests that maintaining interactions with friends and family can promote satisfaction and lessen the impact of loneliness (Wang et al., 2014). Although social interaction occurs among individuals who work or live together, it may become stressors themselves because conflicts could arise, and it must allow to disconnect from others to rejuvenate (Bachman et al., 2012). Interaction with others benefits the physiological and psychological systems (Palinkas, 2007). A team of astronauts work together in arduous task during a space mission and teamwork is not only mandatory, but crucial. Having to socially separate from other astronauts for some personal time is also viewed as essential.

Performance is another detrimental effect in an ICE. Understanding how neurocognition is affected by long-duration spaceflights will be essential for ensuring the success of explorationclass missions and the safety of the crew. Studies have found that this poses little threat to health and well-being of the crew or the success of spaceflight missions (Kanas et al., 2009). However, there have been a limited number of studies due to the limited sample size (MacNeil, Che, & Khan, 2016). Other studies have suggested that isolated and confined extreme environments are no more stressful than other environments (Suedfeld & Steel, 2000). This could be the case since astronauts are highly motivated and capable individuals that can maintain high levels of performance in such extreme environments over long periods of time (Palinkas, 1985). Importantly, these individuals simply do better than others (Johnson, Boster, & Palinkas, 2003). Having a window office does not mean that it is an effective solution against the detrimental effects of performance. Individual and group performance may also be affected when disparities in workload occur, in which some are given too much while others are not given enough (Palinkas, 2007). However, it may contribute with other solutions for a better well-being. Social isolation affects the cognitive performance individually, and therefore affects it as a group. But as social beings, human experience will suffer decrements to the cognitive and affective states when isolated.

2.4 EXISTING SOLUTIONS

There are many solutions that have been proposed which address the negative consequences of isolation and confined environments. The three solutions or applications are biophilia, IVE, and workspace design solution.

BIOPHILIA

Humans are drawn to the natural environment. This predisposition to be with nature is embedded with all humans (Wilson, 1984). Biophilia suggests that individuals have been evolutionarily adapted to gather information by exploring their natural environment (Kellert & Wilson, 1993) (Kahn, 1997). From the creation of national parks, sustainability efforts, recycling endeavors, healthy living choices, or placement of plants in an office shows that, as humans, we value the natural environment.

The psychological and physical well-being of a person can be promoted, influenced, or inhibited by environmental stimuli. For example, employees in windowless offices tend to use more decorative materials than those in windowed offices (Heerwagen & Orians, 1986). Research also suggests that interaction with nature provides positive effects on the well-being of a person (Grinde & Patil, 2009) (Biner et al., 1993)(Li & Sullivan, 2016). It is a reason why most people take vacations, enjoy parks, or beach outings as a means to rejuvenate from the daily obligations of life. Nature substitutes such as plants can counteract some of the negative effects of sensory deprivation (Bringslimark et al., 2011). These materials often include pictures of people, nature scenes, and plants (Biner et al., 1993). Similarly, Antarctica studies have shown that access to a bonsai tree or other small plants have positive effects compared to no access (Jørgensen & Bannova, 2006).

Research has shown that the application of biophilia has a restorative effect such as reducing postoperative recovery amongst individuals who find some comfort in spending a short time in taking a stroll, sitting by a river, walking in a forest, or quiet moments at the park (Depledge, Stone, & Bird, 2011). The effect of natural settings harkens back to our biophilic preferences and the mere presence of flora enhances neural stimulation, which increases the production of mood-enhancing chemicals in the brain (Bachman et al., 2012). A direct correlation of the length of time in contact with nature may have a positive outcome against stressors. A view of nature increases positive interests in their work and reduces negative feelings such as tension (Radikovic, et. al., 2005). The therapeutic potential of plants in an indoor environment is limited, which can add up to a substantial decrease in the health burden (Grinde & Patil, 2009). Furthermore, it is a more effective design solution that evokes ancestral human environments such as Savannah plains as a template for perceptual and cognitive processes (S. Bishop et al., 2016).

There are positive effects of windows and daylight exposure as a countermeasure to mitigate stress. Natural light from the sun is a consideration in building design. Although a full penetration of light in to building is preferred by employees (Kong, et. al., 2018), too much sunlight or in direct view is a visual discomfort.

Another example of a biophilic trigger is water, which can be found in photographs with imagery of water and elicits a strong attractive response (Depledge et al., 2011); regardless of whether the picture imagery of water were urban or natural settings. Aside from the imagery, the sound generated of water flowing, whether it is a river or rain has soothing effect for some people.

The physiological senses constantly gather stimuli which takes a large amount of energy for the brain to process. It could be the sound of rustling leaves, various hues of tree leaves colors, the sense of balance while running, the ability to sense temperature as heat or cold, or as ordinary of a feeling such as cloth texture on the skin. All of these stimuli processing can overwhelm the cognitive functioning of the brain. A possible mechanism of biophilia is how an individual can repress a vast amount of stimulus and disregard unnecessary stimulus automatically. Over the course of human evolution, the human body has adapted to focus on the more important stimuli to process and unconsciously ignore all others. Perhaps, in order to conserve energy, a person has this adaptation ability of an unconscious and selective stimuli-cognitive processing. It is to the benefit of a person to conserve energy especially with brain cognition and functioning. Likewise, hominid species have evolved to conserve energy because of the scarcity of food and allowed them to be more cognitively conscious of the danger of predators. It is a matter of energy conservation through selective cognitive processing that is important for survivability. This evolutionary-adaptability of human physiological responses is important in the context of biophilia. This is an adaptation disconnect with the non-natural environment, such as office settings or a confined spacecraft because our early hominid species did not evolve with such surroundings. I posit that humans are merely adjusting to an environment devoid of many of the natural environmental stimuli.

In the current urban environment, the level of cognitive functioning is different compared to a natural environment of the earlier hominid species. The ability to repress unnecessary stimulus that isn't evolutionarily predisposed is difficult. It takes energy to process the stimulus and the human physiology is not adapted to the modern era. Cognitive activities such as perception, attention, memory functions, and decision making should be the primary interest of a space and workstation design in workplace (Kaarlela-Tuomaala et al., 2009).

IMMERSIVE VIRTUAL ENVIRONMENT (IVE)

An immersive virtual environment is an amalgamation of digital media and the physical world. The projection can be achieved through many mediums such as virtual reality devices, augmented reality devices, holograms, or video monitors. The possibilities in overcoming detrimental effects of long exposure to confinement and isolation is a growing interest especially with the application of an IVE. IVE technology is found valuable in perceptual and spatial research, and it is also relevant in areas such as psychology and social behavior science (Loomis et al., 1999). One of the earliest implementations of IVE is the CAVE (cave automatic virtual environment). It involves projecting computer generated visual imagery onto translucent walls, floor, and ceiling (Cruz-Neira, Sandin, & DeFanti, 1993). Research has suggested that people can derive satisfaction of the real world from interactions in a virtual world (Ott et al., 2016).

Mimicking a serene natural environment can be done easily in a computer generated IVE. Showing the natural environment together with the perception of depth is an effective way to combine biophilia and IVE.

Fig. 07: Immersive virtual environment example.

Image Source: (Wilson B, et. al., 2018)

An IVE alters the perception of depth by showing a bigger space through a display (Cruz-Neira et al., 1993). Replicating imagery of natural environments in an IVE is a necessary design step in enhancing experience for individuals. Studies have shown effectiveness in a controlled IVE in mimicking extreme environments in polar exploration (Bachman et al., 2012) (Loomis et al., 1999). In another example, an artificial window IVE was shown as a better window substitute than a static image, with a stronger effect on human well-being, and a good simulation of a window interface (Radikovic et al., 2005).

Another method of a viable IVE is a head-mounted display (HMD). A variation to an HMD is the addition of a head tracker. An HMD can create a more immersive visual environment. With an HMD, outside light is minimized, and the user can only see what is being shown on the screen inside of the device. Virtual and augmented reality devices such as the Oculus Rift and Microsoft HoloLens are becoming popular and great examples of an HMD. It allows for users to be immersed in a digital world. Virtual reality devices are more digitally immersive than augmented reality devices which allows an interaction with the real world. Although its limitation is that it is restricted to a single user, it is a simpler way to simulate a 3D environment. Other negative issues with an IVE, that is not limited to an HMD, are motion (simulator) sickness, disturbance of balance and of eye-hand coordination, drowsiness, and instances of memory “flashbacks” (Loomis et al., 1999).

Fig. 08: Microsoft HoloLens is an example of a single user HMD.

Image Source: https://www.microsoft.com/en-us/hololens

One toolset which was developed as a countermeasure to social isolation among flight crew and their family and friends during space flight missions is A Network of Social Interactions for Bilateral Life Enhancements (ANSIBLE). The main focus is to maintain social contact during long duration mission space flights beyond emails or non-interactive communications. It expands asynchronous communication. This system increases the feelings of closeness and satisfaction with family and friends, but also showed marginal decrease feelings of stress (Ott et al., 2016). This supports other studies highly suggesting the it is important to keep astronauts socially and intellectually engaged and have optimal amounts of stimulation at all phases of the mission (S. L. Bishop, 2010). Having constant support from ground operations of a space mission contribute in mitigating the stressors of IVE because it allows for remote monitoring of the mental and emotional state of a space crewmember. A suggested solution is to use two-way audio and video transmissions between space and ground team members (Manzey, 2004).

Examining the different types of environments within the ICE spectrum, the fatigue experience may be mitigated on how to properly adjust any IVE implementation and mimic true natural environments. To facilitate the inherent evolutionary predisposition of an individual to be close to nature, a combination of biophilic design, and a nature-based stimulus should be considered for the primary use of IVE devices (Bachman et al., 2012).

WORKSPACE DESIGN

Current working office environments is a complex relationship between the occupier and workspace (Haynes et al., 2017). Both an open-space and an enclosed working space have benefits and are productive in different scenarios. Physiological senses are constantly gathering stimuli including noxious noises from computers, printers, colleague conversations, office room climate, lighting, and many more. All these stimuli contribute to performance decrement if not taken into consideration in the design process.

Work productivity relies on performance of a given work task or responsibility, but it requires focus and cognitive functioning. In an open-space office, whether the bench-like shared desks, or short partitioned cubicles, noise distraction is an ongoing issue. Firstly, younger employees listen to background music through earphones while senior employees would find an alternative place to work, for example a meeting room not in use (Hills & Levy, 2014). Secondly, using headphones is a means of coping to illicit privacy from other people that carries a connotation to not disturb. Sound distraction should also be mitigated because noise causes waste of working time significantly, especially in an open-plan office than in a private room office (Kim & de Dear, 2013).

Privacy is a known issue in an open-space office. Customizability or modularity of work desks to create privacy should be considered in workspace design. A modular exterior or partition can be another solution to deal with confinement, which lessens the burden of over-familiarity by allowing a flexible interior configuration (Hills & Levy, 2014). If an employee feels confined in their workstation, having the ability to open-up a partition can provide a positive physiological sense stimulus. A variation to this modularity or customizable solution is creating stimulating areas or small gardens that can counteract with structured social activity and interior design.

Lighting conditions in any space such as offices, classrooms, or hospitals can affect the performance of the occupiers. A well-lit room is always encouraged in designing a building or interior space. Using sunlight to brighten a room is economically better because it limits the cost of electricity. Taller or wider windows are recommended for deeper sunlight penetration. On occasions, direct sunlight can cause visual comfort. The outside natural light should be dispersed evenly to avoid the discomfort. It is found that occupants that sat adjacent to windows or faced a window directly had a higher risk of experiencing visual discomfort (Kong et al., 2018). On the other hand, natural light cannot penetrate fully the interior of a space due to partitions of workstations. If natural light is not available, such as windowless rooms or workspaces that are further away from a window, the only recourse is maximizing the ceiling lighting. Although an open-space office solves full lighting dispersion issues, it is still detrimental to work productivity. Open-plan offices also has to consider the *quotidian experiences of workers* who used them every day (Kaufmann-Buhler, 2016b). It has been suggested that a more open workstation and flexible furniture can maximize interior lighting conditions and can have a positive impact (Kong et al., 2018).

Although using visual and auditory solutions are evident, another physiological stimulation solution that should be considered is somatosensorial (touch or haptic) feedback. This is one of the five traditional senses often ignored. A suggested haptic feedback solution is a *force feedback* device such as inflatable gloves that provide modest kinesthetic and cutaneous stimulation of the hands and fingers (Loomis et al., 1999). This allows a user to feel and identify objects easily. This solution requires a user input, haptic feedback can be achieved by passive means and eliciting a biophilic response such as a wind.

Maintaining and strengthening of social skills are crucial to counteract the risk for deterioration after extended periods of isolated activity. A workspace solution must accommodate developing new ties with colleagues as suggested by prior research (Wang et al., 2014). Maintaining tolerance between space crewmembers or office employees is not a sufficient solution but true accommodation (S. L. Bishop, 2010).

Workplaces that are more generic in design have a higher occupational density and have a greater emphasis on shared spaces. A “one size fits all” may not be the most effective approach given the uniqueness of individuals, different roles, space needs, and work styles (Hills & Levy, 2014).

CHAPTER 3: DESIGN DEVELOPMENT

3.1 BACKGROUND MARKET RESEARCH

The initial development of the product design is to address the market. The proposed idea is to create a virtual window where a natural environment can be projected or shown. The following are considered: the market segmentation, customer insight, life cycle use, design goals, and competitive advantage.

3.1.1 MARKET SEGMENTATION

The virtual window is the product idea to apply the IVE and biophilia solution in an ICE and in a low-risk setting. The goal of the product is to realize the solution of alleviating the stressors in a low-risk confined space, then it can be construed to be applicable in a moderate or extreme risk environment. The techniques and questioning in identifying markets are taken from the book *Disciplined entrepreneurship: 24 steps to a successful startup (2015).* The Lean Start-up methodology is applied throughout the book to maximize a success of a venture idea.

The following questions are the key categories in addressing the market:

1.) Can you identify a market industry where this could be applied?

2.) Can you sub-categorize the market industry identified?

3.) Is the target customer well-funded?

4.) Is it readily accessible to your sales force?

5.) Does the target customer have a compelling reason to buy?

6.) Can you today, with the help of partners, deliver a whole product?

7.) Is there entrenched competition that could block you?

8.) If you win this segment, can you leverage it to enter additional segments?

9.) Is the market consistent with the values, passions, and the goals of the founding team?

10.) Why will this work in this category?

Eleven initial market industries were identified and the corresponding sub-categories. The top markets for the application of an IVE are the co-working space, building office, and hospitals or clinic waiting rooms (highlighted in green) (fig. 09).

Industry	Industry Market Sub-Categories	Customers	Is the target customer well-funded	readily accessible to your sales force	Target customer have a compelling reason to buy	Can you today, with the help of partners, deliver a whole product?	Is there entrenched competition that could block you?	If you win this segment, can you leverage it to enter additional segments?	Is the market consistent with the values, passions, and the goals of the founding team?	Why
Office	Open-Space, Shared Space, Traditional	Interns, Entry Level Employee, Mid-level Employee, Executive Employee	Yes, the Executive and Mid-level executives	No, might through managers or procurements	Maybe, they may not need to add more windows	Yes, installers	Not really, TV	Yes	Yes	Increase performance
Hotels	Hotel Rooms, Lobby, Conference Rooms, Dining Area	Hotel Guests, Conference Guests, Dining Guests, Guests of Guests	Vacationers, Business related guests. More expensive hotels are more appropriate customers	Not really, needs to go to corporate office, or interior designers	Yes, incorporate the experience	Yes, installers	Maybe, Decorations	Yes	Yes	Create inviting feel in the lobby and rooms
Restaurants	Fast Food, Casual, Fast Casual, High End	Budget consumers, Occasional diners, Foodies	Yes, themes restaurants, Experience oriented restaurants	Yes, usually just direct to owners	Maybe, if it fits into their restaurant concept	Yes, installers	No	Yes	Yes	Create an ambience
Public Transportation	Buses, Trains, Shuttles	Daily Commuter, Occasional Commuter	No, need to be on budget and works on minimum capital	No	No	No	Advertisers	No	Yes	Pleasurable commute
Apartment	Large Dense City Dwellers, Small-Medium Size City dweller	Small Apt, High Income Dwellers,	Yes, high income dwellers	Yes, has the income to improve home life	Yes, and Maybe	Yes, installers	No, and maybe, TV and paintings	Yes	Yes	Create a relaxing atmosphere

Building Developers	Coworking Spaces	Freelancers, Small Business, Mobile Corporate Users	Yes, because they take up small sq. ft. and get take smaller tenants	Yes, simple approach	Millennial specific situation. User experience. Retention rates needed to be profitable. And remedy sick building syndrome	Yes. Independent stallers only	No	Yes. This will attract other segments.	Yes	Can have a good purpose.
Building Developers	Office Tenants, Tenant Clients	Small Company Dwellers, Med-Size Company Dwellers,	Yes, Large building developers	Yes, they have in house architects and designers	Yes, anything to attract tenants for a compelling workplace	Independent Installers, Commercial Buildings Material Market, Wholesale electronics distributor	No	Yes	Not so much, but Yes	Invigorate tenants
Library	Public patrons	Internet Users, Book Readers, Past timers	No, uses city resources. They visit the library because its free	No	No	No	No	Yes	Yes	Attract patrons
Medical	Hospital Departments, Clinics,	Floor Dept, Office Dept, Waiting Lobby, Patients Room, OR, Nurse Station	Yes, frequently buys equipment. Sometimes No because they are resource strapped	Yes, through procurement office or direct showcasing to staff	Yes, improve staff well-being	Yes, installers	No	Yes	Not so much, but Yes	Alleviate stress with their high-pressured jobs. Bring back their circadian rhythm for night shift workers
Medical	Hospital Departments, Clinics,	Patients, Guests and Family	Yes, No, and Maybe (Insurance)	Maybe	Yes, improve patient well-being	Yes, physical product	Yes, iPad, portable devices for entertainment. Flowers also.	Maybe	Yes	Inviting for the patients waiting
Art	Museum, Digital Artists,	Modern Museums, Interactive, Painting Gallery,	Yes and No. Some museums have bigger budgets, but might also have limited budgets	Yes, can directly talk to the museum directors	No, wall space might be an issue.	Yes, might use in house staff	Yes, the art pieces themselves	Yes	Yes	Attract a new medium of art (Digital Art)

Fig. 09: Market industry discovery for an IVE solution.

3.1.2 CUSTOMER INSIGHTS

An initial market background survey was taken to gather a basic ethnographic end-user information and the decision-making unit (DMU). The market survey intention was to initially find patterns or current sentiments of employees working in an office space. The end-user profile is an educated guess and a person who is intended to use the device and establishes the life cycle use and the minimum viable product. The end-user profile was identified as office building tenants.

END-USER PROFILE:

Gender: Male & Female

Age Range: 28-40

Marital Status: Single or Married

Career History: No career path changes but have changed companies along the way of their career. Some have been employed with the same company since the beginning of survey respondents' career. Respondents' are satisfied with their job but may have reservations of rewarding or fulfilling work.

Personality (Heuristic): Most respondents' like the outdoors. They often eat out during weekends. They also travel more frequently. They find that job security is important to them. They often have an exercise regimen such as running or going to the gym after work.

Fig. 10: End-user profile.

A DMU is a marketing tool that identifies people who may be involved in the decision-making buying process of an end-user. Three primary roles in a DMU is composed of the champion, primary economic buyer, and the influencers. The primary economic buyers are individuals who will purchase the product; they are identified as the office workers. The *influencers* are primarily the individuals close to the social network of the primary economic buyer that persuades to purchase and use the product; the influencers identified are friends and coworkers. The champion is a person who advocates the product. Usually and especially in this example, the champion is also the primary economic buyer.

3.1.3 LIFE CYCLE USE CASE

A life cycle use (LCU) case is another marketing tool to help a potential user find information about the product, how to acquire and find value with it, and endorse it with others. The steps involved for potential users are the following: 1) user finds a small desk to be sensory depriving, 2.) user listens to music using a headphone, 3.) a coworker distracts the user, 4.) the user loses focus and needs to refocus again to return to their work, 5.) lastly, the user is frustrated because of the distraction. In step 4, the potential user will compensate of the distraction. In step 5, the user will try to find a product the will make them feel less frustrated with the distractions.

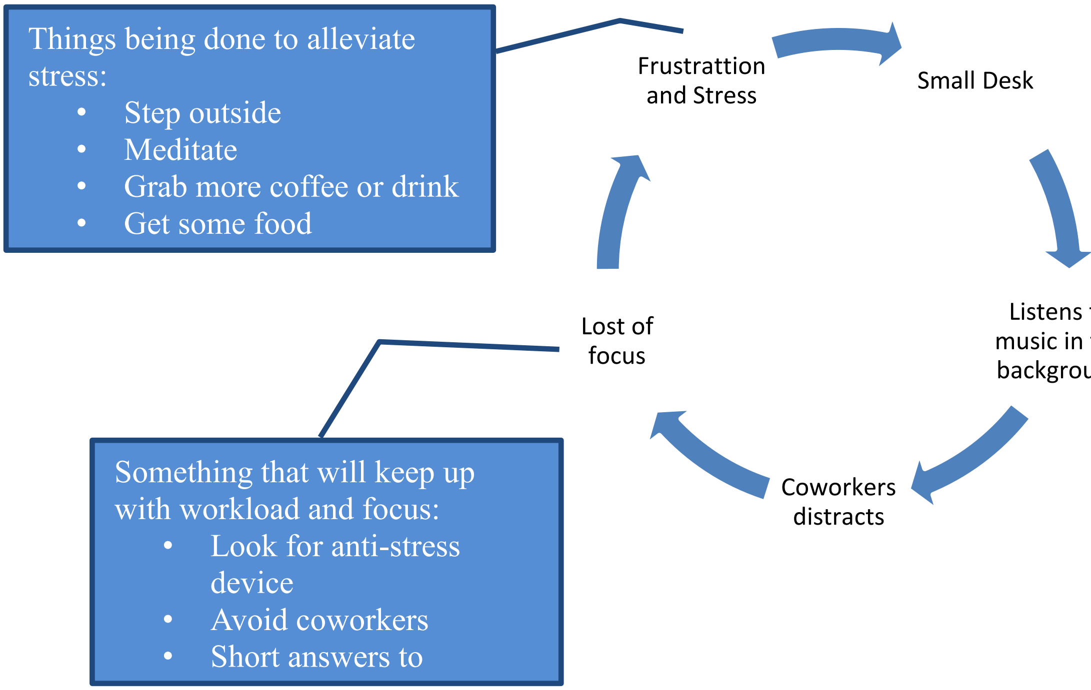


Fig. 11: Life-cycle use case of product discovery.

3.1.4 DESIGN GOALS

The design goal has to satisfy the needs of the potential users. From the LCU case, the user loses focus and needs to regain focus after a distraction. Furthermore, the users work performance is compromised because it requires additional cognitive functioning to return to their tasks before the distraction. The five design goals, or product specification, include the following: 1.) Invigorates and sharpens focus, 2.) motivates and inspires, 3.) mental relaxation, 4.) lessens work monotony, and 5.) less frequent breaks.

3.1.5 COMPETITIVE POSITION

A competitive advantage is defined as a circumstance that places a product in a favorable or superior position. The competitive position of the intended device relies on two criteria, stress management techniques and how focus/concentration is perceived. The context of the competition is not with another similar product, but the behavior of an office worker identified in the LCU step 5.

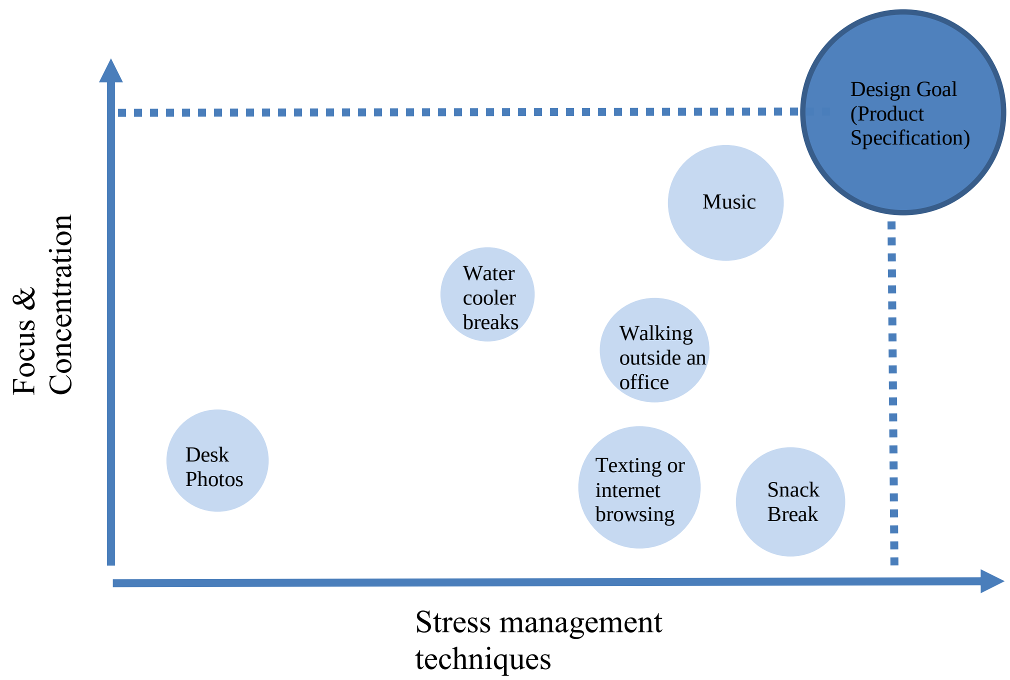


Fig. 12: Competitive advantage to other stress relieving techniques.

3.2. DESIGN APPROACH

The design approach is wide-ranging. Using the background market research as a technique or tool to identify product opportunities, the concept can be envisioned in context of a low-risk ICE. Furthermore, an office environment is corroborated by the market research.

3.2.1 DESIGN CONCEPTS PART I

During the ideation phase, several concepts were generated based from the literature review and market background. The product includes biophilic stimulation, incorporates an IVE in a workspace, and easily accessible for continuous functionality throughout an employee’s daily activities. The application of physiological sense stimulation varied on each ideation, but the visual sense is the primary medium to display a natural scenery (i.e. forest, savanna plains, jungle, or beach scenes). Projecting through a screen or monitor was chosen as a simpler IVE because it avoids additional user accommodation and avoids more discomfort for the user such as an HMD. Lastly, workspaces that were considered included simple desks, bench-like shared desks, partitioned walls (low or high), and private offices. Lighting and sound conditions, and general office settings were ignored because it is the premise of the product to use a humans biophilic predisposition to ignore distractions.

The first product idea is a simple picture frame concept that continuously show natural scenery videos. Visual stimulation is the only physiological sense applied and thus a limitation. This product can be incorporated on a variety of desks.

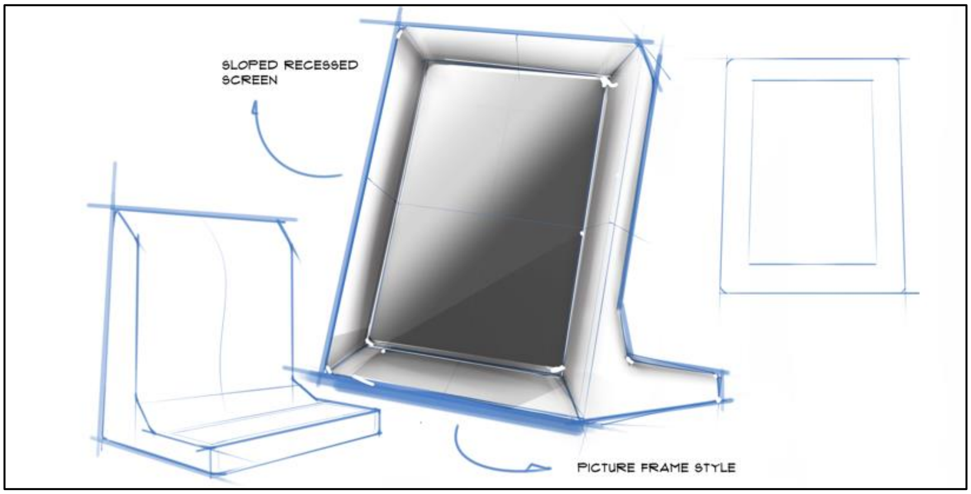


Fig.13: Ideation 01. Picture frame concept.

The second product idea is a digital window concept. The multiple screens act as a virtual window. The scenes for the virtual window display natural scenery and there is an added parallax functionality. A parallax motion is the ability of the scene to move in relation to the viewers angle. For example, if the user is viewing it an angle, the video or scenery translates automatically to the opposite direction. If the user passes by and motion is detected, the scene adjusts to the viewing angle of the user. This concept is limited to a single user parallax functionality. If multiple users are detected, the parallax will not work.   No other physiological senses were considered. The main limitation is the proximity of some users if it is going to be attached to a wall.

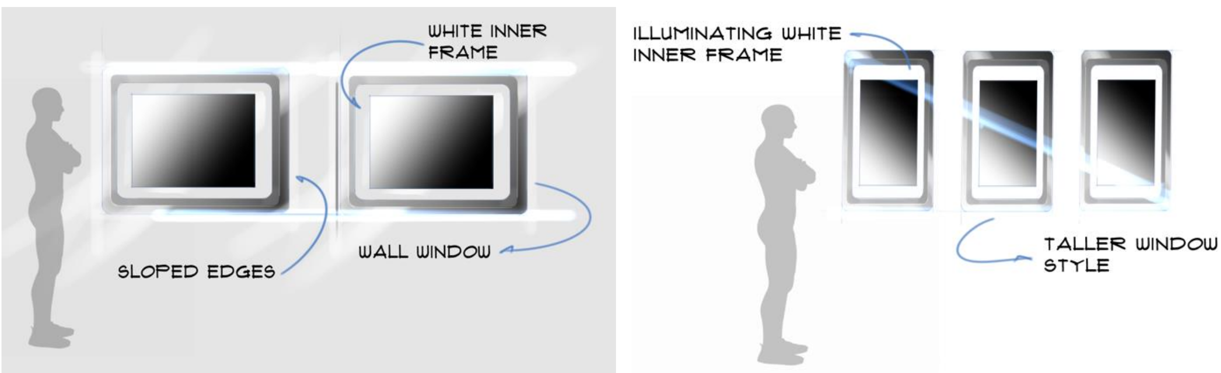


Fig. 14: Ideation 02. LEFT and RIGHT: Digital/Virtual window concept.

The third product idea is a mirror IVE. It can be hanged on a wall or partitions for configurability of a workspace. Visual sense is the primary stimulation and limitation. It will display natural scenery. This concept does not have the motion parallax functionality. The overall size can vary and the positioning on the wall will be from a user's waist and up.

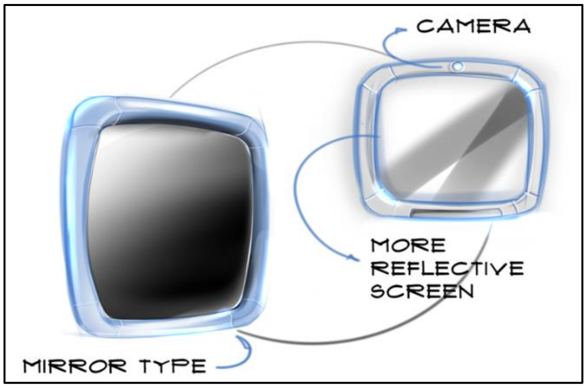


Fig. 15: Ideation 03. Mirror IVE concept.

The fourth product idea is a movable platform. The visual and somatosensorial sensations are the physiological sense stimulation. The air purifier system integration can act as a haptic feedback. It can be used in all office or workspace settings because it can be moved anytime. The limitation is the proximity and space available from a user.

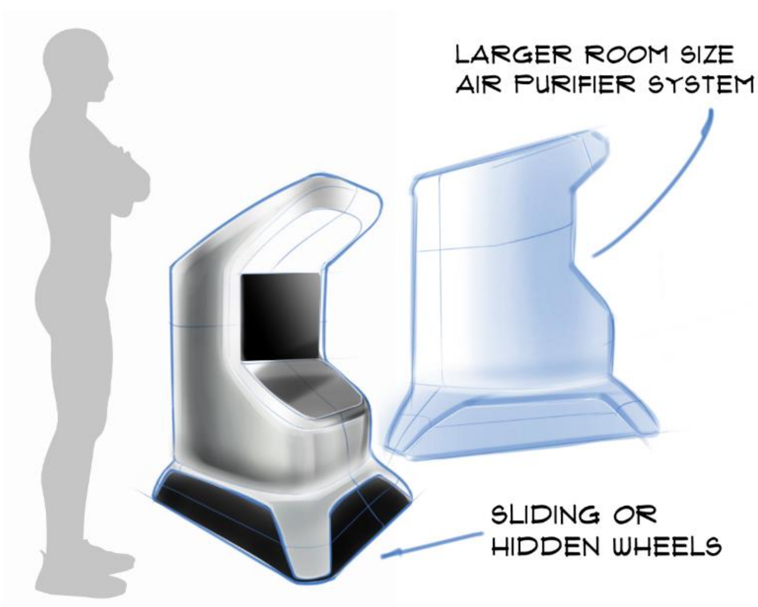


Fig. 16: Ideation 04. Movable platform IVE.

The fifth product idea is an articulating arm window. It allows for modularity and configurability. The viewing angle can be adjusted to the user's visual comfort. The visual sense is the only physiological stimulation with the device.

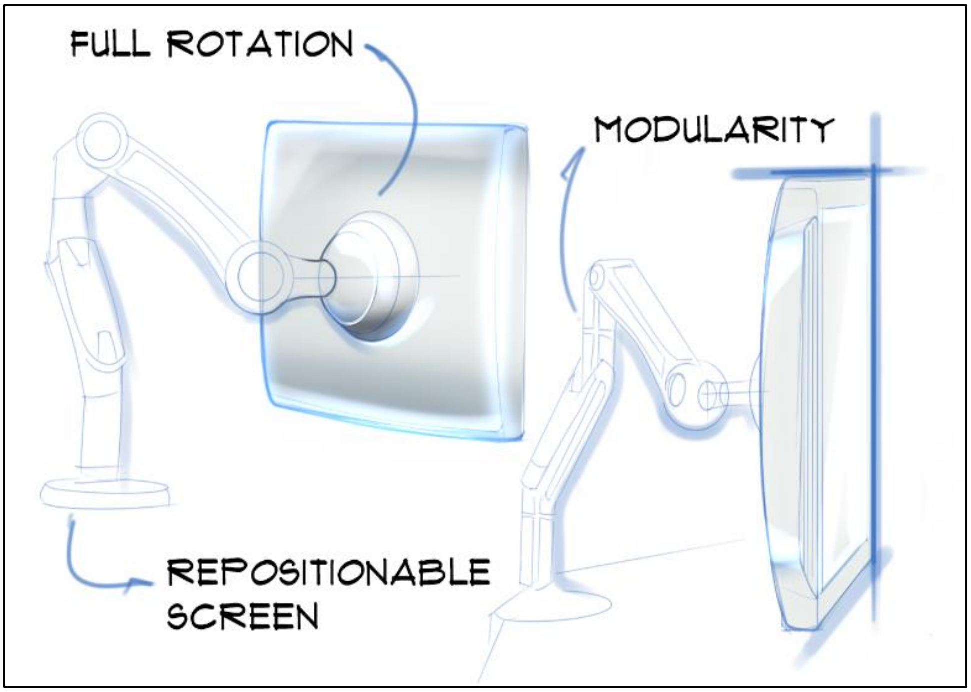


Fig. 17: Ideation 05. Articulating arm window.

The sixth product idea is a hanging partition wall window. The main limitation is that it can only be utilized in a workstation with a partition wall, either high or low. It tracks user movement with a tracking camera for parallax motion and uses wind haptic feedback aside from the visual stimulation.

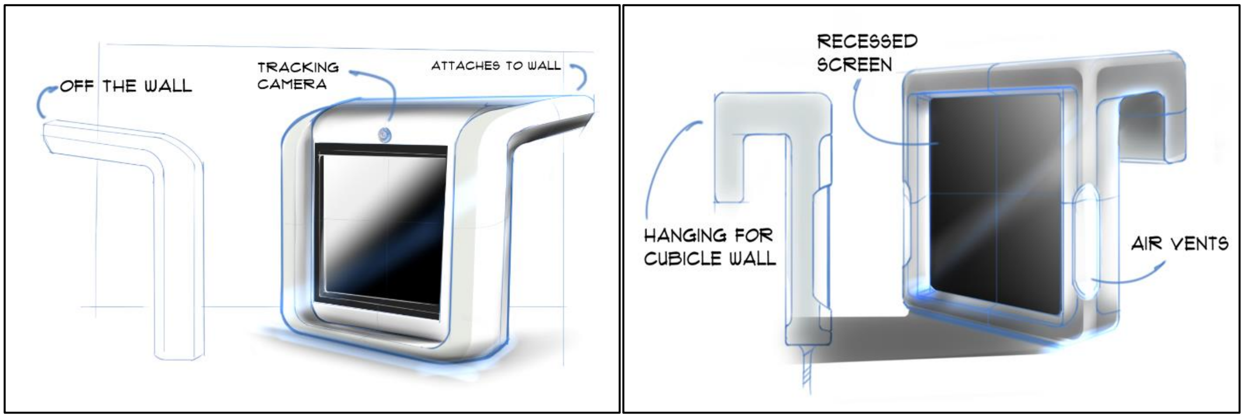


Fig. 18: Ideation 06. Small hanging monitor.

The seventh idea is a larger desk picture frame concept the incorporates visual, somatosensorial and auditory senses. This can be used on a variety of desks. However, it will take a large usable space on the user's desk. The device can tilt forwards and backwards for configurability.

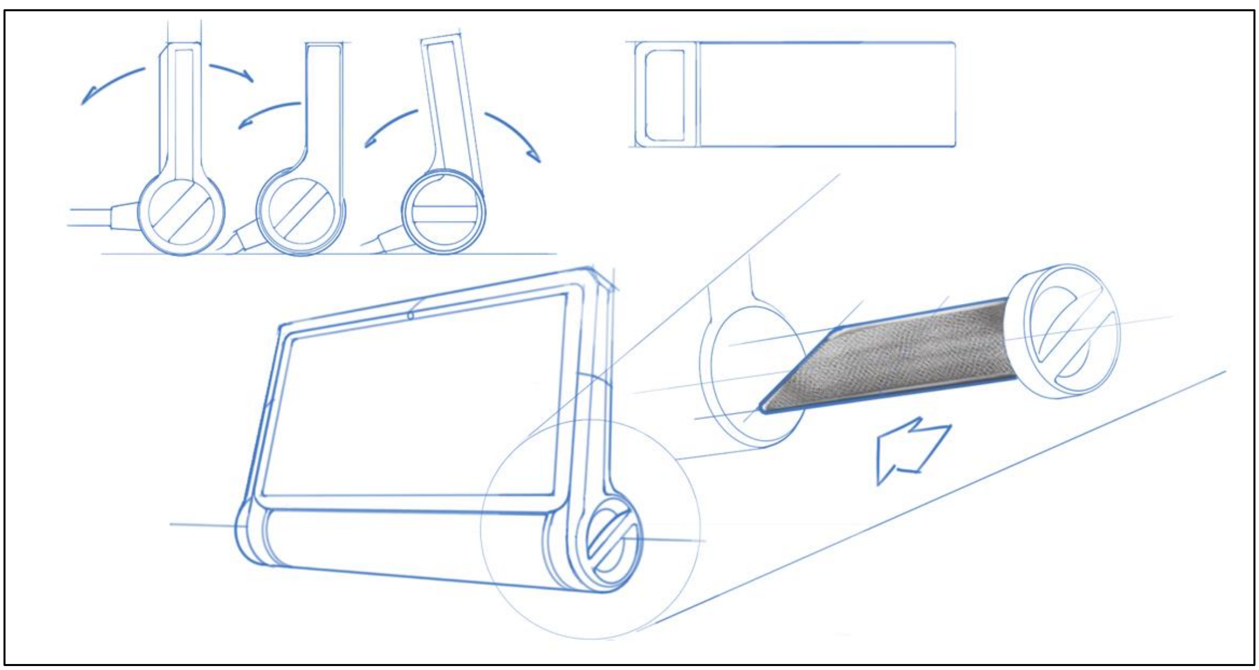


Fig. 19: Ideation 07. Large desk frame concept.

The eigth product idea is hanging virtual window attaching to a partition of a cubicle, building wall, or any partitioned wall. This concept incorporates the visual, auditory, and somatosensorial feed back. The thin frame will not take up a significant amount of space within the user's work area. It can track the user for the parallax motion. The limitation on this concept is that it does not rotate left to right and thus might not be within the user's line of sight, or peripheral vision.

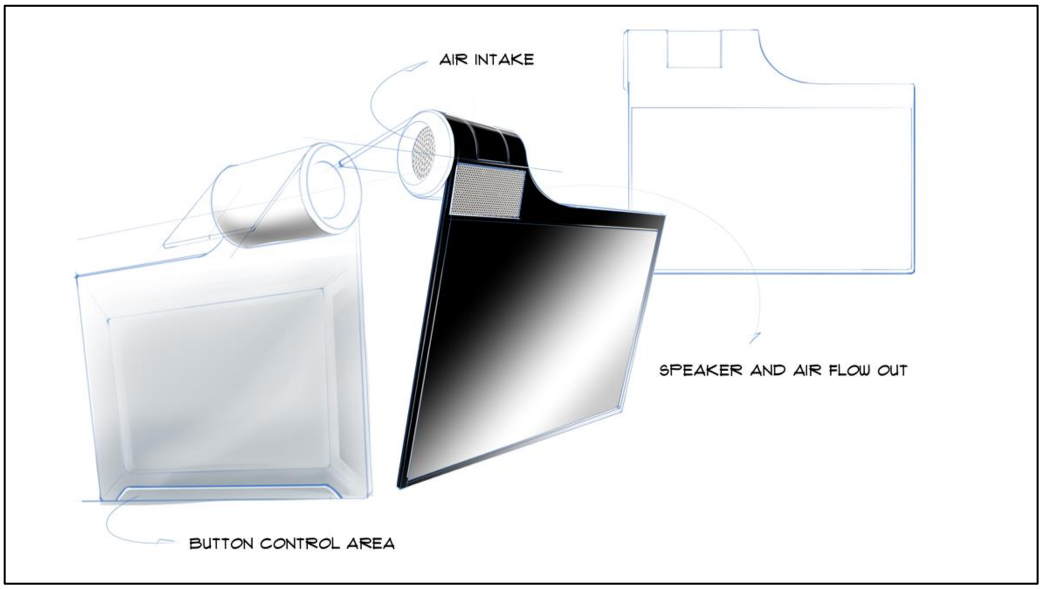


Fig. 20: Ideation 08. Thin hanging monitor.

The eight concepts have trade-offs and limitations such as the number of physiological senses that are stimulated, immersive quality, and desk accommodations. The immersive quality is expressed if there is an interaction with the user such as motion parallax, haptic feedback, or auditory output. None of the product idea concepts had a comprehensive solution because it is limited to the purpose and usage of the concepts. Figure 21 below summarizes the concepts.

Concept Number	Product Concepts	Physiological Senses	Immersive Quality	Workspace Consideration
01	**Desk Picture Frame**	Visual	No Motion Detection, No Haptic Feedback	Most desk types
02	**Wall Virtual Window**	Visual	Motion Detection, No Haptic Feedback	Wall only
03	**Mirror IVE**	Visual	No Motion Detection, No Haptic Feedback	Wall and desk partitions
04	**Movable Platform**	Visual, Touch	Motion Detection, Haptic Feedback	Movable (limited portability)
05	**Articulating Window**	Visual	No Motion Detection, No Haptic Feedback	Desk attachment. Configurable
06	**Small Hanging Monitor**	Visual, Touch	Motion Detection, Haptic Feedback,	Partitioned wall only
07	**Large Desk Frame Monitor**	Visual, Touch, Auditory	No Motion Detection, Haptic Feedback, Sound Output	Desk only (needs a large desk area)
08	**Thin Hanging Monitor**	Visual, Touch, Auditory	Motion Detection, Haptic Feedback, Sound Output	Building wall and desk partitions

Fig. 21: Product concepts summary.

After evaluating the 8 product ideas, a ninth product was conceptualized. The ninth product is a more comprehensive because it includes the visual, touch, and auditory senses maximizing the stimulation of biophilic triggers such as the visual scenery, wind reproduction, and nature sounds. For user context, a universal desk workstation was chosen rather than a partitioned wall, a building's wall, or portability, because it captures a larger user base. For example, a person may not receive a full stimulation if the product is attached to a building's wall, and the person's desk is distant. Each office worker is assigned a desk and therefore sensible for the ninth concept because every single person can have one. The ninth concept has an articulating arm to accommodate the user preference. It can be vertically translated, tilted, and rotated.

Fig. 22: LEFT: Vertical translation. MIDDLE: Tilt. RIGHT: Rotation.

The ninth concept has the auditory and somatosensory feedback component separated by a position-configurable monitor. The sound and wind feedback work conjointly with the scenery of the visuals. Furthermore, this concept has a motion tracking sensor for the video parallax feature. Most importantly, the concept is attached to the back of the desk and takes minimal space of a user's work area, so it does not impede their workflow.

Fig. 23: Prototype of concept 09.

Concept Number	Product Concepts	Physiological Senses	Immersive Quality	Workspace Consideration
01	**Desk Picture Frame**	Visual	No Motion Detection, No Haptic Feedback	Most desk types
02	**Wall Virtual Window**	Visual	Motion Detection, No Haptic Feedback	Wall only
03	**Mirror IVE**	Visual	No Motion Detection, No Haptic Feedback	Wall and desk partitions
04	**Movable Platform**	Visual, Touch	Motion Detection, Haptic Feedback	Movable (limited portability)
05	**Articulating Window**	Visual	No Motion Detection, No Haptic Feedback	Desk attachment. Configurable
06	**Small Hanging Monitor**	Visual, Touch	Motion Detection, Haptic Feedback,	Partitioned wall only
07	**Large Desk Monitor**	Visual, Touch, Auditory	No Motion Detection, Haptic Feedback, Sound Output	Desk only (needs a large desk area)
08	**Thin Hanging Monitor**	Visual, Touch, Auditory	Motion Detection, Haptic Feedback, Sound Output	Building wall and desk partitions
09	**Articulating Window 2**	Visual, Touch, Auditory	Motion Detection, Haptic Feedback, Sound Output	Most desk types. Configurable

Fig. 24: Updated concepts including ideation 09.

Fig. 25: Concept 09 attached to a desk.

Fig. 26: In-context application of concept 09.

DESIGN CONCEPT ANALYSIS

Unfortunately, concept 09 was abandoned because several key issues arose from user feedback. First, the concept did not suggest a strong biophilic trigger and immersive quality even though it included the 3 physiological sense stimulations and natural scenery. In other words, the device was perceived as another computer monitor. It did not generate the feeling of being in a natural environment. Second, the device was seen as a novelty rather than a tool to help focus and improve work productivity. There was a disconnect with the concept's purpose and the user. Third, the concept did not address lighting issues such as creating a well-lit work area, especially in a workstation with high partitioned walls. The device's monitor was distracting because it added visual fatigue; it competed with the user's visual attention when the device is placed next a computer. Fourth, the device's sound was not working conjointly with the nature scenery. Users suggested they could use the sound system to play their music instead. This could potentially create distracting sounds for neighboring colleagues.

The issues raised prompted me to discontinue developing this concept any further. The ideation process necessitated a second round of conceptualization.

3.2.2. DESIGN CONCEPTS PART II

In this second round of conceptualization, the product does not need to be a stand-alone device, rather, it had to be an actual workstation, desk, or cubicle (furniture) design. Exploring a *furniture* concept, now, is more sensible because sensory deprivation and social isolation exist within an enclosed environment. If, in some way, a confined environment can be manipulated, it could provide a better biophilic stimulation, improve the immersive quality, and overall workspace satisfaction. In other words, instead of adding a device in an already cognitively-challenging ICE, positive stimulations should be integrated better in the environment. Moreover, new concepts should address the short-comings from the ninth concept: unstimulating biophilic trigger, unconducive for work productivity, no lighting improvement, and for the video and sound to work together in a natural scenery video.

I established some design objectives to be incorporated into the new concepts. To trigger a more biophilic stimulation of a natural environment, specifically trees, the concepts had to incorporate a wood or wood-like material. Concepts must be constructed with any wood types (veneer, plywood, hardwood, or softwood etc.), any wood species, or combination of wood types and species. Second, it has to show water or features inferring water. Third, it has to have some sort of wind somatosensorial feedback.

Other considerations include easy assembly, installation, and shipping method. The assembly and installation must use common or industry standard fasteners. The furniture concept has to be flat packed for efficient and cost-effective shipping. Furthermore, the pieces and components of the concept must be handled easily. For instance, pieces should not be too large that it requires two or more people for assembly.

10TH CONCEPT

The tenth concept is similar to a traditional cubicle. It has 2 digital windows/monitors on the left and right side of the inside panels. It has see-through panels that minimize the feeling of being enclosed. It can provide enough privacy and noise reduction. This also allows for more light penetration inside the workstation. The sound and wind feedback will be projected from the same component of the monitor. The concept has no inference of water. The partitions are double paneled for outside sound absorption.

Fig. 27: Concept 10. More cubicle-like idea.

11TH CONCEPT

The eleventh concept is a workstation with 5 sides; it is a decagon split in half. Interesting honeycomb-like arrangement can be deduced with this workstation form. Consequently, this form factor allows the user to ideally view the two monitors at their peripheral vision. Same as with the tenth concept, the sound and wind feedback are incorporated with the monitors. The panels are double panel as well for sound absorption. The panel is less than 5 feet tall and thus considered to have a short partition. The concept features two large vertical glass panels to minimize the detrimental effect of being confined. The most important feature with this concept is the addition of a water pattern on the desk because a video of a natural scenery with water will not be as necessary.

Fig. 28: Concept 11. Half-decagon workstation/cubicle.

12^{TH} CONCEPT

The twelfth concept is a semi-circle workstation. Although the form factor makes it more confined, there are two see-through panels at the top of both ends of the workstation opening to lessen the feeling of confinement. The concept does not show a water-like feature. Furthermore, there is no visual feedback monitor on this concept because the round shape makes it difficult to incorporate flat monitors.

Fig. 29: Concept 12. Semi-circle workstation.

13TH CONCEPT

The thirteenth concept returns to a more traditional cubicle design, but this concept has angled corner sides to future monitor implementation. There is no water feature incorporate in the concept. The glass panels lessen the of feeling enclosed. The partition panels are intended to be single paneled thus a wider base at the feet for stability.

Fig. 30: Concept 13. Angled corner workstation.

14TH CONCEPT

The fourteenth design concept is an open workstation. The concept blends an enclosed and open workstation. The simple framing of the workstation eliminates many of the paneling materials. Inherently, reducing the partition paneling of the workstation will make it easier to assemble and ship. With less overall paneling, to limit visual distraction, a thin back panel is added behind the computer to minimize the user's visual distraction. The concept imposes stronger biophilic stimulation by introducing real plants on the left and right side of the workstation. Also, the water-like feature on the desk is much more pronounced. Furthermore, two angled corners allow the incorporation of two monitors for visual natural scenery videos.

Fig. 31: Concept 14. Open workstation with incorporated plants.

The 5 new concepts are potential solutions that attempts to improve an ICE with better biophilic design integration, create a feel of privacy, and lessening of visual and noise distractions. These new concepts had overlooked opportunities that was set out from the first round of conceptualization. For example, concepts 12 and 13 did not have video monitors, water-like features, and any wind feedback. While concept 10 was promising, but it did not have a water-like feature nor consideration for simple assembly. Concept 11's shortfall is that the workstation requires many panels, 5-sided versus a traditional 3-sided partition; potentially making the assembly slightly more complex. Also, intrinsically, the thicker panels will be more difficult to assemble and expensive to ship. Concept 14 on the other hand, met all the important requirements. Therefore, a final design was developed from concept 14.

Concept Number	Video Monitors	Water-Like Features	Wind	Conducive to Lighting Penetration	Form (simple assembly and shipping)
10	Yes	No	Yes	Yes	No
11	Yes	Yes	Yes	Yes	No
12	No	No	No	No	No
13	No	No	No	No	Yes
14	Yes	Yes	Yes	Yes	Yes

Table 32: Summary of concepts 10 to 14.

3.3. 15th CONCEPT WORKSTATION

ASSEMBLY, INSTALLATION, & SHIPPING

The 15th concept workstation is derived from concept 14 and it attempts to mitigate sensory deprivation and social isolation in an ICE, thereby improving work performance. Construction of this workstation concept aims for an easy assembly and installation. Concept 15 is made mostly of flat and rectilinear pieces. There are no compound surfaces that may add complexity during manufacturing and assembly. A loose tenon joinery is the primary method used for assembly because it is the most versatile; a loose tenon guides the pieces together during assembly. Furthermore, this kind of joinery creates a strong joint because of the face-grain surface-to-surface contact of two pieces, and importantly, a loose tenon adds rigidity. At the intended area of joining, a mortise (hole) is made and consistent with the rest of the pieces. Loose tenon shapes include a dowel-type peg, rectangular tenons with rounded edges, and a thin-oblong *biscuit*. A Festool Domino tenon was used for concept 15 workstation because of the variety of loose tenon sizes. This allowed the used of small sized tenons in close-fitting locations and thin pieces.

Fig. 33: Loose tenon joinery. Image Source:

https://www.popularwoodworking.com/projects/loose-tenon-joinery/

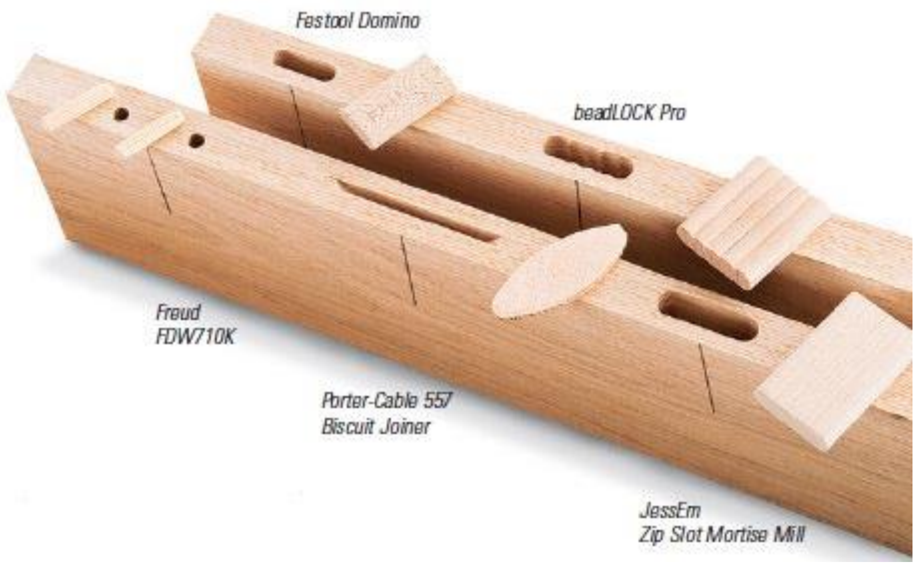
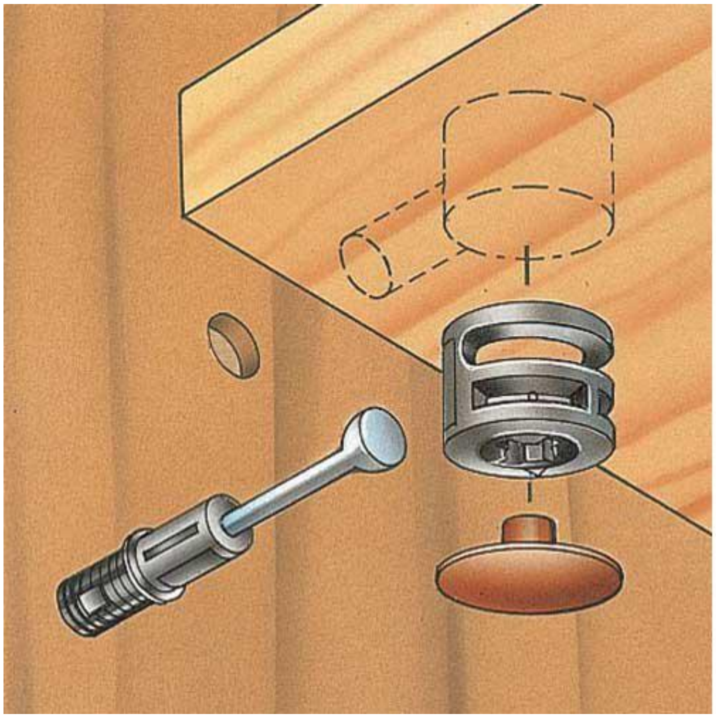


Fig. 34: Various kinds of loose tenons.

Image Source: https://www.rockler.com/learn/cut-mortise-loose-tenon-joinery-biscuits-joiners-mills/

A loose tenon joinery does not secure the pieces together. Second, some of the loose tenons are proprietary. There are many knock-down fasteners available to secure pieces together. The most popular and easily available are cam-lock nuts. This type of fastener was used for the concept 15 workstation. The combination of a loose-tenon and cam-lock nut makes the assembly of the workstation easy and simple.



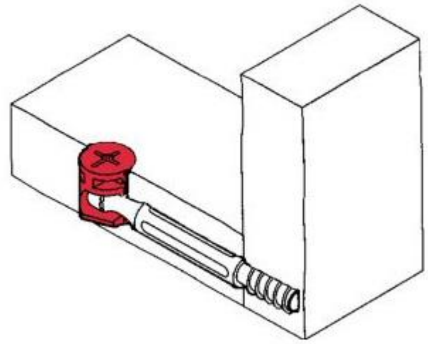


Image 35: Cam-lock nut fastener

Image Source: https://www.core77.com/posts/27725/Death-to-Cam-Lock-Nuts-Flatpack-Hardware-That-Will-Hopefully-Become-Obsolete

Concept 15 will be flat-packed for easy shipment and transportation. This is ideal because it allows for stacking when it's still flat-packed. Also, concept 15 will be packaged as a single large box (image 37). Multiple layers can be stacked on each other and, consequently, the shipping cost will be more affordable. Manufacturing costs were considered against three raw materials: particle board, pine (softwood), and maple (hardwood). The table below illustrates a hypothetical manufacturing/production costs per unit.

Itemization (per unit cost)	Good		Better (softwood)		Best (hardwood)	
Raw Material:	**Particle/veneer Board**		**Pine**		**Maple**	
Weight (lbs)		180		100		146
	Cost/bf		Cost/bf		Cost/bf	
20 board foot / unit	$2.00	$40.00	$6.00	$120.00	$18.00	$360.00
Resin Table (including tabletop and epoxy)		$400		$400		$400
Cam-Lock Nuts		$5		$5		$5
Electronics (Monitor, Fan, Lights)		$300		$300		$300
Sub-Total		$745.00		$825.00		$1,065.00
Labor (@ $15/hr):		$15.00		$15.00		$15.00
	# hrs/unit		# hrs/unit		# hrs/unit	
Ripping	0.75	$11.25	1.75	$26.25	2.25	$33.75
Machining	0.5	$7.50	2	$30.00	2.5	$37.50
Sanding	0	$0.00	2	$30.00	2	$30.00
Assembly	1.25	$18.75	1.25	$18.75	1.25	$18.75
Finishing	0.5	$7.50	0.5	$7.50	0.5	$7.50
Packaging	0.5	$7.50	0.5	$7.50	0.5	$7.50
Sub-Total	3 hrs	$52.50	8 hrs	$120.00	9 hrs	$135.00
Manufacturing:						
Consumables (glue, rag, loose-tenons, etc.)		$10		$10		$10
Edge banding		$10		$0		$0
Sub-Total		$20		$10		$10
TOTAL		$817.50		$955.00		$1,210.00
NOTES:	Easily manufactured and consistent quality.		Easier to process than a hardwood.		Hardest and longest to process.	

Image 36: Manufacturing Costs Table (Per Unit).

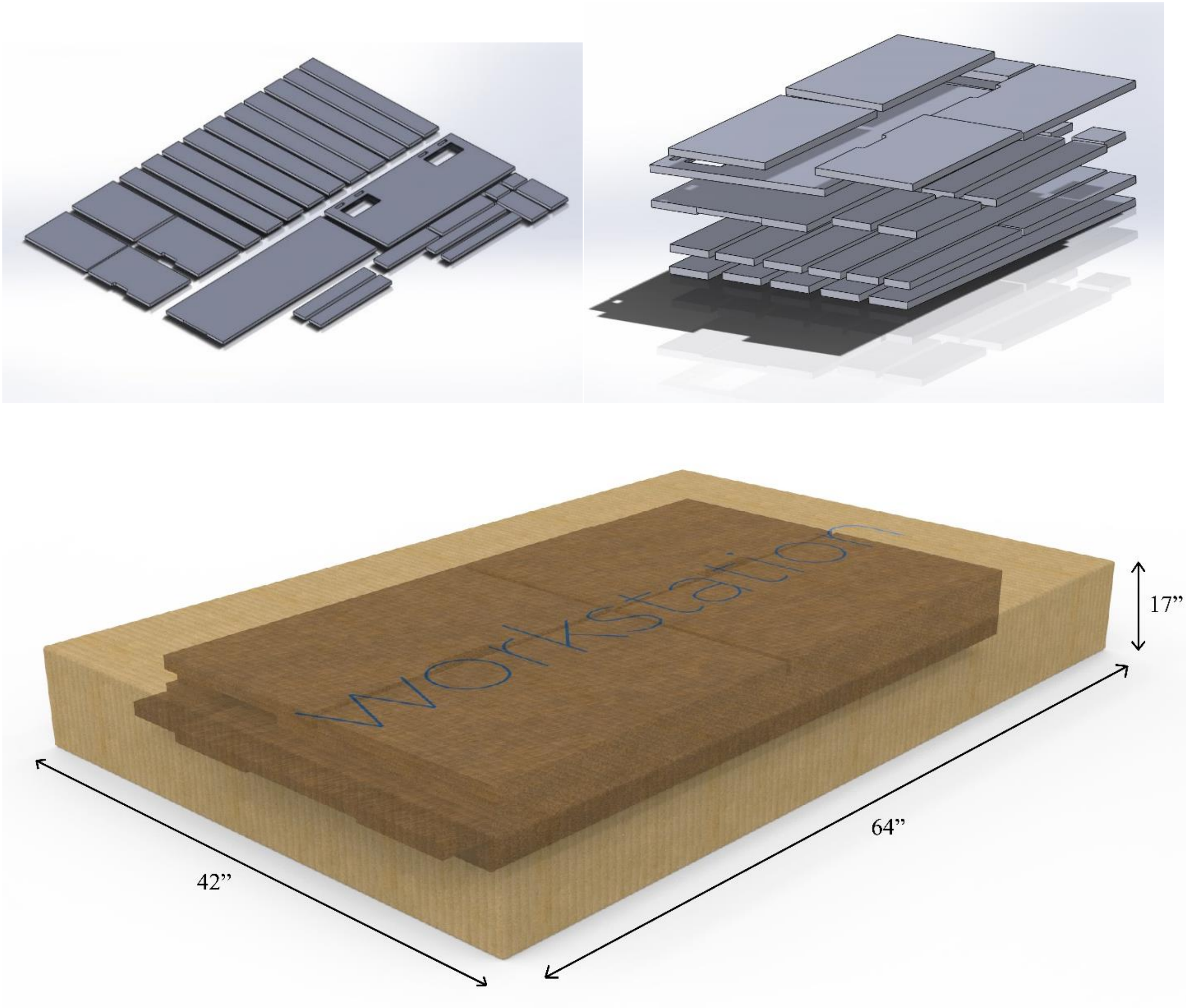


Image 37: TOP LEFT. Laid flat. TOP RIGHT. Flat packing. BOTTOM. Approximate shipping box size.

ERGONOMICS

The work zones were considered on concept 15. The suggested distance from the user to the edge of the primary work zone is 15 inches. The maximum distance reach for a user to the edge of the tertiary work zone is 20 inches. The dimension of the desk is 24 inches depth by 56.50 inches width. The reach of the user is within the comfortable bound of concept 15's desk.

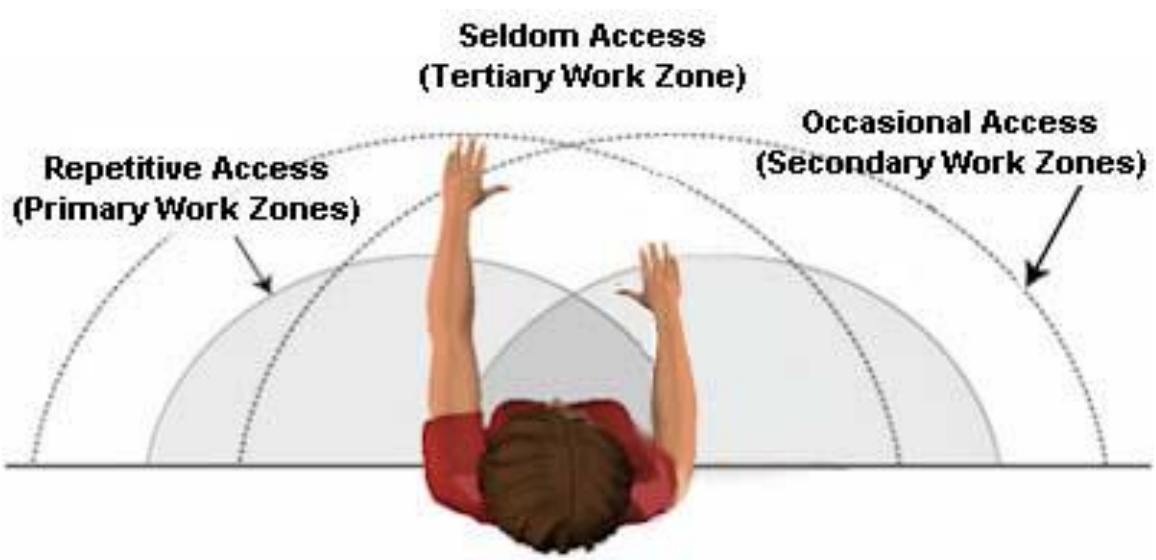


Fig. 38: Work zones on a desk.

Image: Work Zones
https://www.osha.gov/SLTC/etools/computerworkstations/components_desk.html

The line of sight of the user was considered as well. The recommended line of sight of from the top of the desk is approximately 20 inches. The video monitor had to be placed within the cone of easy eye rotation. The placement video monitor in the workstation is between -10^0 to $+ 5^0$ from the horizontal plane. The speaker is integrated to the screen; therefore, the sound source is optimally in front of the user.

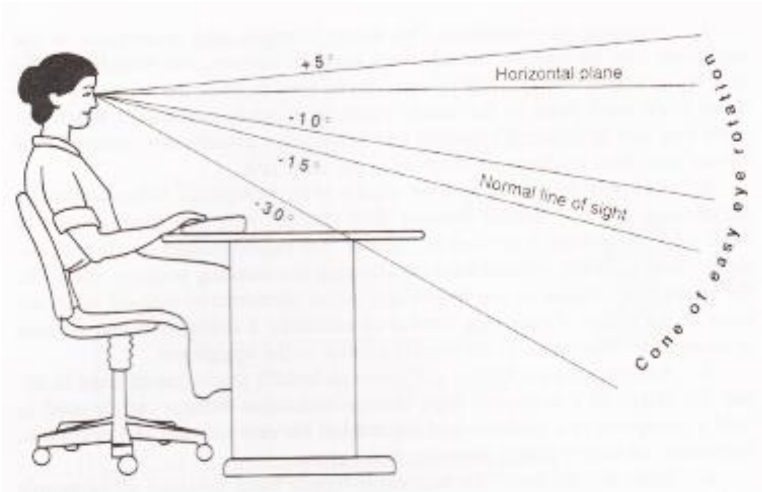


Fig. 39: Line of sight.

Image Source: Wickens, C. D., Gordon, S. E., & Liu, Y. (2011). *An introduction to human factors engineering (p. 262)*. New Delhi: PHI Learning.

Fig. 40: Actual line of sight of the workstation.

Image: Concept 15 workstation line of sight

According to the *Introduction to Human Factors Engineering* (Wickens et. al., 2014), the rule of thumb to determine the work surface height is to design the work height above the user's elbow at between 2-4 inches. The workstation height from the ground is 29 inches. With the use of an adjustable height chair, a large majority of the population can be comfortable with the concept 15 workstation.

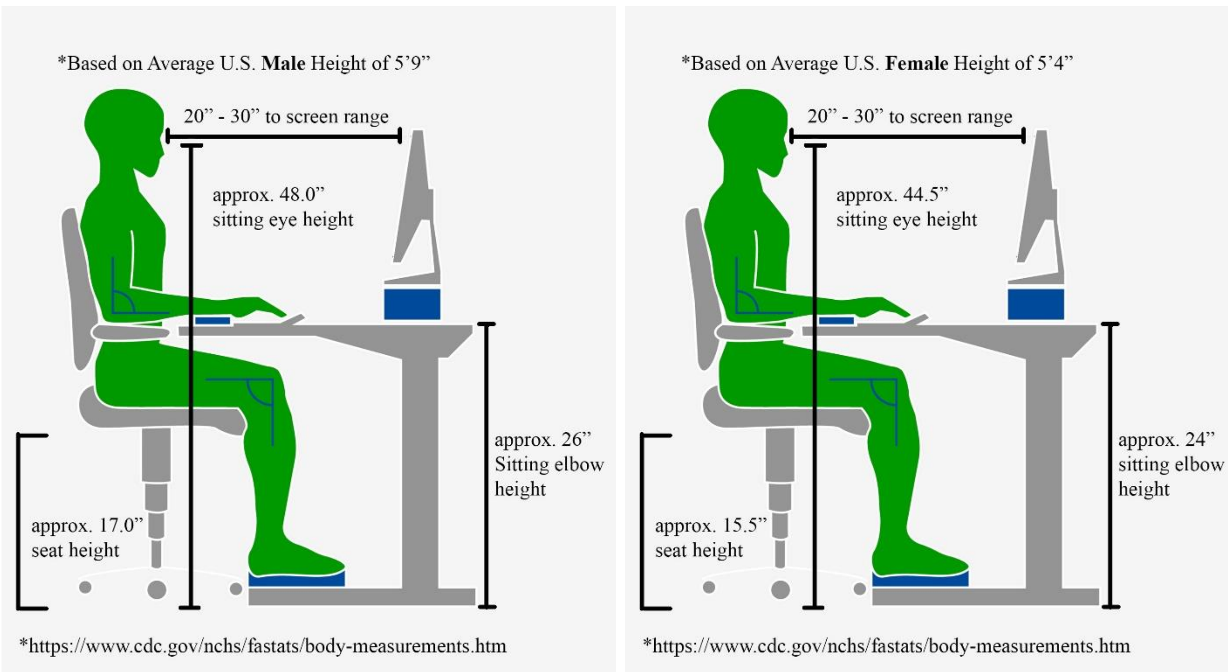


Fig. 41: Example of desk height and chair of a 5'9" male and 5'4" female.

Source: https://www.thehumansolution.com/ergonomic-office-desk-chair-and-keyboard-height-calculator/

PROTOTYPE

The desk height and width were tackled first in the prototyping phase. A cardboard construction of the desk was made to verify the desk height. As established beforehand, the entire workstation will be built out of wood. Any type or species of wood can be used, walnut was used for the desk and pine for the rest construction.

Fig. 42: Desk dimension testing.

The second step in the workstation build was to create the water-like feature on the walnut desk. A live edge was chosen because the live edge can be used to depict a sort of shore or coastal line. The walnut was cut in half in the middle. The two pieces were flipped for the live edge to be positioned in the middle. To create the water-like feature, an epoxy resin with metallic blue color particles was used for the first half of the pours. The resin and hardener mixture ratio is

50:50. The second half of the pours, a clear epoxy-resin was used because it would create a visual depth.

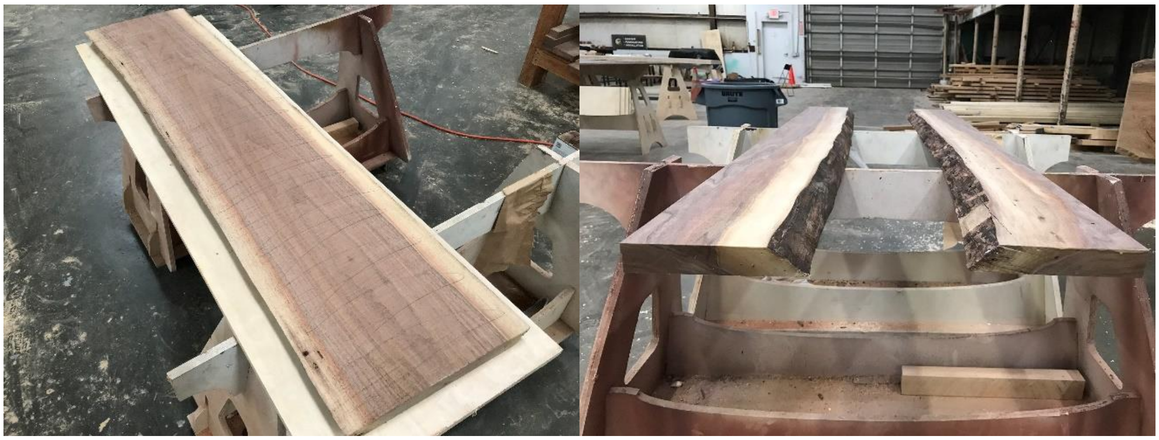


Fig. 43: LEFT: Live edge walnut for the desk. Right: Walnut cut in half for resin pour.

Fig. 44: Epoxy-resin mixing with metallic blue particles.

Before the epoxy resin was poured, a containment box was created to position the 2 pieces of walnut in place and to hold the epoxy resin pour in. The epoxy resin is an exothermic chemical process and during the curing time, it created bubbles. I eliminated the bubbles by using a heat gun. This was an important step because the bubbles could degrade the strength of the desk. The total amount of the epoxy resin used was approximately 5 gallons. The curing time of the epoxy resin is about a week, but it was acceptable to do subsequent pours after 24 hours. It took about four weeks to complete the pouring and curing process and to create the water-like feature. The final piece had bowed due to epoxy contraction. It had to be flattened.

Fig. 45: Containment box and pouring process. Facilitating the release of bubbles.

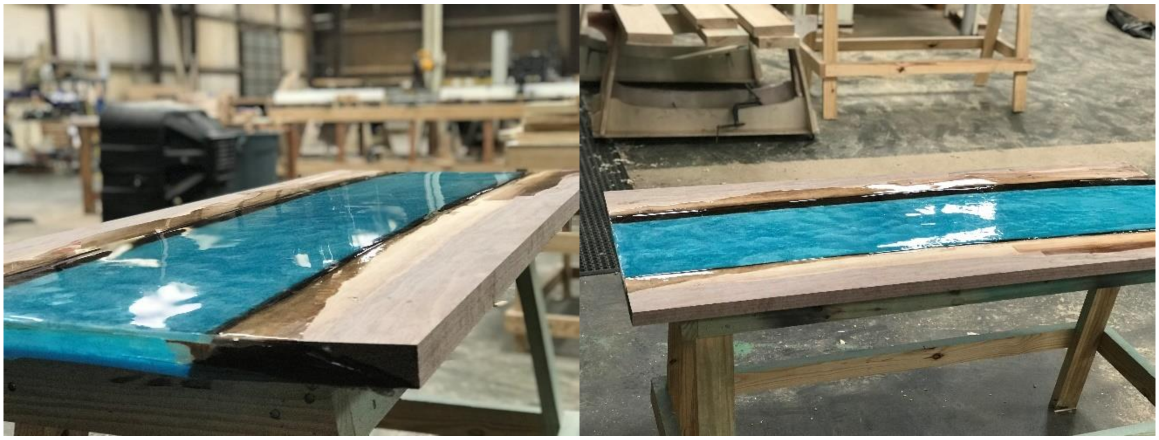


Fig. 46: Curing process finished. The desk bowed due to epoxy contraction.

The next stage of the prototyping process is building the desk frame and the back panel. The pieces were cut to size and processed. The pine wood was planed and jointed to flatten the raw lumber. All the pieces were 1 inch thick.

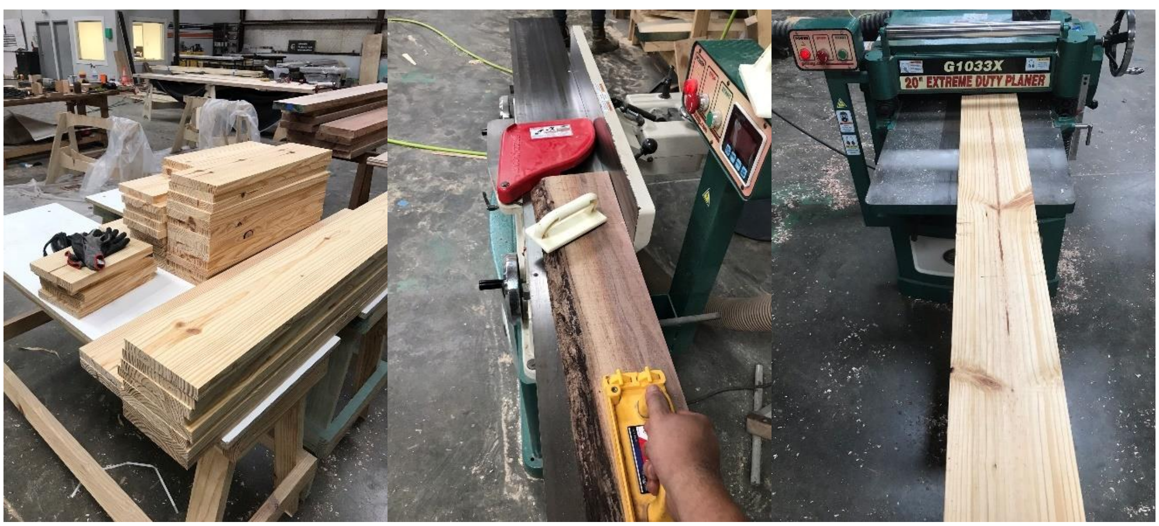


Fig. 47: Processing of raw and rough pine wood lumber.

The assembly process started after the correct individual pieces were cut to the right dimension. The mortises were created with a Festool Domino tool. It is a specialized tool that allows to use the specific loose-tenon joinery. The pieces were secured using cam-lock nuts.

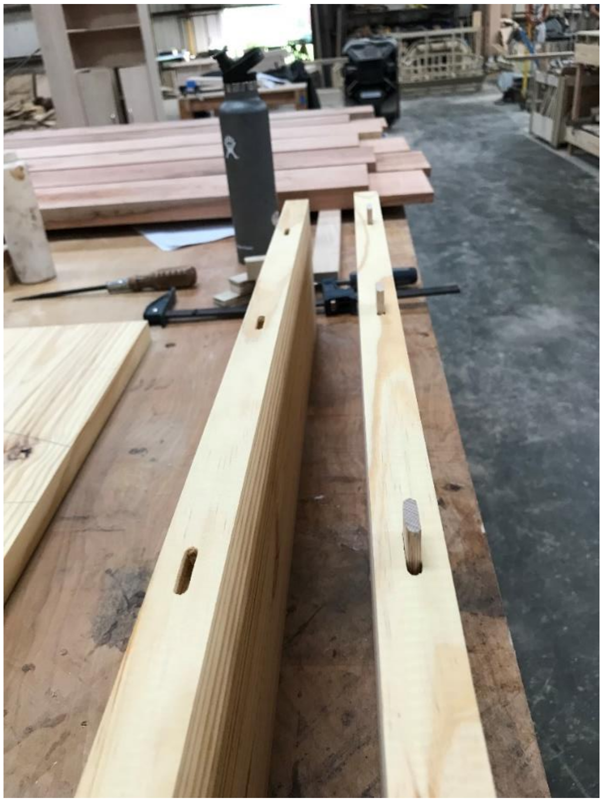


Fig. 48: Loose-tenon joinery using a Festool Domino tenon.

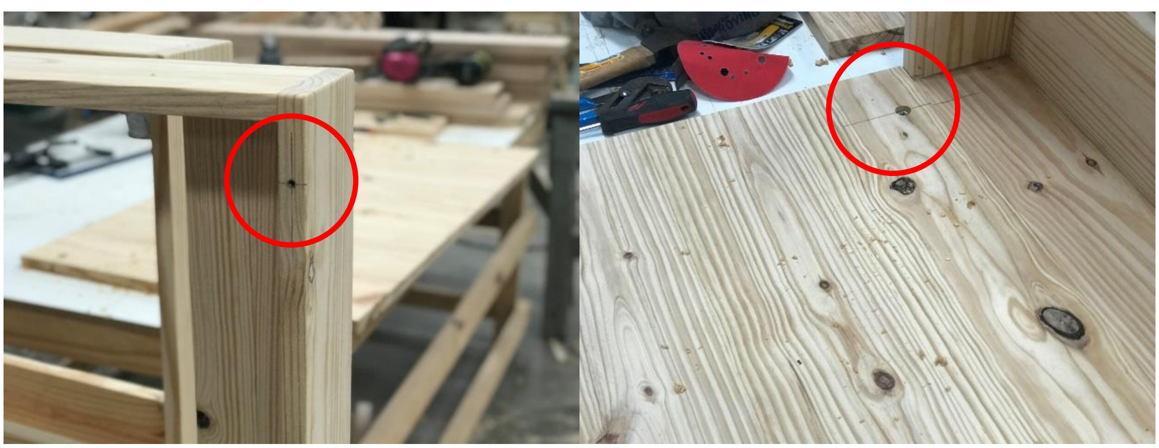


Fig. 49: Holes created for the cam-lock nut.

The left and right side of the frames were first created so the back panel and drawers can be installed. The desk was test fitted on the frames, so adjustments could be made.

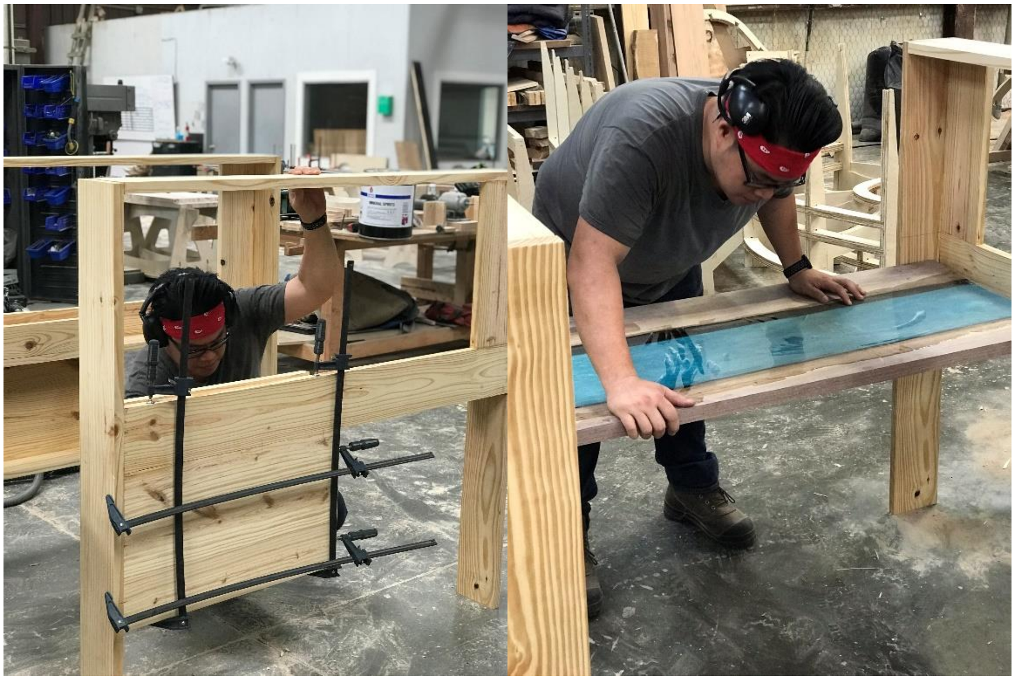


Fig. 50: Assembly process and test fitment.

Fig. 51: Frames and desk ready for staining.

The wood was bare and needed a sealant to prevent the wood from contracting and expanding too much. Five kinds of stains were tested to check the aesthetics on pine wood. The walnut desk was not treated with a stain, rather, Danish oil was used to protect from dirt. The dark walnut stain was chosen to match the color of the desk. The staining required applying stain conditioner to even out the color and avoid patches. Stain was applied one a week. It required 5 coats of stain and a period of 24 hours in between for proper stain curing and penetration.

Fig. 52: Wood stain testing.

After the staining process, the pieces were wet sanded to obtain a sheen. Any imperfections were corrected at this stage. The back panel was test fitted again to ensure the pieces can be secured correctly.   Frames were created for the monitor, but a cut-out of the screen was created after the experiment phase based on the participant interviews.

Fig. 53: Cam-lock is visible after staining the workstation.

Fig. 54: Picture frame construction for the video monitor.

The concept 15 workstation was assembled in the Industrial Design graduate room to begin the experiment. Plants were added at the sides completing the prototype. The workstation stayed flat and stable. It didn't need any more fasteners. The desk is attached to the frame using the cam-lock nut as well. There is ample space from the back edge of the desk and the back panel for wire clearance of computers etc.

Fig. 55: Prototype assembled and ready for the experiment.

Fig. 56: Testing the peripherals on the workstation.

The iPad mini 2 is visible with a Bluetooth enabled keyboard. The fan is right next to video monitor, but it is not as visible because of the shadow casting. A modified version of the prototype was modeled in Solidworks and rendered in Keyshot. The modification included the video monitor integrated into the back panel, sound speakers above the monitor, and the fan above the plants. The modifications were made because of participants feedback. An in-context perspective is available on appendix F.

Fig. 57: Modified concept 15 workstation.

Fig. 58: Side view of the modified concept 15 workstation.

Fig. 59: In-Context renders of the concept 15 Workstation.

CHAPTER 4: RESEARCH METHODOLOGY

4.1 IRB APPROVAL

The study required human subject participants. Thus, the study necessitated an Institutional Review Board (IRB) approval from University of Houston's Division of Research. The study IRB ID is STUDY00001234 and was approved on October 12, 2018.

4.2 RESEARCH & STUDY DESIGN

In a philosophical research perspective, this thesis is considered a Pragmatic Worldview. It emphasizes the research problem's concern of applications and solutions. Under the Pragmatic Worldview, the approach is a *Mixed Method Desig*n with the primary model of convergent parallel approach. Both quantitative and qualitative data were collected at the same time in order to provide a comprehensive analysis of the research problem.

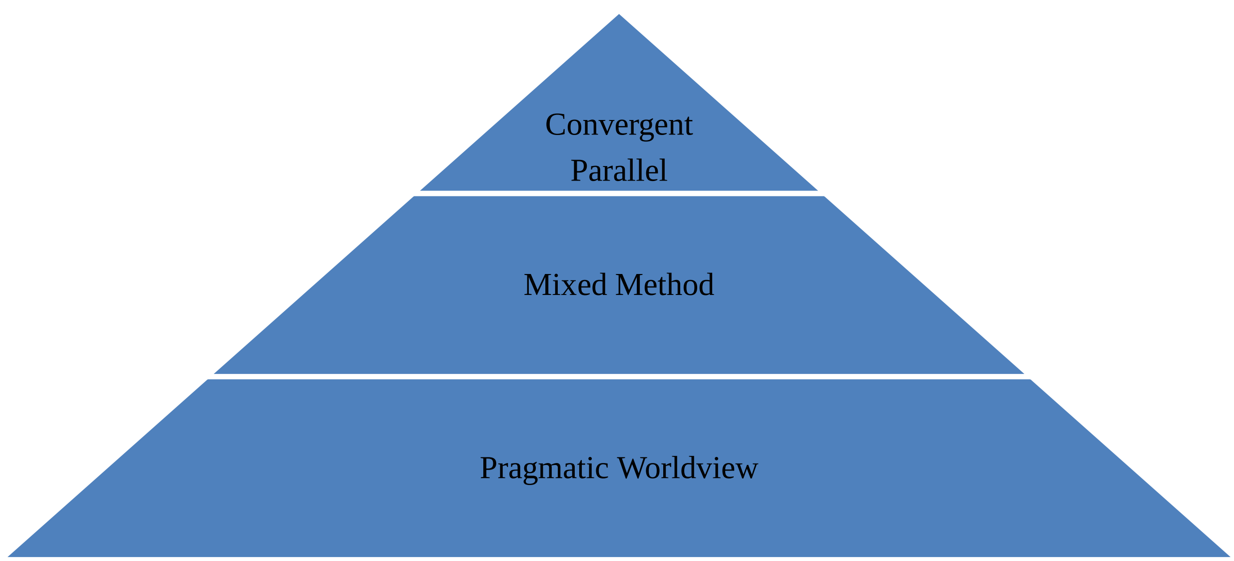


Fig. 60: Research method hierarchy.

4.3 EXPERIMENT DESIGN & METHODOLOGY

Each participant was informed of the procedures, risk, and had to acknowledge that their participation is voluntary, and they may withdraw anytime without repercussions. Participants gave their verbal informed consent (waived IRB written consent) to participate with the study. The experiment was conducted in the Industrial Design graduate room (376) of the Gerald D. Hines College of Architecture and Design.

The first part of the study was responding to an Engagement in Meaningful Activities (EMAS) questionnaire (Eakman, 2012). The second part of the study is an experiment composed of four conditions in which participants take all the assessments. The assessments are the following: (1) keyboard/typing, (2) cognitive performance assessment (Stroop Effect), and a (3) game-based task-analysis assessment (Mastermind). An iPad mini 2 with a Bluetooth keyboard was provided to perform all the assessments. The last part of the study was conducting a qualitative interview.

4.3.1 PARTICIPANT SELECTION

The primary subjects of the study were local college students of the University of Houston. College students are analogs of office workers because both are categorized as low-risk in the ICE spectrum; college students and office workers are exposed to the same sensory deprivation and social isolation stressors. A total of 15 college students were screened, but only 10 college students were enrolled in the study. To take part in the study, the participants must meet the following requirements: ages between 18-65 yrs. old and must have a dedicated work desk they use on a frequent basis on the University of Houston campus.

4.3.2 STUDY PROCEDURES

The participants were asked to answer the EMAS questionnaire prior to beginning the 2nd part of the study (environmental condition experiment). In the 2nd part of the study, each participant must first do the typing/keyboard assessment (*TapTyping*), second, the Stroop Effect assessment (*Encephalapp*), and finally, the Mastermind game (*Mastermind – Classic*). Furthermore, conditions were randomized but not the assessments.

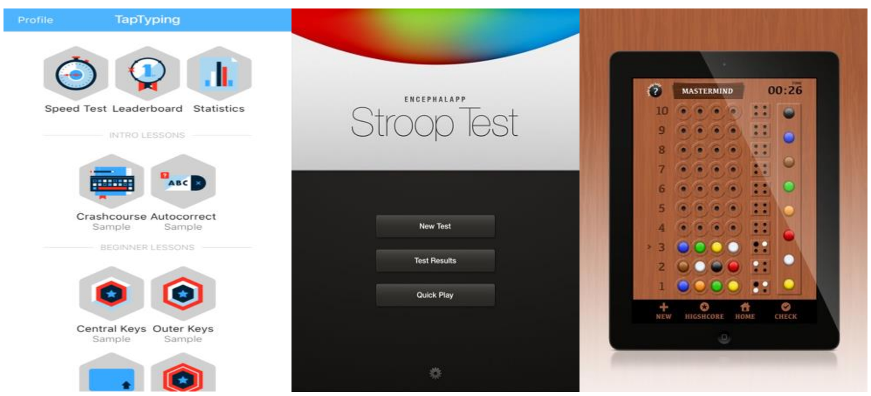


Fig. 61: Left: TapTyping. Middle: Encephalapp. Right: Mastermind.

The following are the four conditions of the experiment: condition 01 is the control, condition 02 is video only, condition 03 is video and sound, and condition 04 is video and wind stimulation feedback. In condition 01, there is no video, sound, or wind feedback. Participants performed the condition 01 experiment on their personal desks while conditions 2 to 4 were performed in the workstation. The estimated time to complete all assessments (per conditions) were approximately about 15-20 minutes; it took longer for other participants. The participants could not complete the conditions one after the other without 45 minutes to an hour break in-between.

	Video Stimulation	Sound Stimulation	Wind Stimulation
(Control) Condition 01	No	No	No
Condition 02	Yes	No	No
Condition 03	Yes	Yes	No
Condition 04	Yes	No	Yes

Fig. 62: Experimental conditions.

The integrated monitor played nature-scenery videos, while the speakers played the accompanying nature sounds, and the fan blew a constant flow of air. The monitor, speakers, and fan were a separate system of the iPad mini 2 controls. The nature-scenery video used were the following: *ocean coast*, *beach area*, *forest waterfalls*, and *aquarium*.

Fig. 63: Top Left: Ocean Coast. Top Right: Beach Shore. Bottom Left: Waterfalls. Bottom Right: Aquarium.

I set up the apps prior to starting the environmental-condition experiment. The participants followed the on-screen instructions of the TapTyping app to begin the assessment. They needed to type 3 small passages and repeat the typing tests 3 times. Data was collected after each test completion. The necessary data was the average words-per-minute (WPM) and the average accuracy percentage; the app has a built-in results page.

In the next assessment (Stroop Effect), the participant only needed to complete the Encephalapp test once. The Stroop Effect is a phenomenon that occurs when the color of the word's typeface is different from actual word (incongruency). The data collected were the reaction times, the Off-Time, and the On-Time in seconds (s). The Stroop Effect ran 14 measurement points; 2 congruencies and 2 incongruency practice runs, 5 actual congruencies and 5 actual incongruency runs. The reaction time of matching the congruent words differ from matching incongruent ones.

Lastly, the final assessment is the Mastermind game, and it had to be played 3 times. It is a time-on-task test that engages the participants to learn a pattern. A player is given 10 chances to solve the problem. The data collected were the trials and time (in seconds) it took to win or lose the game.

After each participant has completed the environmental-condition experiment, they answered a post-experiment questionnaire. In it, they ranked the environmental-condition preference, and answered qualitative interview questions.

CHAPTER 5: RESULTS & ANALYSIS

5.1 EMAS QUESTIONNAIRE

10 responses from the Engagement in Meaningful Activities Survey questionnaire (EMAS) were collected. An EMAS is a 12-item survey that assess the perception of one's daily activities as being personally meaningful. The participants responses were classified whether their daily activities were meaningful against an established scoring of low (EMAS<29), moderate (EMAS 29-41), or high (EMAS>41). The college students were within the expected values of their respective population of 33.4 (SD 5.8).

Participants	**Score**	**Rankings**
1	44	high
2	32	moderate
3	46	high
4	28	low
5	36	moderate
6	29	moderate
7	33	moderate
8	32	moderate
9	35	moderate
10	27	low

Fig. 64: EMAS results and scoring (Eakman, 2012).

Questions	Mean	Minimum	Maximum	SD
1. The activities I do daily help me take care of myself.	3.30	2.00	4.00	0.67
2. The activities I do daily reflect the kind of person I am.	3.30	2.00	4.00	0.67
3. The activities I do daily express my creativity.	2.70	2.00	4.00	0.82
4. The activities I do daily help me achieve something which gives me a sense of accomplishment.	3.00	2.00	4.00	0.82
5. The activities I do daily contribute to my feeling competent.	2.80	2.00	4.00	0.92
6. The activities I do daily are valued by other people.	2.30	1.00	4.00	0.95
7. The activities I do daily help other people.	2.70	2.00	4.00	0.82
8. The activities I do daily give me pleasure.	2.90	1.00	4.00	1.10
9. The activities I do daily give me a feeling of control.	2.80	2.00	4.00	0.79
10. The activities I do daily help me express my personal values.	3.00	2.00	4.00	0.67
11. The activities I do daily give me a sense of satisfaction.	3.00	2.00	4.00	0.67
12. The activities I do daily have just the right amount of challenge.	2.40	1.00	4.00	1.07

Fig. 65: EMAS results.

5.2 TYPING ASSESSMENT

The typing assessment measured the speed and accuracy of each participants (WPM). The results of the typing assessment are reported on fig. 65. A repeated measures ANOVA (analysis of variance) within-subjects was used for analysis. The typing speed did not differ significantly on $F(3,27)=0.8216$, $p<0.05$. The typing accuracy did not differ significantly on $F(3,27)=0.9222$, $p<0.05$. The statistical analysis result of the typing speed is on fig. 66, and the typing accuracy result is on fig. 67. Based on the analysis of both the speed and accuracy, the null hypothesis was accepted.

Participants	Condition 01		Condition 02		Condition 03		Condition 04	
	Speed	Accuracy	Speed	Accuracy	Speed	Accuracy	Speed	Accuracy
01	42	92%	42	97%	44	98%	46	98
02	56	98%	62	99%	49	97%	52	97%
03	40	96%	48	97%	44	98%	43	97%
04	51	97%	57	98%	55	97%	52	96%
05	36	96%	39	96%	33	94%	37	96%
06	64	97%	60	96%	62	97%	61	96%
07	62	96%	61	97%	68	97%	67	97%
08	44	96%	37	94%	35	92%	46	95%
09	31	97%	31	98%	26	98%	22	96%
10	24	94%	41	97%	39	97%	44	98%

Fig. 66: Typing WPM and accuracy.

ANALYSIS (SPEED)	SS	dF	MS	F	p
Intercept	85840.23	1	85840.23	150.2155	0.000001
Within Subjects (Error)	5143.03	9	571.45		
Between (R1)	50.68	3	16.89	0.8216	**0.493349**
Within Error (Error))	555.08	27	20.56		

Fig. 67: Repeated measures ANOVA speed analysis.

ANALYSIS (ACCURACY)	SS	dF	MS	F	p
Intercept	37.22970	1	37.22970	95122.02	0.000000
Within Subjects (Error)	0.00352	9	0.00039		
Between (R1)	0.00053	3	0.00018	0.92	**0.443338**
Within Error (Error)	0.00515	27	0.00019		

Fig. 68: Repeated measures ANOVA accuracy analysis.

5.3 STROOP EFFECT

The Stroop Effect assessment measures the reaction time of congruent words and incongruent words. The Stroop Effect argues that the congruent words are faster to process cognitively. A repeated measures ANOVA within-subjects was also used for analysis. The results are shown in figure 68. The cognitive-performance on the four conditions differ significantly on $F(3,27)=3.5402$, $p<0.05$. The null hypothesis had to be rejected. The mean squared error (MSE) is 0.58051, and the degrees of freedom is 27, respectively.

STROOP	SS	dF	MS	F	p
Intercept	4969.052	1	4969.052	557.5249	0.000000
Within Subjects (Error)	80.214	9	8.913		
R1	6.165	3	2.055	3.5402	0.027800
Within Error (Error)	15.674	27	0.581		

Fig. 69: Repeated measures ANOVA of the Stroop Effect.

The nest step of the analysis to conduct a post-hoc Fisher's Least Significant Difference (LSD). It is found that there is a difference between condition 01 and with the others: condition 01 vs 02, 01 vs 03, and 01 vs 04.

FISHER LSD	11.82	10.97	10.951	10.842
Condition 01		0.018911	0.016693	0.007848
Condition 02	0.018911		0.956962	0.710927
Condition 03	0.016693	0.956962		0.751378
Condition 04	0.007848	0.710927	0.751378	

Fig. 70: Fisher LSD post-hoc.

The reaction time difference was calculated and shown in table 0X. The Off-Time is when the words were congruent, and Off-Time is when the words were incongruent. The reaction times shows a positive difference. Thus, it validates the incongruency words took longer to cognitively process.

	Condition01				**Condition02**			
Participant	Off-Time (s)	On-Time (s)	Difference	% change	Off-Time (s)	On-Time (s)	Difference	% change
01	53.10	53.16	0.06	0%	49.80	46.90	-2.90	-6%
02	65.43	67.18	1.75	3%	60.60	59.85	-0.75	-1%
03	53.31	51.13	-2.18	-4%	44.85	53.40	8.55	19%
04	58.99	60.64	1.65	3%	51.43	53.75	2.32	5%
05	16.44	86.82	70.38	428%	67.46	79.73	12.28	18%
06	55.88	56.33	0.45	1%	58.19	77.28	19.10	33%
07	69.85	78.79	8.94	13%	56.81	63.11	6.30	11%
08	9.50	44.53	35.03	369%	43.05	46.03	2.98	7%
09	57.67	64.65	6.98	12%	58.60	60.35	1.75	3%
10	68.01	69.68	1.67	2%	57.70	60.71	3.02	5%

	Condition03				**Condition04**			
Participant	Off-Time (s)	On-Time (s)	Difference	% change	Off-Time (s)	On-Time (s)	Difference	% change
01	47.43	46.92	-0.50	-1%	9.11	44.84	35.73	392%
02	57.12	60.15	3.03	5%	56.87	58.90	2.03	4%
03	46.39	49.95	3.56	8%	46.32	48.39	2.08	4%
04	52.15	50.69	-1.45	-3%	51.96	54.56	2.60	5%
05	72.14	92.39	20.25	28%	63.28	73.25	9.97	16%
06	55.81	62.28	6.47	12%	57.82	66.71	8.90	15%
07	52.55	63.13	10.58	20%	54.08	63.67	9.59	18%
08	42.34	42.85	0.50	1%	41.04	46.77	5.73	14%
09	62.40	60.06	-2.33	-4%	68.18	73.96	5.78	8%
10	59.23	68.58	9.35	16%	55.98	59.90	3.92	7%

Fig. 71: Difference of congruency and incongruency.

To illustrate which conditions showed a larger difference, an average of the Off-Time and On-Time were taken and compared it between the conditions (figure 71). Conditions 2, 3, and 4 shows a lesser difference when compared to condition 01 (figure 72). The data suggests again that the cognitive processing is better in conditions 2,3 and 4.

Condition01			**Condition02**		
Off-Time	**On-Time**	**%**	**Off-Time**	**On-Time**	**%**
50.8179	63.2909	24.54%	54.8477	60.1111	9.60%

Condition03			**Condition04**		
Off-Time	**On-Time**	**%**	**Off-Time**	**On-Time**	**%**
54.7543	59.6997	9.03%	50.4633	59.0954	17.11%

Fig. 72: Percent difference comparison.

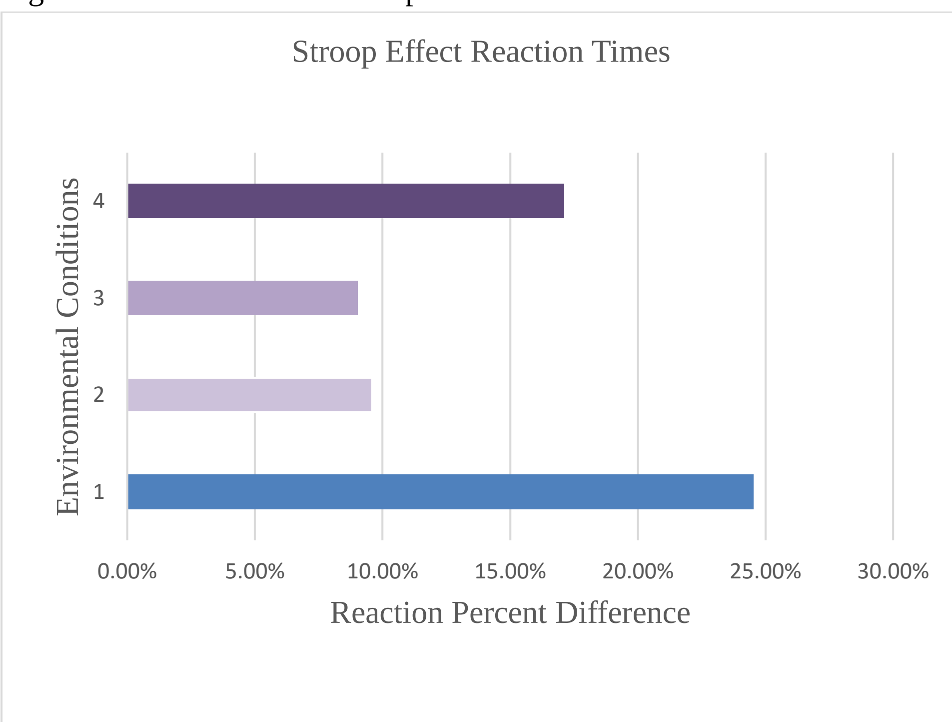


Fig. 73: Bar graph of the percent differences.

5.4 TIME ON TASK GAME

The time on task (Mastermind) assessment measures the time of the participant to learn with each chance to solve win the game. There were only 10 chances per game. Each participant had to play 3 times and the average time (seconds) was taken because there is a strong likelihood that the participant can guess the correct pattern early on the game. The results of the time on task game is shown in figure 73. A repeated measures ANOVA within-subjects was also used for analysis. The results are shown in figure 74. The four conditions did not differ significantly on $F(3,27)=0.8170$, $p<0.05$. The null hypothesis had to be accepted. A post-hoc test is not needed.

Participants	Condition 01 (sec.)	Condition 02 (sec.)	Condition 03 (sec.)	Condition 04 (sec.)
01	428.33	51.33	240.33	104.67
02	311.67	180.00	61.67	111.67
03	84.33	155.67	112.33	116.67
04	189.67	122.00	97.67	100.00
05	73.67	232.00	377.00	179.67
06	94.67	155.33	61.33	54.67
07	175.33	112.00	162.00	202.33
08	135.00	101.67	59.67	82.00
09	144.33	65.33	109.00	115.00
10	165.33	266.67	132.00	170.00

Fig. 74: Data results time on task.

Time On Task	SS	dF	MS	F	p
Intercept	868480.9	1	868480.9	104.2312	0.000003
Within Subjects (Error)	74990.3	9	8332.3		
Between (R1)	16887.4	3	5629.1	0.8170	0.495775
Within Error (Error)	186030.8	27	6890.0		

Fig. 75: Repeated measures ANOVA Mastermind game analysis.

5.5 ENVIRONMENT CONDITION RANKING & SURVEY

An environmental condition ranking survey was conducted. It ranked the perceived important work-related factors compared to the four conditions. Importantly, the last survey question is ranking the participant's overall preference. The participants rank 1 as the most preferred, and 4 as the least preferred condition. A total of 10 responses were collected from the survey (figure 75). A repeated measures ANOVA was used to analyze the survey results (figure 76). There was no significant difference from each survey statements. The null hypothesis had to be accepted on all. A post-hoc test is not needed. An average score was taken on each survey statement for comparing the conditions (figure 76).

Ranking Statements	Condition 01	Condition 02	Condition 03	Condition 04
Rank the conditions you think will improve PERFORMANCE?	2.4	2.5	2.4	2.7
Rank the conditions you think will improve FOCUS?	2.6	2.4	2.3	2.7
Rank the conditions you think will decrease BOREDOM?	2.8	2.2	2.4	2.6
Rank the conditions you think will lessen the notion of MONOTONY?	2.7	2.8	1.9	2.6
OVERALL preferred	2.6	2.7	2	2.7

Fig. 76: Ranking results of participant's preference.

		SS	dF	MS	F	p
PERFORMANCE	Intercept	250.00	1	250.0000	**0.1093**	**0.9539**
	Within Sub (Error)	0.00	9	0.0000		
	Between (R1)	0.60	3	0.2000		
	Within error (Error)	49.40	27	1.8296		
FOCUS	Intercept	250.00	1	250.0000	**0.1837**	**0.9066**
	Within Sub (Error)	0.00	9	0.0000		
	Between (R1)	1.00	3	0.3333		
	Within error (Error)	49.00	27	1.8148		
BOREDOM	Intercept	250.00	1	250.0000	**0.3750**	**0.7717**
	Within Sub (Error)	0.00	9	0.0000		
	Between (R1)	2.00	3	0.6667		
	Within error (Error)	48.00	27	1.7778		
CHALLENGING	Intercept	250.00	1	250.0000	**1.0000**	**0.4079**
	Within Sub (Error)	0.00	9	0.0000		
	Between (R1)	5.00	3	1.6667		
	Within error (Error)	45.00	27	1.6667		
OVERALL	Intercept	250.00	1	250.0000	**0.6567**	**0.5858**
	Within Sub (Error)	0.00	9	0.0000		
	Between (R1)	3.40	3	1.1333		
	Within error (Error)	46.60	27	1.7259		

Fig. 77: Repeated measures ANOVA ranking results.

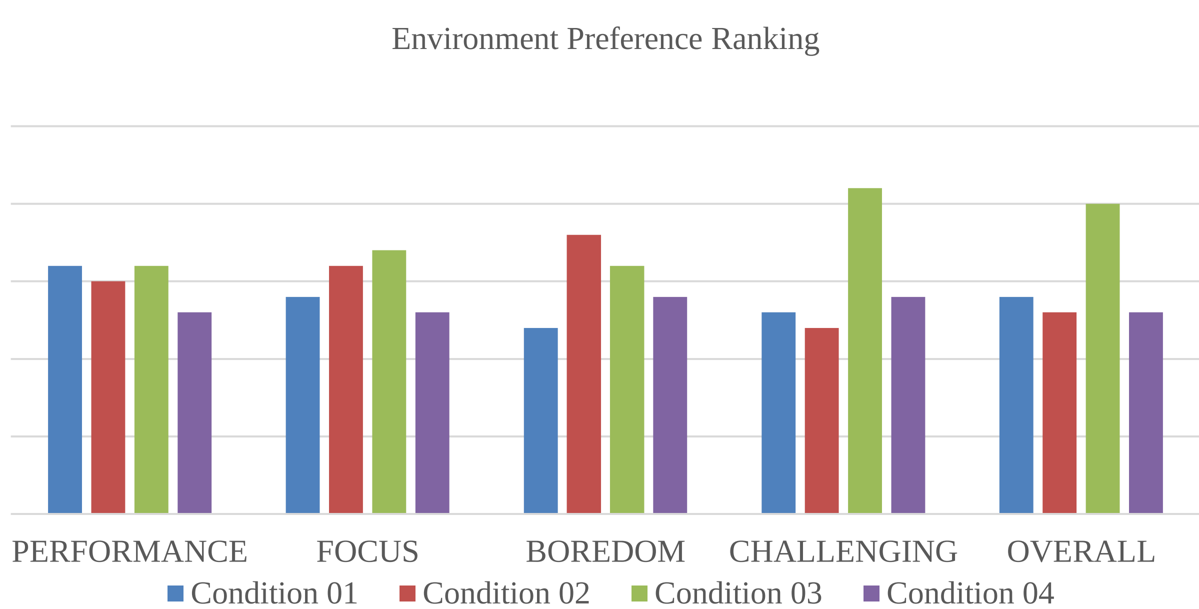


Fig. 78: Repeated measures ANOVA ranking results.

The participants answered a set of interview questions and allowed to them to respond freely in length. The following questions are:

1.) What did you think of the aesthetics of the workstation design?
2.) What is your overall impression?
3.) What did you think of the ergonomics, visuals, fan, sound, and others?
4.) In what conditions did you prefer and why?
5.) What is your feeling of the space in the workstations?
6.) Do you have any suggestions, comments, or anything to add?

In terms of the aesthetics, the consensus was that most participants found the workstations appealing, cozy, and hospitable. One participant said that the dark color of the wood helped in concentrating; additionally, some found the natural surface wood texture of the desk pleasing.

The participants commented on the ergonomics of the desk as "*encouraging for productive work*." Another participant found that it was enjoyable doing work in the workstation: *"I had an enjoyable time working on this study from the look and feel of the workspace and the tests I did were challenging and revealed some areas where I want to get better."* One participant found that the workstation proportions were appropriate. There was no complaints or negative comments on the height, work area zones, or the feeling of being confined.

For most participants, the video monitor placement was appropriate, some found it too high. Some did mention that they were too focused on the assessments and did not look at the video. One participant found that the natural scenery video was *boring* while another participant mentioned that the "*ocean sounds in the background [made her] quicker to react"* during the Stroop Effect assessment. Unsurprisingly, one participant wanted the video only condition because he or she wants to listen to their own music, podcasts, etc. On the other hand, a participant mentioned that the ocean sound helped in concentrating because it eliminated other background sounds. Most participants prefer either just the video, or video with sound.

The biggest issue that all the participants reacted negatively was the fan. The dissatisfaction was mostly about the noise it generated. Participants described as an *"annoying buzzing."* The fan created the distraction rather than the room the study was conducted in. During the experiment phase, I observed that there were consistent people moving about the room, talking, and other noises generated, but the fan was the most distracting.

A revelation in the interview was that none of the participants found privacy an issue, but one participant did find it felt "*unsafe*" because he or she felt alone. Perhaps, the experiment was conducted on a day that the room was mostly vacant and felt emptier than normal.

CHAPTER 6: CONCLUSION & FUTURE WORK

6.1 CONCLUSION

Only recently has the real possibility of human exploration beyond earth made the topic of isolated and confined environment as fascinating and imperative as it is now. Additionally, negative effects of sensory deprivation and social isolation do not only exist in extreme environments, such as those found in space exploration, but also in ICE's found in general workplaces, schools, other normally mundane environments. Understanding the relationship between an extreme environment and a low-risk environment may reveal a possible solution that could be applied to any situations within the ICE spectrum. The participants were tested on performance in a monotonous task, a cognitive selective-attention capacity, and a cognitively challenging game. Importantly, this thesis looked at the role of the somatosensorial feedback as a means to enhance the human interaction with the environment.

There are many biophilic solutions that can be incorporated in the workstation environment, but the primary solution was stimulating three physiological perceptions: the visual, audition, and touch. The concept 15 workstation applied biophilia in an immersive environment to test the work performance of an individual. During the interview, the environmental condition that was preferred the most were conditions with the visuals and sounds (conditions 2 and 3). This was corroborated with the environmental-condition questionnaire results as well. Although the participants preferred an environmental stimulus, they didn't seem to have a preference on the type of natural scenery they want to see or hear. Furthermore, I observed that the plants were primarily ignored by the participants and particularly were indifferent. These are interesting because it could be a possible indication of an unconscious and selective *stimuli-cognitive processing*. In other words, it didn't matter what kind of nature scenery the video or sound was projecting, the participants remained completely engrossed on the assessments especially with the Mastermind game.

The participants gravitated to the natural material construction of concept 15, but they still had apprehension. A probable reason for this is that many of the commercial office furniture's are made of engineered materials, such as MDF and/or plastics, and devoid of imperfections. Raw materials such as rough pine lumber used for the prototype is processed to usable parts, but imperfections can only be minimized.

Most participants found the mastermind game too challenging and stated their frustrations. Additionally, the frustrations were exacerbated by the *buzzing* sound the fan generated. Although the typing test and the Mastermind game analysis did not show performance improvement from the repeated measures ANOVA analysis, the Stroop Effect was significant. Participants were 10% faster in condition 2 and condition 3 when compared to the control. It suggests that the environmental stimulus had an effect to the participants' selective-attention capacity. It could also be inferred that even though the Stroop Effect required less demanding cognitive processing than the Mastermind game, the cognitive selective-attention capacity needed of the Stroop assessment was more vital. The Mastermind game should have resulted in a longer completion time in conditions 2 to 4 when compared with the control because, the Mastermind game is cognitively more demanding than the Stroop assessment. It could be suggested that the Mastermind game portion of the experiment's execution was flawed. If the participants could play the game with unlimited chances, and importantly, winning the game was the only option, the results are expected to be different. In short, the cognitive processing required to do a mundane task such as typing, is very minimal. Consequently, the attention-capacity of the brain requires more cognitive processing than a typing task, while the Mastermind game, requires the most demanding cognitive processing.

The most revealing of the experiment was that any activity that requires selective-attention capacity could be a more effective solution in an ICE. This could also be grounded on the idea of *selective-stimuli processing.* A possible explanation is that demanding cognitive function requires more energy, while selective-attention processing only gets activated when needed, thus conserving energy.

Concept 15 workstation can be improved further. Primarily, incorporating a better sound stimulation and consideration of sound proofing without having to enclose the workstation. Second, the privacy can be addressed even though the participants didn't indicate the need; this is perhaps the main distinction between an office workspace and college student environment. Third, the study only had 10 participants; more participants can make the statistical analysis robust. Fourth, the experiment was not conducted in an office workplace even though a school setting is an analog. Making this change could have revealed a better representation of the low-risk environment. Fifth, the lighting conditions was only considered based on the existing room lighting. The ability to control the lighting conditions as part of the study parameter, such as adjustability of lighting intensity could have an affect with participants performance. Lastly, giving the participants a choice of sound stimulation, such as music or *white noise*, could also have yielded a different outcome.

Finally, it is not fair to compare an extreme-risk and low-risk ICE. For example, space missions are cognitively demanding than the experiences of employees in an office setting. The performance required to do a task is not similar. On the other hand, contrasting the conditions in an isolated and confined environment should describe differences.

6.2 FUTURE WORK

This thesis has brought to light other research opportunities. Firstly, a comprehensive literature study which compiles all the detrimental effects associated with ICE. Subsequently, establishing of a well-defined criterion for ICE and its analog environments can be categorized appropriately. For example, a hospital waiting room can be categorized as a low-risk environment, while a hospital ICU as moderate risk environment. Both are hospital settings but differs with the environmental context. Another research area worth investigating is the biological mechanism of biophilia, not just describing the observations of an individual's tendency to be close with the natural environment. Additionally, exploring more of the idea of *selective-stimuli processing* and the *selective-attention* capacity, and how it relates as a biochemical tactic for energy conservation.

Future works should include exploring novel technologies in IVE. Virtual environments should not be limited to visual and auditory physiological perceptions but could include more haptic feedback. The human body has an extensive amount of physiological senses that demands to be stimulated in an IVE. Lastly, exploring the possibility of a virtual or augmented reality generated office with the inclusion of more natural environments. This can generate a plethora of scenarios in which individuals can choose a more preferred situation such as having more trees or plants generated in a virtual office environment. Finally, future work for the 15th concept workstation could be executed in a longitudinal study, but with an improved iteration of the workstation.

Although this thesis is only part of broader research in many areas such as isolated and confined environments, office work environments, cognitive performance, and biophilia, the effects can be far-reaching. Future research of these topics could potentially have a direct impact to countless people in their daily lives, or for future space explorations.

APPENDIX A: Initial Market – Ethnographic Survey

Office Space/Cubicle Problem Survey - not a multiple choice survey.

Inaccessible window or cubicle work environment countermeasure fact finding.

* Required

1. **Name and Age** *

2. **What's your profession and current industry?** *

3. **Have you worked in an office where you don't have easily accessible window (e.g. cubicle, windowless office room etc.)? If so, please describe? If not, would you mind it? Please elaborate.** *

4. **Would you like an office with a window? Why? If not, why?** *

5. **What do you like to do if you have no choice working in windowless work space or a cubicle situation?** *

6. **What are your hobbies? Why do you enjoy it?** *

7. **What stress relieving strategies do you do at work? Is work related stress something that you just have to deal with or have control over it? Please elaborate.** *

8. **If you any further comments that comes in to mind regarding this topic, please briefly explain.** *

APPENDIX B: EMAS Scoring

Engagement in Meaningful Activities Survey*

"Below is a list of statements about your day to day activities. Please read each one carefully and choose the answer that best describes to what extent each statement is true for you. Take your time and try to be as accurate as possible."

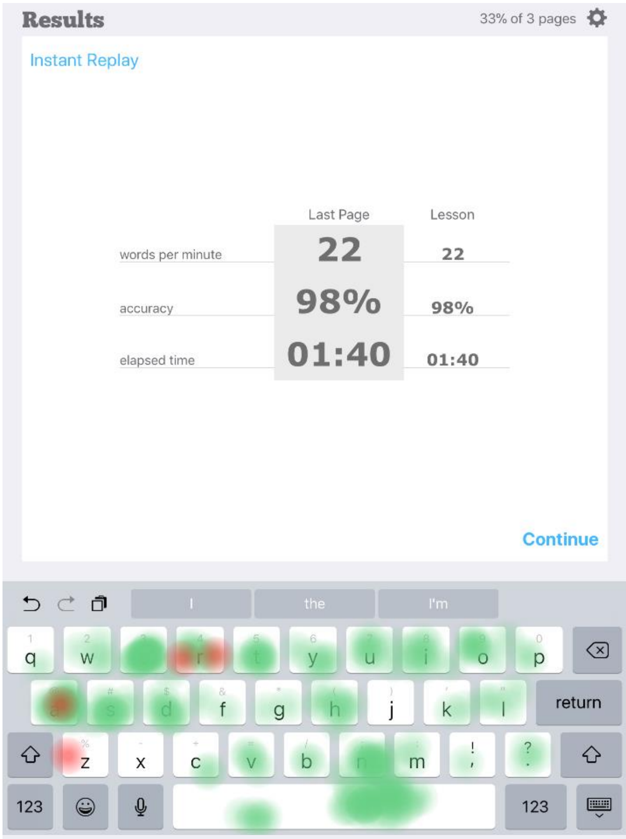
1. The activities I do help me take care of myself.
2. The activities I do reflect the kind of person I am.
3. The activities I do express my creativity.
4. The activities I do help me achieve something which gives me a sense of accomplishment.
5. The activities I do contribute to my feeling competent.
6. The activities I do are valued by other people.
7. The activities I do help other people.
8. The activities I do give me pleasure.
9. The activities I do give me a feeling of control.
10. The activities I do help me express my personal values.
11. The activities I do give me a sense of satisfaction.
12. The activities I do have just the right amount of challenge.

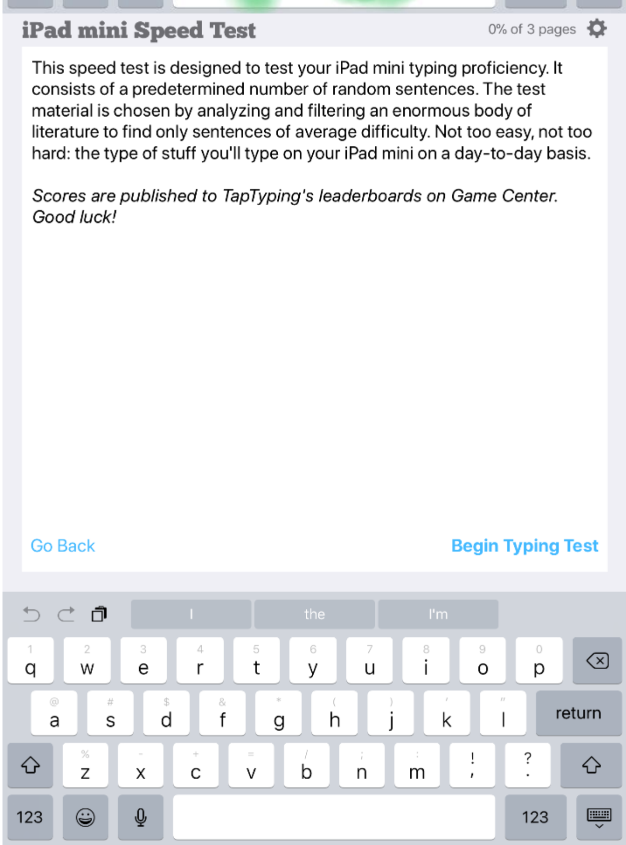
1-Rarely, 2-Sometimes, 3-Usually and 4-Always

Scoring is conducted by summing the responses (ranging from 1=Rarely to 4=Always) of the 12 EMAS items for a possible score range of 12-48. Persons may be classified as perceiving the meaningfulness of their activities as being either low (EMAS < 29), moderate (EMAS 29 – 41) or high (EMAS > 41); sample means (standard deviations) for the EMAS include: college students 33.4 (5.8), post 9/11 veterans with disabilities in post-secondary education 29.7 (7.7), and community-dwelling older adults 36.4 (6.2).

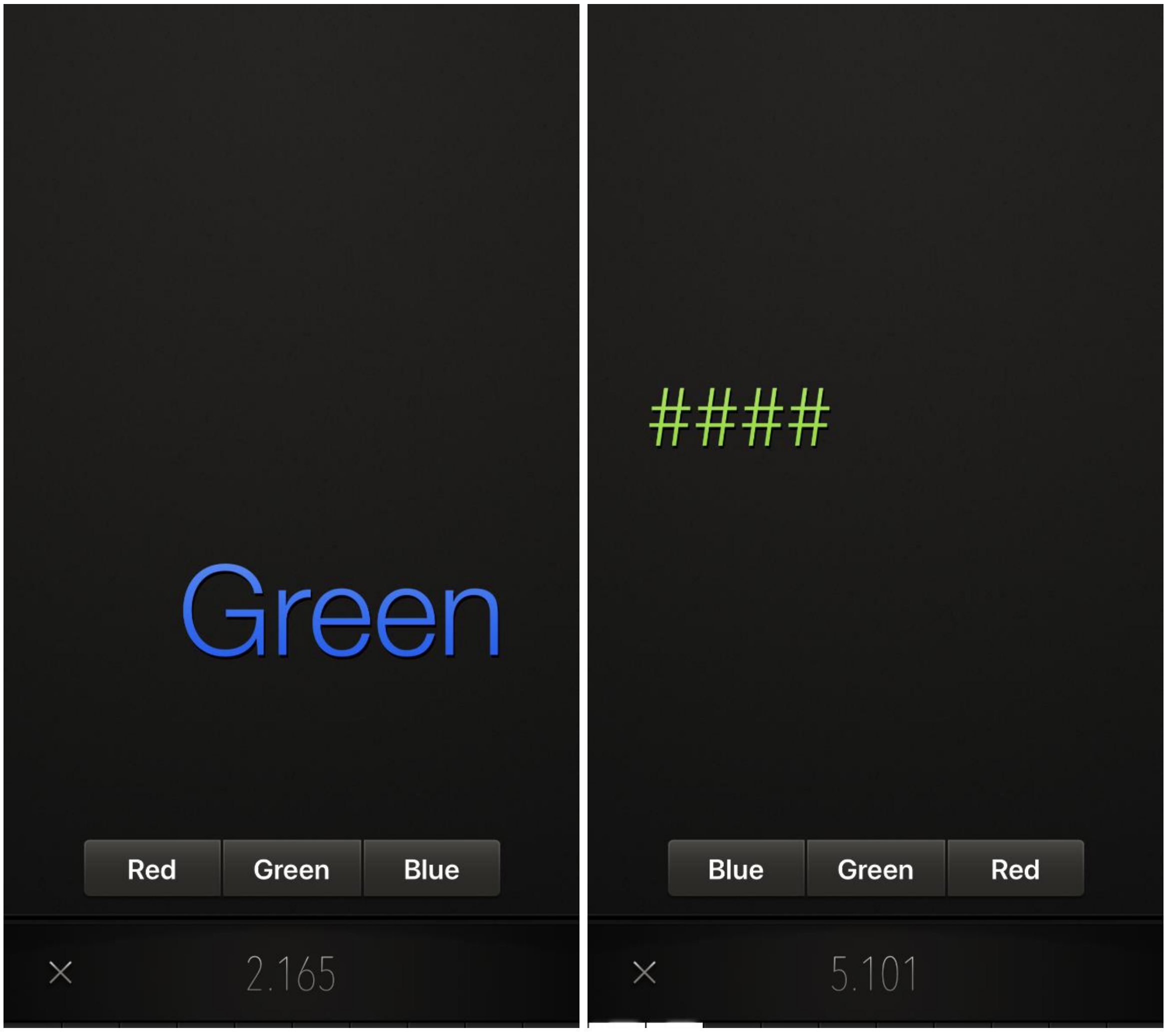
* This format has been adapted from the original scale first introduced by Goldberg, et al. (2002). The revised formatting was derived through additional studies (Eakman, 2007, 2011; Eakman, Carlson, & Clark, 2010a, 2010b) and has been informed by a thorough IRT analysis of the EMAS (Eakman, 2012). If the prior version of the EMAS is used which has a response range from 1=Never to 5=Always (e.g., Eakman, 2011; Goldberg, Britnell & Goldberg, 2002) scoring is conducted by summing the responses of the 12 EMAS items with a possible score range of 12-60. The sample means (standard deviations) reported for the 5-category response format, include: college students 45.3 (5.8), community-dwelling older adults 48.1 (6.6), and persons with mental illness 41.6 (8.3) (Eakman, 2011; Eakman, Carlson & Clark, 2010b; Goldberg et al., 2002).

APPENDIX C: TapTyping Example

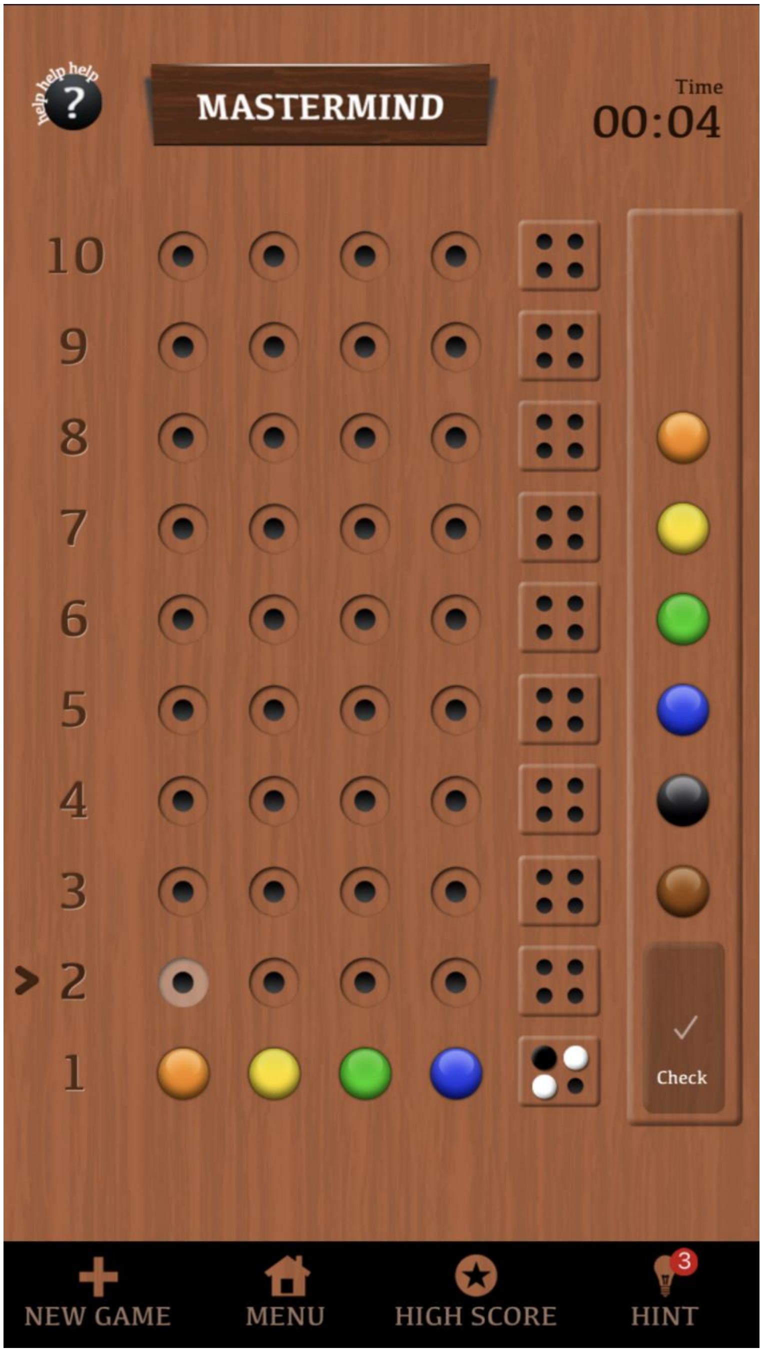




APPENDIX D: Stroop Effect Example



APPENDIX E: Mastermind Game Example



REFERENCES

Bachman, K. R. Ob., Otto, C., & Leveton, L. (2012). Countermeasures to Mitigate the Negative Impact of Sensory Deprivation and Social Isolation in Long-Duration Space Flight.

Basner, M., Dinges, D. F., Mollicone, D. J., Savelev, I., Ecker, A. J., Di Antonio, A., … Sutton, J. P. (2014). Psychological and Behavioral Changes during Confinement in a 520-Day Simulated Interplanetary Mission to Mars. *PLoS ONE*, *9*(3), e93298. https://doi.org/10.1371/journal.pone.0093298

Biner, P. M., Butler, D. L., Lovegrove, T. E., & Burns, R. L. (1993). Windowlessness in the Workplace: A Reexamination of the Compensation Hypothesis. *Environment and Behavior, 25*(2), 205–227. https://doi.org/10.1177/0013916593252003

Bishop, S., HÄuplik-Meusburger, S., Guined, J., & Peldszuz, R. (2016). Bionomic Design Countermeasures for Enhancing Cognitive and Psychological Functioning and Crew Performance in Isolated and Confined Habitats. 46th International Conference on Environmental Systems.

Bishop, S. L. (2010). Moving to Mars, there and back again: Stress and the psychology and culture of crew and astronaut. *Journal of Cosmology*, *12*, 3711–3722.

Bishop, S. L. (n.d.). PSYCHOLOGICAL AND PSYCHOSOCIAL HEALTH, 13.

Cruz-Neira, C., Sandin, D. J., & DeFanti, T. A. (1993). Surround-screen projection-based virtual reality: the design and implementation of the CAVE (pp. 135–142). ACM Press. https://doi.org/10.1145/166117.166134

Bringslimark, T., Hartig, T., & Grindal Patil, G. (2011). Adaptation to windowlessness: Do office workers compensate for a lack of visual access to the outdoors? *Environment and behavior*, *43*(4), 469-487.

Cacioppo, J.T., & Patrick, W. (2008). Loneliness: Human nature and the need for social connection

Depledge, M. H., Stone, R. J., & Bird, W. J. (2011). Can Natural and Virtual Environments Be Used To Promote Improved Human Health and Wellbeing? *Environmental Science & Technology*, *45*(11), 4660–4665. https://doi.org/10.1021/es103907m

Eakman, A. M. (2012). Measurement Characteristics of the Engagement in Meaningful Activities Survey in an Age-Diverse Sample. *American Journal of Occupational Therapy*, *66*(2), e20–e29. https://doi.org/10.5014/ajot.2012.001867

Grinde, B., & Patil, G. (2009). Biophilia: Does Visual Contact with Nature Impact on Health and Well-Being? *International Journal of Environmental Research and Public Health*, *6*(12), 2332–2343. https://doi.org/10.3390/ijerph6092332

Haynes, B., Suckley, L., & Nunnington, N. (2017). Workplace productivity and office type: An evaluation of office occupier differences based on age and gender. *Journal of Corporate Real Estate*, *19*(2), 111–138. https://doi.org/10.1108/JCRE-11-2016-0037

Heerwagen, J. H., & Orians, G. H. (1986). Adaptations to Windowlessness: A Study of the Use of Visual Decor in Windowed and Windowless Offices. *Environment and Behavior*, *18*(5), 623–639. https://doi.org/10.1177/0013916586185003

Hills, R., & Levy, D. (2014). Workspace design and fit-out: what knowledge workers value. *Property Management*, *32*(5), 415–432. https://doi.org/10.1108/PM-02-2014-0011
Ihle, E. C., Ritsher, J. B., & Kanas, N. (2006). Positive Psychological Outcomes of Spaceflight: An Empirical Study, *77*(2), 10.

IJsselsteijn, W. A., Oosting, W., Vogels, I. M., de Kort, Y. A., & van Loenen, E. (2008). A room with a cue: The efficacy of movement parallax, occlusion, and blur in creating a virtual window. *Presence: Teleoperators and Virtual Environments*, *17*(3), 269–282.

Johnson, J. C., Boster, J. S., & Palinkas, L. A. (2003). Social roles and the evolution of networks in extreme and isolated environments. *The Journal of Mathematical Sociology*, *27*(2–3), 89–121. https://doi.org/10.1080/00222500305890

Jørgensen, J., & Bannova, O. (2006). Essential aspects of habitat design for extreme and space applications. In *International Astronautical Congress*.

Kaarlela-Tuomaala, A., Helenius, R., Keskinen, E., & Hongisto, V. (2009). Effects of acoustic environment on work in private office rooms and open-plan offices – longitudinal study during relocation. *Ergonomics*, *52*(11), 1423–1444. https://doi.org/10.1080/00140130903154579

Kahn Jr, P. H. (1997). Developmental psychology and the biophilia hypothesis: Children's affiliation with nature. *Developmental review*, *17*(1), 1-61.

Kanas, N., Sandal, G., Boyd, J. E., Gushin, V. I., Manzey, D., North, R., … Wang, J. (2009). Psychology and culture during long-duration space missions. *Acta Astronautica*, *64*(7–8), 659–677. https://doi.org/10.1016/j.actaastro.2008.12.005

Kaufmann-Buhler, J. (2016a). Progressive Partitions: The Promises and Problems of the American Open Plan Office. *Design and Culture*, *8*(2), 205–233. https://doi.org/10.1080/17547075.2016.1189308

Kaufmann-Buhler, J. (2016b). Progressive Partitions: The Promises and Problems of the American Open Plan Office. *Design and Culture*, *8*(2), 205–233. https://doi.org/10.1080/17547075.2016.1189308

Kellert, S. R., & Wilson, E. O. (Eds.). (1995). *The biophilia hypothesis*. Island Press.
Kim, J., & de Dear, R. (2013). Workspace satisfaction: The privacy-communication trade-off in open-plan offices. *Journal of Environmental Psychology*, *36*, 18–26. https://doi.org/10.1016/j.jenvp.2013.06.007

Kong, Z., Utzinger, D. M., Freihoefer, K., & Steege, T. (2018). The impact of interior design on visual discomfort reduction: A field study integrating lighting environments with POE survey. *Building and Environment*, *138*, 135–148. https://doi.org/10.1016/j.buildenv.2018.04.025

Kubzansky, P. E. (1961). The Effects of reduced environmental stimulation on human behavior: A review. In A. D. Biderman & H. Zimmer (Eds.), *The manipulation of human behavior* (pp. 51-95). New York. John Wiley & Sons, Inc.

Landon, L. B., Rokholt, C., Slack, K. J., & Pecena, Y. (2017). Selecting astronauts for long-duration exploration missions: Considerations for team performance and functioning. *REACH - Reviews in Human Space Exploration*, *5*, 33–56. https://doi.org/10.1016/j.reach.2017.03.002

Li, D., & Sullivan, W. C. (2016). Impact of views to school landscapes on recovery from stress and mental fatigue. *Landscape and Urban Planning*, *148*, 149-158.

Loomis, J. M., Blascovich, J. J., & Beall, A. C. (1999). Immersive virtual environment technology as a basic research tool in psychology. *Behavior Research Methods, Instruments, & Computers*, *31*(4), 557–564. https://doi.org/10.3758/BF03200735

MacNeil, R. R., Che, H., & Khan, M. (2016). Human space exploration: neurosensory, perceptual and neurocognitive considerations. *University of Toronto Medical Journal*, *93*(2), 19.

Manzey, D. (2004). Human missions to Mars: new psychological challenges and research issues. *Acta Astronautica*, *55*(3–9), 781–790. https://doi.org/10.1016/j.actaastro.2004.05.013

Miller, N. (n.d.). Estimating Office Space per Worker, 28.

Nagy, G. (2016). Designing for Focus work. Haworth, Inc. Retrieved from https://eu.haworth.com/docs/default-source/white-papers/designing-for-focus-work.pdf?sfvrsn=6

Ott, T., Wu, P., Morie, J., Wall, P., Ladwig, J., Chance, E., … Binsted, K. (2016). ANSIBLE: A Virtual World Ecosystem for Improving Psycho-Social Well-being. In S. Lackey & R. Shumaker (Eds.), *Virtual, Augmented and Mixed Reality* (Vol. 9740, pp. 532–543). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-39907-2_51

Palinkas, L. A. (2007). Psychosocial issues in long-term space flight: overview. *Gravitational and Space Research, 14*(2).

Radikovic, A. S., Leggett, J. J., Keyser, J., & Ulrich, R. S. (2005). Artificial window view of nature. In *CHI'05 Extended Abstracts on Human Factors in Computing Systems* (pp. 1993–1996). ACM.

Sandal, G. M. (2007). Psychosocial issues in space: future challenges. *Gravitational and Space Research*, *14*(2).

Solignac, A., & Kuntz, S. (2015). EVE: Exercise in Virtual Environments. In *Virtual Reality (VR), 2015 IEEE* (pp. 287–288). IEEE.

Suedfeld, P., & Steel, G. D. (2000). The Environmental Psychology of Capsule Habitats. *Annual Review of Psychology*, *51*(1), 227–253. https://doi.org/10.1146/annurev.psych.51.1.227

Wang, Y., Jing, X., Lv, K., Wu, B., Bai, Y., Luo, Y., … Li, Y. (2014). During the Long Way to Mars: Effects of 520 Days of Confinement (Mars500) on the Assessment of Affective Stimuli and Stage Alteration in Mood and Plasma Hormone Levels. *PLoS ONE*, *9*(4), e87087. https://doi.org/10.1371/journal.pone.0087087

Wickens, C. D., Gordon, S. E., & Liu, Y. (2011). *An introduction to human factors engineering (p. 262)*. New Delhi: PHI Learning.

Wilson B, Bounds M, McFadden D, Regenbrecht J, Ohenhen L, Tavakkoli A, Loffredo D. VETO: An Immersive Virtual Environment for Tele-Operation. *Robotics*. 2018; 7(2):26.

Zuckerman, M., Persky, H., Link, K. E., & Basu, G. K. (1968). Responses to Confinement: An Investigation of Sensory Deprivation, Social Isolation, Restriction of Movement and Set Factors. *Perceptual and Motor Skills*, *27*(1), 319–334. https://doi.org/10.2466/pms.1968.27.1.319