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Understanding the potential of Immersible Virtual Environment (IVEs) for Biophilic Design

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Understanding the potential of Immersive Virtual Environment (IVEs) for Biophilic Design

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Construction Management

by
Asalsadat Emamjomeh
B.A., Louisiana State University, 2016
May 2019

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ABSTRACT

Biophilic design, which translates literally to love of life [1], is a new and popular trend in sustainable building design. Architects are applying this style in different building types, from offices to schools to hospitals. Research that assesses mental health and cognitive benefits of biophilic design in interior environment and immersive reality is ongoing. This study intends to determine the capability of immersive virtual environment (IVE) to support building design by comparing the psychological and cognitive responses to natural elements in an interior environment (*In-Situ*) and IVE. Thirty-five LSU students from undergraduate and graduate levels participated in this experiment. A wearable heart rate monitor was used to measure heart rate variability in each condition. Individuals performed working memory tests after being exposed to each environment (In-Situ and IVE). After completing the working memory tests, they were asked to fill out the PANAS survey. The PANAS survey is about the participant's mood at that moment. Additionally, if they were doing the IVEs part of the experiment, they were asked to answer the IPQ survey. The IPQ survey is about their presence in each virtual reality environment.

Our results demonstrate that participants had a less negative mood, a more positive feeling, and a better cognitive performance in a biophilic environment in In-Situ. Furthermore, our results indicate that individuals had significantly fewer negative moods in a biophilic environment in IVEs. Our results also show that individuals had more positive moods in a biophilic environment in IVEs but not at 95% level of significance. Additionally, our results show that biophilic design's effect on cognitive performance is not statistically significant. Since biophilic design did not change cognitive performance

in IVEs, more studies need to be done to measure the required time to impact cognitive performance in IVEs.

CHAPTER 1. INTRODUCTION

1.1. Background

1.1.1. Overview of biophilic design

From the beginning of incorporating electricity in our buildings, we no longer needed the warmth of the sun or cool breezes to stay comfortable. Buildings' walls became barriers between humans and nature. Gradually, human-made interior spaces became larger while the inner area of such spaces became darker and more separated from nature. You can find an ultimate example of this separation between humans and nature in the architecture of the 1960s and 1970s, known as Brutalist architecture. The heavy and enclosed building envelopes with limited glazing make climate control economically better, but at the same time, they created a big gap between humans and nature. During this period of architecture, in 1964, Dr. Erich Fromm, a German-born American social psychologist, used the term biophilia for the first time in his book; he described it as "the passionate love of life and of all that is alive" [2]. American biologist Edward O. Wilson used this term later, describing it as "the urge to affiliate with other forms of life" [2]. Wilson argued that biophilia had roots in our humanity and that it created a connection between humans and all other creatures [3]. Later, Wilson and his colleague, Stephen R. Kellert, introduced the biophilia hypothesis as part of the theories of evolutionary psychology [4]. Kellert also introduced biophilic design as a concept that can be used to incorporate natural features and systems into an indoor environment to create more sustainable interior environments [5]. Later architects like Roger Ulrich, Oliver Heath, and Amanda Sturgeon incorporated biophilic elements in their design.

1.1.2. What we do and don't know about biophilic design in IVE

Although there is a lot of evidence that shows how biophilic design can improve our mental and physical health in the long term, research that evaluates biophilic design impact on a human in the short time is sparse [6]. There is also limited research about the effects of biophilic design in an Immersive Virtual Environment (IVE).

The construction industry attempts to produce more sustainable buildings at lower costs, which leads architects and building engineers to make more suitable sustainable decisions in the early stages of design [7]. Since the public is the end-user of a construction project, their inputs in a project are crucial in the initial phases of design. Technologies like Immersive Virtual Environment (IVE) help designers communicate better with the public and enable them to make more sustainable decisions in the early stages of design.

Most studies about the impact of nature and biophilic design on human are limited to actual pictures and videos of an environment. While in the early stages of design, architects only have a model of a building. This study aims to distinguish that biophilic design can impact human mood and working memory in an Immersive Virtual Environment created by architectural software.

1.1.3. Objectives of this Research

The impact of biophilic design on humans, in reality, can be categorized into three groups: stress reduction, cognitive performance, and mood enhancement [8]. To further investigate the relationship between humans and biophilic design in an IVE, this research study has been designed to test three main hypotheses:

- First, natural element exposure in IVE reduces negative moods in the same way as natural element exposure in In-Situ.
- Second, natural element exposure in IVE creates more positive moods in the same way as natural element exposure in In-Situ.
- Third, natural element exposure has the same impact on cognitive performance (working memory) in both IVE and In-Situ.

To answer these questions, I prepared a study to record participants' cognitive performance and mood levels after experiencing the actual environment and the virtual representation of that environment. Wearable sensors, working memory tests, and mood surveys were used to measure these objectives.

This thesis includes five chapters, which describe the work that has been done to answers the research questions. Following is a brief description of the contents of each section:

1.2. Outline of the Thesis

- Chapter 1 provides a background of biophilia and the biophilic design concept. This chapter also briefly explains the aim and objective of this research.
- Chapter 2 presents a concise collection of literature review, which contains:
 - 1- History and definition of biophilia, biophilia hypothesis, and biophilic design
 - 2- Attributes of biophilic design
 - 3- Human wellbeing and biophilic design
 - 4- Research studies to determine the benefits and potential issues of biophilic design

5- Research that evaluates the impact of biophilic design in virtual reality

- Chapter 3 discusses the methods and tools used to collect and analyze data.
- Chapter 4 illustrates the results of the statistical tests on each set of data, discusses the results that came from statistical analyses, and explains the answers for each objective of this research.
- Chapter 5 provides conclusions that have been learned by conducting this research. This chapter also explains the limitations that were found in this study and suggests areas for future studies.

CHAPTER 2. LITERATURE REVIEW

2.1. History and definition

2.1. Biophilia

The term biophilia originates from the Greek words bio (“life”) and philia (“affinity”) [9].

The word biophilia means "love of life or living systems" [10]. A German-born American social psychologist, Erich Fromm, introduced this term in his book, *The Heart of Man: Its Genius for Good and Evil* [11]. Biophilia highlights the psychological orientation of being engaged to all species [10].

2.1.2. Biophilia hypothesis

In 1984, an American biologist, Edward O. Wilson, popularized the term biophilia [3].

Later in 1993, Wilson introduced the biophilia hypothesis [4]. He described it as a tendency in humans to connect with nature and other forms of life [4]. His biophilia hypothesis tells us that human connection to nature is part of the human biological inheritance.

2.1.3. Biophilic Design

According to the U.S. Census Bureau, 80 percent of the U.S. population lives in cities [12]. As Kellert described, the human is a bicultural creature, which means humans can learn certain behaviors over time [13]. Although in modern times humans face the lack of interaction with nature due to urbanization [14], they can make a connection to the natural world again. Biophilic design will help humans bring natural elements into their buildings. Biophilic design applies natural components or representations of nature into the built environment to fulfill the innate human tendency toward nature [5]. Biophilic

design is an architectural design approach. It is a thoughtful attempt to understand humans' inherent affinity to affiliate with nature [15]. Designers applied biophilic design at both small (building) and big (urban designing) scales. It is considered to have physical and psychological benefits for building occupants and city residents [16][17].

Social ecologists like Stephen R. Kellert recently developed the concept and principles of biophilic design [5]; we can see this tendency in the earliest human-made structures. Illustration of animals and plants have a long history in architecture. There are many cases in the world's oldest civilizations that show a human tendency to nature. Some examples include the gardens of Babylon and the leafy filigrees of Rococo design [8].

2.2. Attributes of Biophilic Design

Stephen Kellert, who is the pioneer of biophilic design, established a framework, known as the Attributes of Biophilic Design, to satisfy an experience of nature in the built environment [18]. These characteristics are guidelines that architects and designers can apply to their designs to promote people's physical and mental health.

Kellert categorized these attributes into three main groups:

1. The first group is called "*direct experience of nature*" or "*Nature-in-the-Space Patterns*"; these attributes indicate the actual contact with nature in a built environment[8][16].
2. The second group, which is known as "*indirect experience of nature*" or "*Natural Analogues Patterns*", indicates a connection with elements that represent nature in the built environment [8][16].

3. The third group, known as “*experience of space and place*” or “*Nature-of-the-Space Patterns*”, are spatial features that remind human complexity and order that they see in nature [8][16].

The following table shows attributes of biophilic design which is created by Kellert and Calabrese [18].

Direct Experience of Nature	Indirect Experience of Nature	Experience of Space and Place
<ul style="list-style-type: none">• Light• Air• Water• Plants• Animals• Weather• Natural landscapes and ecosystems• Fire	<ul style="list-style-type: none">• Images of nature• Natural materials• Natural colors• Simulating natural light and air• Naturalistic shapes and forms• Evoking nature• Information richness• Age, change, and the patina of time• Natural geometries• Biomimicry	<ul style="list-style-type: none">• Prospect and refuge• Organized complexity• Integration of parts to wholes• Transitional spaces• Mobility and wayfinding• Cultural and ecological attachment to place

Figure 2.1. Attributes of Biophilic Design [16]

2.3. Human wellbeing and biophilic design

I will review the relationship between humans and biophilic design from three perspectives: the evolutionary perspective [19], evidence of the impact of nature on humans [8], and a typology of values of nature [20].

2.3.1. Evolutionary perspective

One way of studying human behavior and psychology is through the evolutionary perspective [19]. Forces of evolution have shaped modern humans. The concept of an Environment of Evolutionary Adaptation (EEA) was introduced by John Bowlby [19]. Bowlby describes the environment to which a species is adapted. The content of an Environment of Evolutionary Adaptation (EEA) is used to designate the conditions in which humans spent over 99% of their evolutionary history [19][21][22]. The concept of adaptation is useful for understanding the human mind and human behavior [19].

Due to urbanization, the environment that humans now experience is different from EEA. Urban living is the new phenomenon that most of the world's population now faces. Nearly half the world's population are city dwellers [23]. According to Sharp, "Urbanization will continue to accelerate in the coming decades" [24]. Six out of every ten people will live in cities by 2013 [25]. This number will rise to seven out of ten people by 2050 [25]. Although urbanization has advantages such as the ease of access to essential amenities, there is a connection between the rate of urbanization and a global decrease of access to natural surroundings, which causes environmental problems [16][23]. It reduces our connection to nature, which is an integral component of the human EEA.

Based on the National Human Activity Pattern Survey (NHAPS) humans spend 87% of their time in a built environment [26], which is causing a disconnect between humans and nature [35]. In modern societies, buildings are becoming barriers between humans and the natural environment [27]. The design concept that enables human to reconnect with nature is biophilic design.

We can consider plants as a vital need for humans during their evolutionary history [28]. Plants were food resources, shelters, and indicators of water in a given area [28]. The presence of plants is an essential part of human EEA and has an impact on human mental health and wellbeing [28].

2.3.2. Nature's effect on humans

Studies provide evidence that exposure to nature has positive results on humans mentally [29], physically [30], and economically [31]. These beneficial impacts can happen through active [32] or passive [33] involvement with nature.

To further investigate the impacts of nature on humans, we need to know why connecting to nature is beneficial for humans. Ulrich points to three possible advantages [34]:

- 1- Being in nature is associated with physical activity, which boosts health [34].
- 2- Nature activities cause socializing, which has the potential to improve health [34].
- 3- Nature makes humans free from everyday routines [34].

A study shows that people who live in urban green spaces have significantly better mental health [35] and health-related behaviors [36]. Living in crowded cities increases stress-related disorders [37]. Stress negatively impacts psychological and physical health [38]. Mental disorders are the second world's most significant disease [39].

Studies show that the number of people who took a day off from work for psychiatric disease doubled between 2000 and 2010 in Germany [40]. In North America, around 40% of work absences are related to depression [39]. However, studies show spending time in nature can have a positive impact on mood states and stress [41]. Studies

provide evidence that exposure to green space increases physical activity, which has positive effects on psychological health [42]. Restorative environments are natural places that allow recovery from stress [29]. Exposure to nature reduces negative mood states and enhances positive emotions [29].

Some studies show that spending time in nature has a significantly positive effect on human physical health [42]. Exposure to green space increases physical activity, which has positive impacts on physical health [42]. There is evidence that short leisurely visits to a forest and spending time in nature have positive effects on human immune function [17]. Some studies show that spending time in a natural environment decreases risk of coronary heart disease and stroke [30]. Also, contact with nature has some healing benefits for patients in hospitals. Studies by Ulrich show that having a view through a window influences recovery from surgery [43]. Exposure to natural elements, be it a direct connection with nature, a view of the natural environment, an indirect connection with nature, or a wood interior in a hospital room, improves the healing process of patients [33].

Studies have revealed that adding biophilic elements to offices can increase productivity and workplace satisfaction [44]. It can also reduce stress, enhance well-being, and create a collaborative work environment [44]. Data are outlining better cognitive performance as the benefits of human-nature contact [45].

2.3.3. A typology of values of nature

Relationships between human well-being and environment can also be understood by nine biophilic expressions that were adapted by Meltzer and colleagues from Kellert [20].

Table 2.1. A typology of values of nature [20]

<i>Aesthetic</i>	Physically appealing
<i>Dominionistic</i>	Mastery or control over nature
<i>Humanistic</i>	Emotional bonding with nature
<i>Moralistic</i>	Ethical or spiritual connection to nature
<i>Naturalistic</i>	Exploration of nature
<i>Negativistic</i>	Fear and aversion of nature
<i>Scientific</i>	Knowledge and understanding of nature
<i>Symbolic</i>	Nature as a source of language and imagination
<i>Utilitarian</i>	Nature as a source of material and physical benefit

2.4. Research and studies to determine the benefits and potential issues of biophilic design

Researchers conduct studies in two ways 1-Empirical Studies in an Outdoor Environment which is helpful for urban design and 2- Empirical Studies in an Indoor Environment which is useful for building design and interior environment design [46].

2.4.1. Empirical studies in an outdoor environment

Field studies show the benefit of nature on humans. People who experience environments that have natural elements like trees tend to feel safer and more comfortable [47] [48]. They have greater stress reduction [39] and improvements in mental health and tranquility [49]. Experiencing natural environments lowers blood pressure and heart rate [50]. Natural light positively impacts the circadian system functioning in students [51]. Doing activities in natural settings like garden or forest positively impacts attitude and overall happiness [52]. Exercise in nature improves mental health [53] and human immune function [17].

2.4.2. Empirical studies in an indoor environment

Some studies show the impact of interior elements of biophilic design on humans. Evidence shows rooms that have a view of nature can rapidly lower the diastolic blood pressure [54] and heart rate [55][56] of occupants. It also improves heart rate recovery from low-level stress [57]. Biophilic design in interior environments positively impact comfort, well-being, and productivity [58], as well as perceived improvements in mental health [59]. Studies show that stress recovery is faster with exposure to pleasant nature sounds [60]. Thermal comfort in a naturally ventilated environment improves the perception of temporal and spatial pleasure [61]. Elements that represent nature in an interior setting, like an aquarium, increase attention and exploration [62].

2.5. Research on biophilic design using virtual reality.

Although there are minimal studies that investigate the effect of Immersive Virtual Environment (IVE) in biophilic design, there are studies on the impact of pictures or

videos of nature on human mental and physical health. Typically, showing images of nature to participants improves their comfort [63], therapeutic reactions [64], and creative performance [65] and reduces their stress [66]. Also, studies show that colors we see in the natural environment like blue or green create more positive emotional responses in human [67]. Some studies show that using technology like a plasma display window will not produce the same positive impact that a real window does on humans [57].

Some studies show that watching a natural environment in an IVE can distract patients during painful medical procedures [68]. There is also evidence that shows inpatients who use IVE describe it as a condition that can decrease pain and anxiety [69].

The Harvard T.H. Chan School of Public Health has made a valuable effort to investigate how IVE can impact biophilic design. This study measures the impact of biophilic design in the short term and virtual reality environments by measuring three categories: physiological response, cognitive function, and self-reported emotion change [70]. Results of this study show that participants had lower blood pressure and skin conductance levels from baseline when they were in the biophilic environment in both actual short term exposure and VR exposure of the experiment [70]. In this study, the following three tasks were used to measure cognitive performance in the physical and virtual environment: visual backward digital span task, visual reaction time task, and Stroop task. Results of this study show that in the visual backward digital span task participants scored 14% higher in the biophilic environment compared to the no-biophilic environment, but their performance in the visual reaction time task and the Stroop task was not statistically significant [70]. Also, “Physical and virtual biophilic exposure had a

similar impact on participants' cognitive performance" [70]. Finally, "participants reported reduced negative emotion and increased positive emotion in the biophilic environment" [70].

2.6. Why is this research needed?

The construction industry is trying to produce buildings with sustainable designs [7]. The benefits of sustainable buildings are the environmental benefits, economic benefits, social benefits, and architectural benefits [7]. It would be very costly to change design decisions during or after construction, so it would be better to make them as early as possible [71].

Architects usually use 2D drawings to communicate their ideas in the design phase of a project, but 2D illustration becomes very weak when architects want to share their plans with the public. 3D rendering can help designers in this phase. Technology has advanced this 3D model. Recently, technology like IVE assists architects in showing their ideas to their clients more easily [72].

Although there is research that shows the impact of being exposed to nature on humans in IVE, most of this research used actual videos or pictures to create an immersive virtual environment. In this study, I built each environment by using a design software, Revit, and transformed the model to be visible in the virtual environment by Unreal engine. Thus, designers can detect the impact of biophilic design in the early stages of design rather than after the design phase and construction phase of a project.

CHAPTER 3. METHODOLOGY

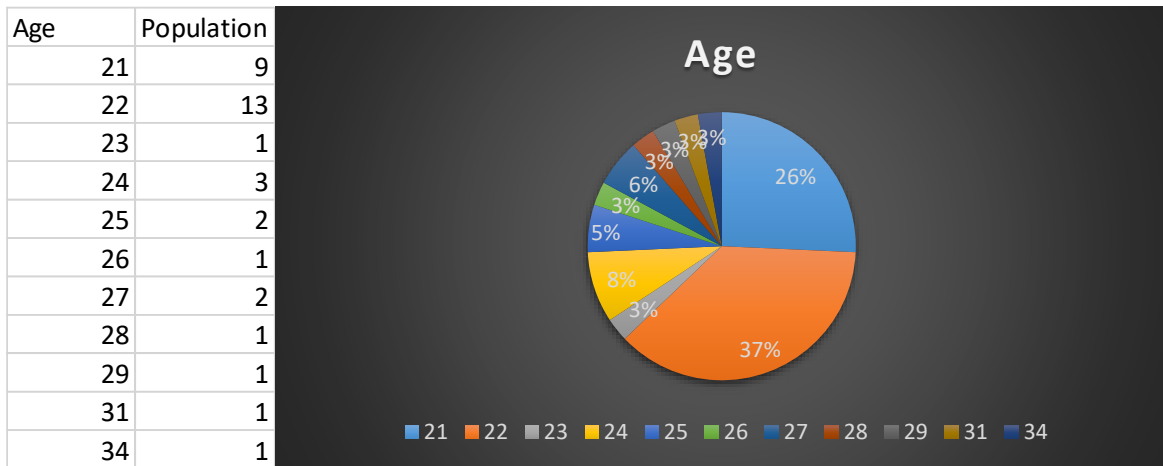
3.1. Subjects Inclusion Criteria

Thirty-five LSU students participated in the experiment; subjects attended the test voluntarily, and they were not compensated. Below, a table summarizes the inclusion criteria.

Table 3.1. Inclusion Criteria

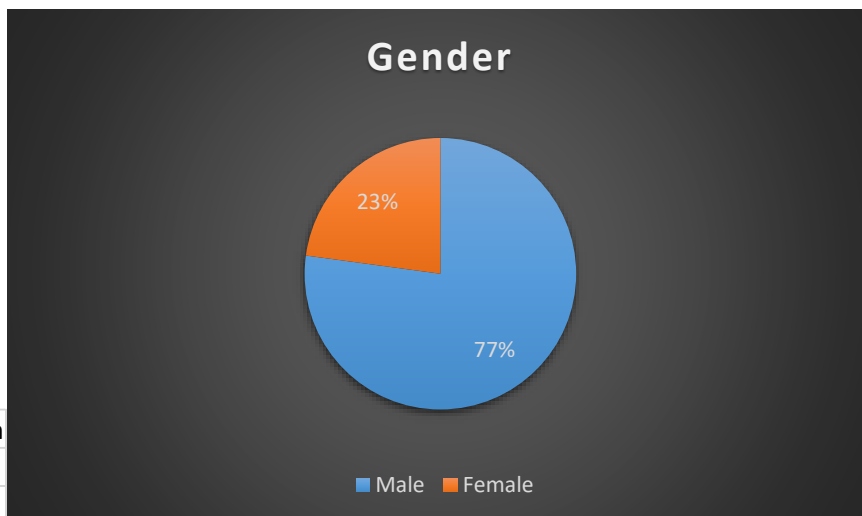
Age	18-30 years
Sex	Men and women (non-pregnant by self-report)
Consent	Willingness to sign written informed consent and to understand the exclusion criteria

Following are demographic data of participants:



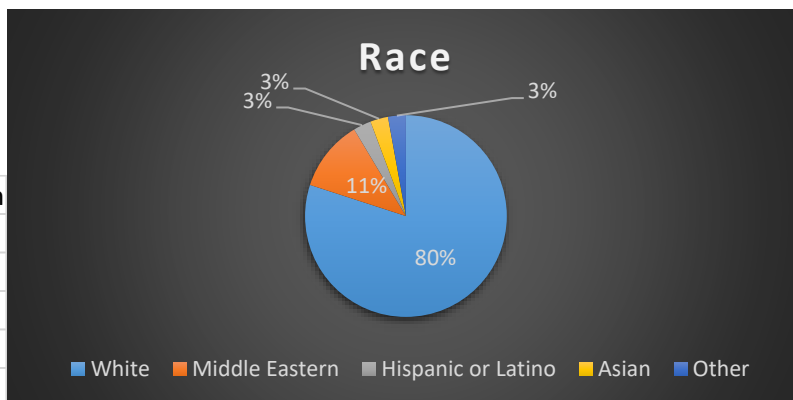
Graph 3.1. Age Distribution

Gender	Population
Male	27
Female	8



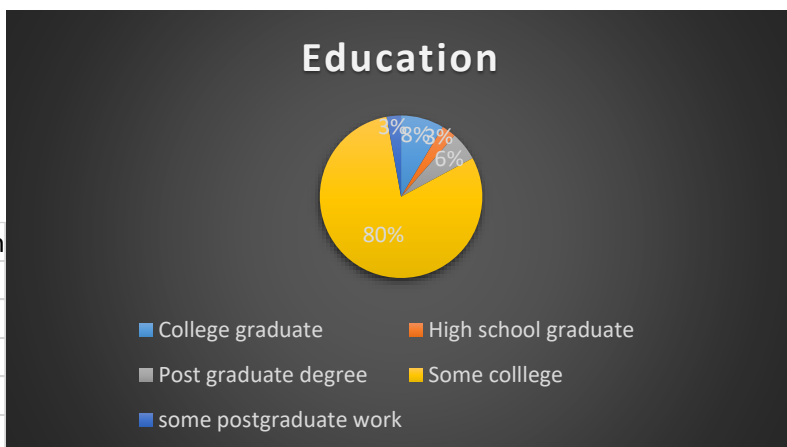
Graph 3.2. Gender Distribution

Race	Population
White	28
Middle Eastern	4
Hispanic or Latino	1
Asian	1
Other	1



Graph 3.3. Race Distribution

Education	Population
College graduate	3
High school graduate	1
Post graduate degree	2
Some college	28
some postgraduate work	1



Graph 3.4. Education level Distribution

3.3. Two condition

Researchers used MMR BIM Cave and a study area in Patrick F. Taylor Hall at LSU as the no-biophilic and biophilic environments for this experiment.

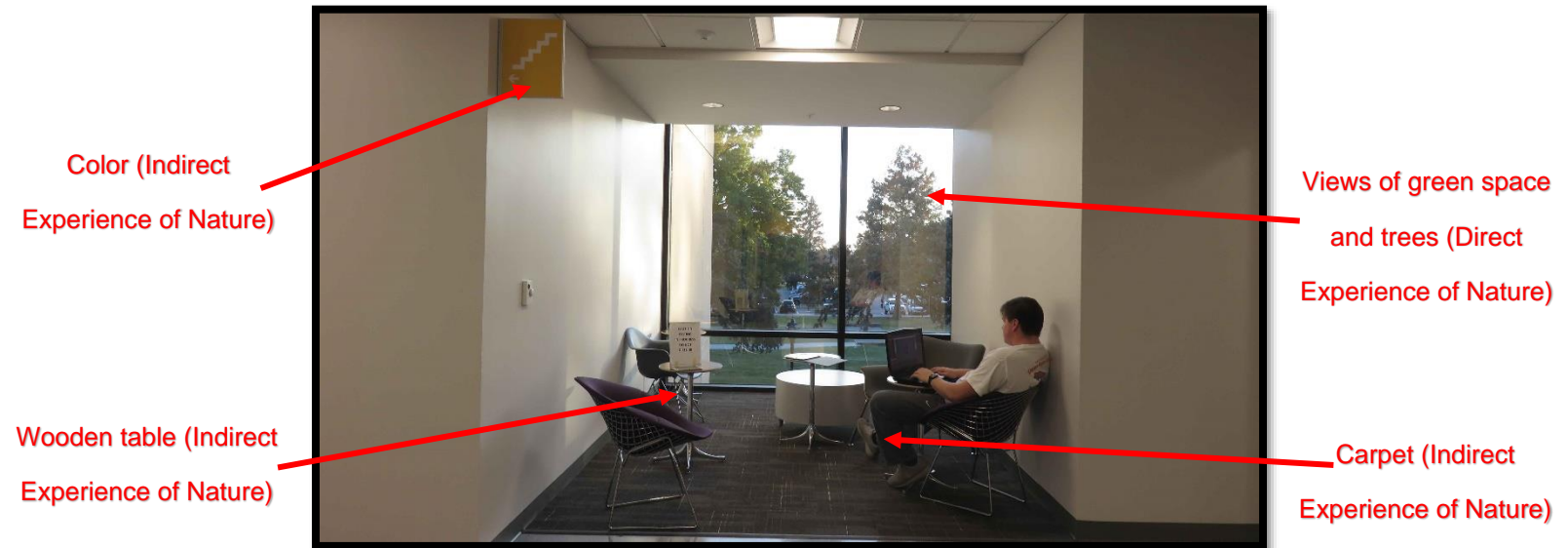


Figure 3.1. Biophilic Environment



Figure 3.2. No-Biophilic Environment

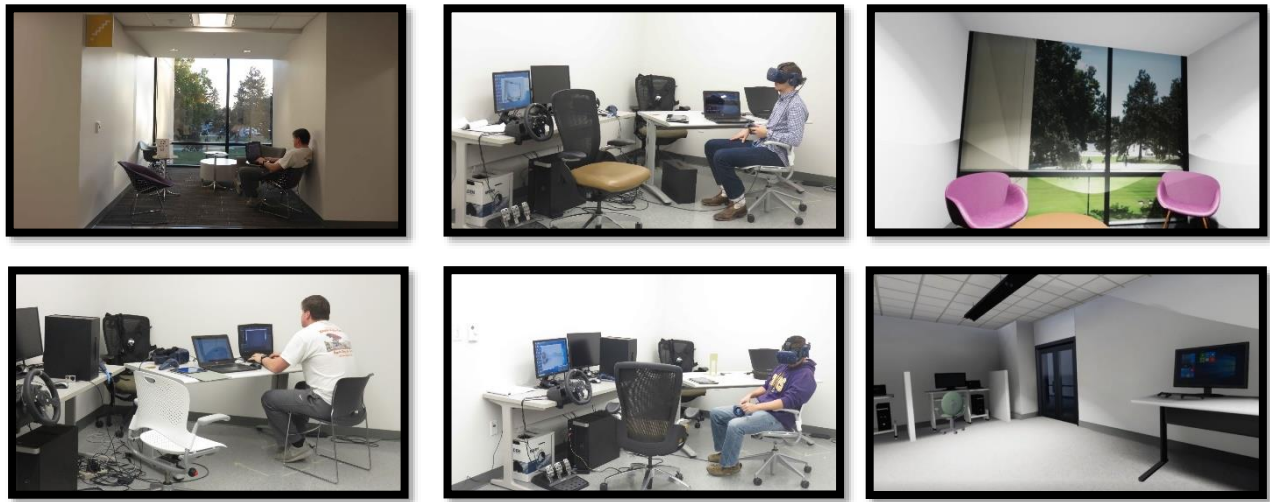


Figure 3.3. Experiment Conditions

3.3. Experiment Procedure

Each participant completed the experiment in two separate days with a few days in between. In each visit, participants were randomly assigned to experience biophilic and no-biophilic environments in either an Immersive Virtual Environment (IVE) or an *In-Situ* environment. The following paragraphs explain the IVE and the *In-Situ* environments briefly.

In-Situ Experiment: The experiment begins by completing a pre-experiment questionnaire followed by the device set-up. Then participants are asked at random to explore either the biophilic or the no-biophilic room for 5 minutes; this period was determined based on another similar study [6]. After the experiment, participants are asked to complete a memory quiz and a mood questionnaire, which takes approximately 15 minutes. Then, participants are asked to change rooms and repeat the above steps. The experiment lasts approximately one hour.

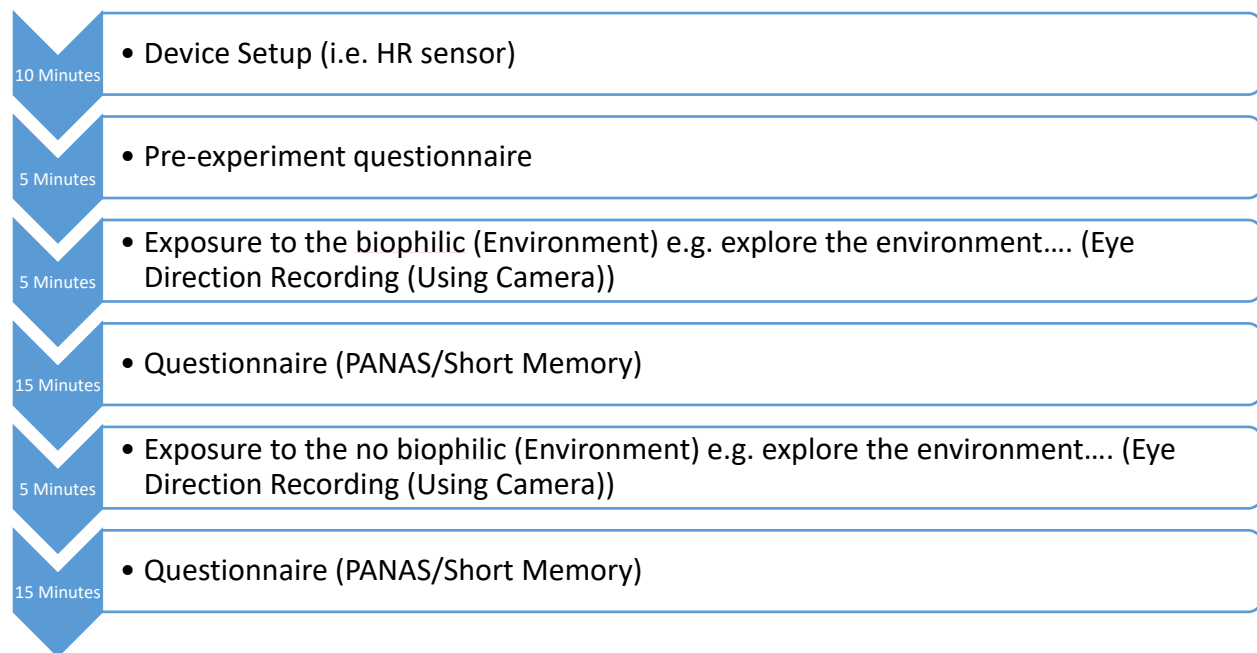


Figure 3.4. Summary of Visit Schedule (In-Situ Experiment)

Immersive Virtual Environment: The experiment starts by device setup and a short orientation section, and then participants are asked to explore the virtual room with biophilic design or no-biophilic design for 5 minutes. After experiencing the virtual environment, s/he is asked to complete a working memory test, which takes approximately 5 to 10 minutes. Then s/he is asked to take off the Head-Mounted Device (HMD) and fill out mood and presence survey. Afterwards, s/he is asked to put on the HMD and explore the other environment for 5 minutes. Then, s/he is asked to repeat the same steps in a different situation. The experiment lasts about one hour.

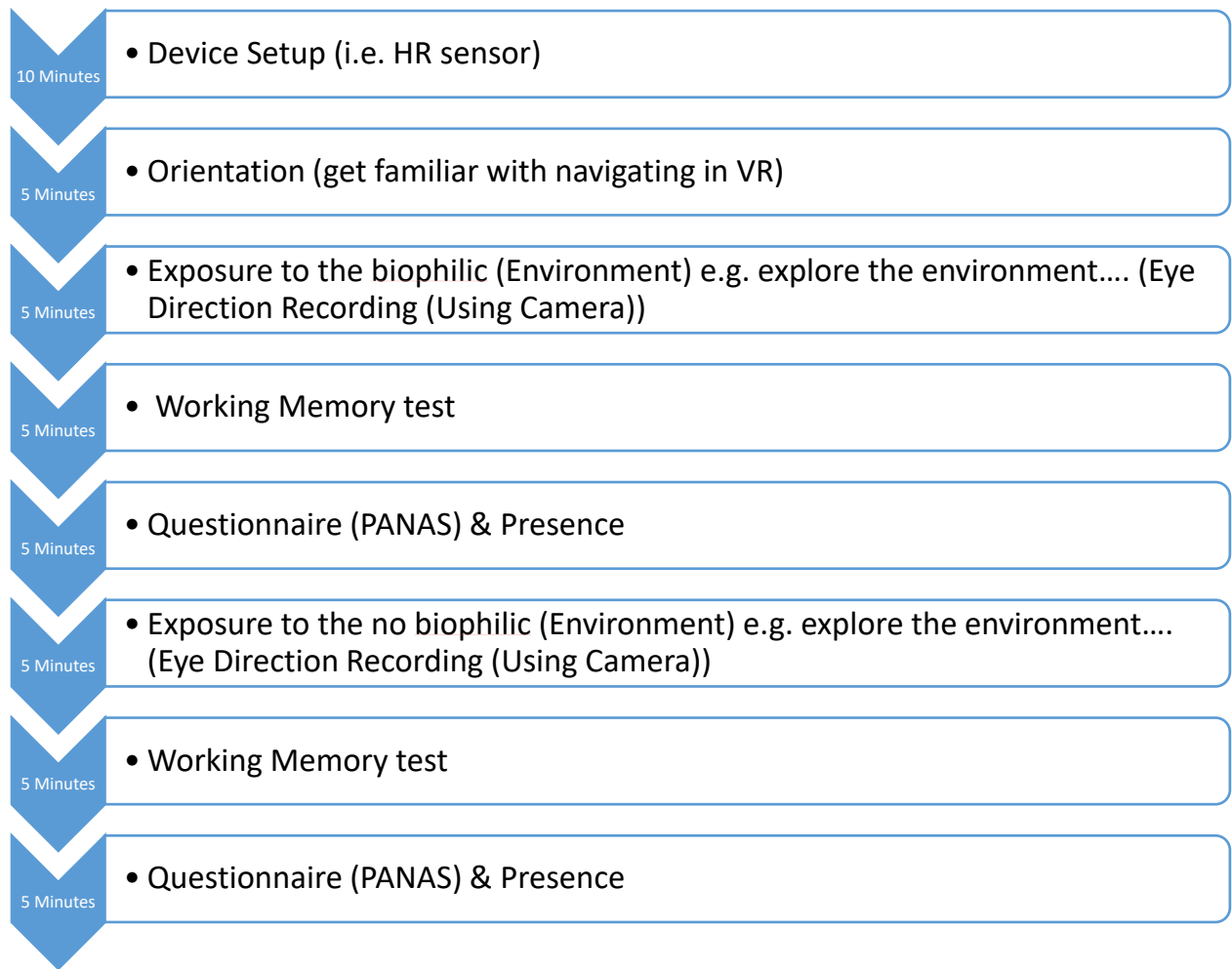


Figure 3.5. Summary of Visit Schedule (IVE Experiment)

3.4. Data Collection Methods

3.4.1. Heart rate

In this study, a wireless electrode-based heart rate monitoring tool, called POLAR Ft7, was used. This device was used to measure the heart rate (HR) of participants. Data were also read and recorded by Heart Rate Variability Logger application. I used a free heart rate variability analysis software to analyze the collected data.



Figure 3.6. POLAR Ft7

3.4.2 Head Mounted Device (HMD)

Participants view the virtual environment of the study area and CAVE through a Head-Mounted Device (HMD). The HMD for this study was the Vive-Pro which supports a 2,880 x 1,600 resolution on a dual-OLED display.



Figure 3.7. Vive-Pro

3.5 Surveys

Surveys were created using online software, Qualtrics. In this study three questionnaire were used:

- 1- Baseline Survey.
- 2- PANAS

3- IPQ

3.5.1. PANAS

PANAS stands for Positive and Negative Affect Schedule. It is a self-report questionnaire that consists of 20 questions. These 20 questions include two groups, 10-items measuring the positive affect and the other 10-items measuring the negative affect. Each item is graded on a 5-point scale of 1 (not at all) to 5 (very much). It takes approximately 5 minutes for each participant to complete PANAS. “Non-clinical studies have found the PANAS to be a reliable and valid instrument in the assessment of positive and negative affect” [73]. The PANAS survey is in APPENDIX A.

3.5.2. Presence

I used the Igroup Presence Questionnaire (IPQ) in this study. The IPQ is a scale for checking the feeling of presence experienced in an Immersive Virtual Environment (IVE) [74].

This version of the IPQ includes three subscales and one additional general item which did not belong to the three subscales. These subscales are independent factors that developed from principal component analyses [74]. They are:

- 1- Spatial Presence: measures the feeling of being physically present in the Immersive Virtual Environment (IVE)
- 2- Involvement: measure how much participants are paying attention to the IVE and the engagement they experienced
- 3- Experienced Realism: measures the sense of realism in IVE

You can find the IPQ survey in APPENDIX B.

3.6. Working Memory

Throughout the working memory test, participants answered 60 questions (20 shapes, 20 colors, 20 shapes & colors); the order of items was randomized.

To create each question, eight colors were used: cyan, orange, red, yellow, blue, purple, brown, and green (Figure 3.8) [75]. Also, twelve shapes were used (Figure 3.9) [76].

Each question includes four slides. The first slide asks if the participant is ready to start; in this part the participant can press the space bar or say yes to see the first image. The first image lasts for 500ms; after that, a blank page lasts for 900ms. After that, the participant sees either the same image or another image. In each part, ten questions are the same, and ten questions are not the same. The following color palette and shapes were used to create the 60 items.

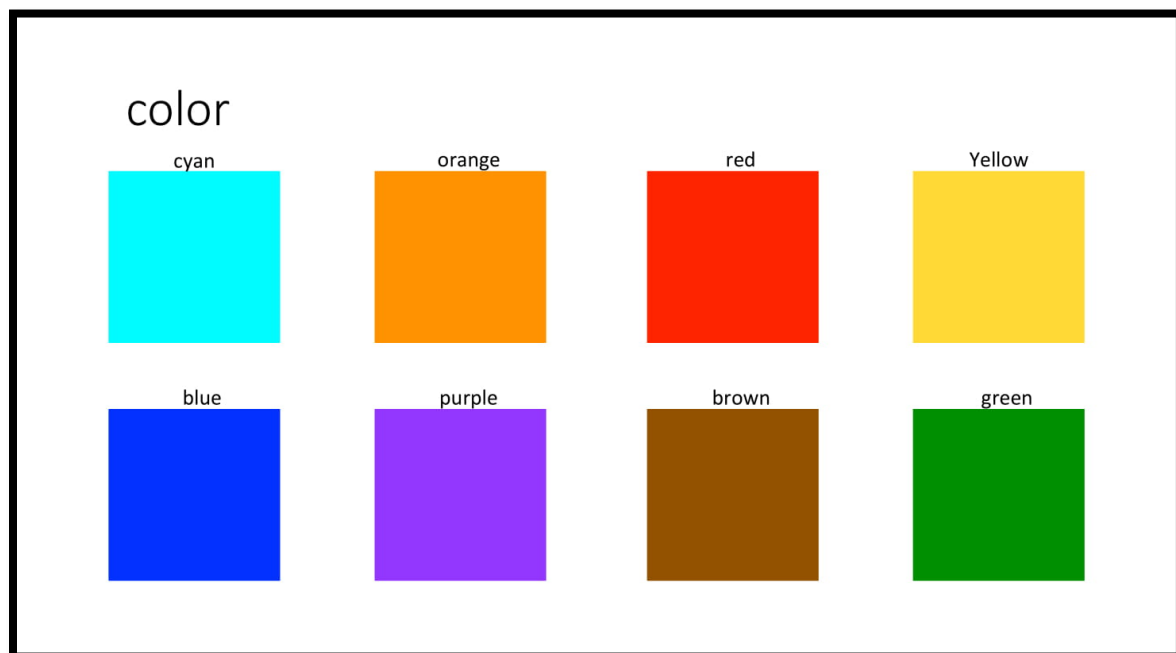


Figure 3.8. Color Palette

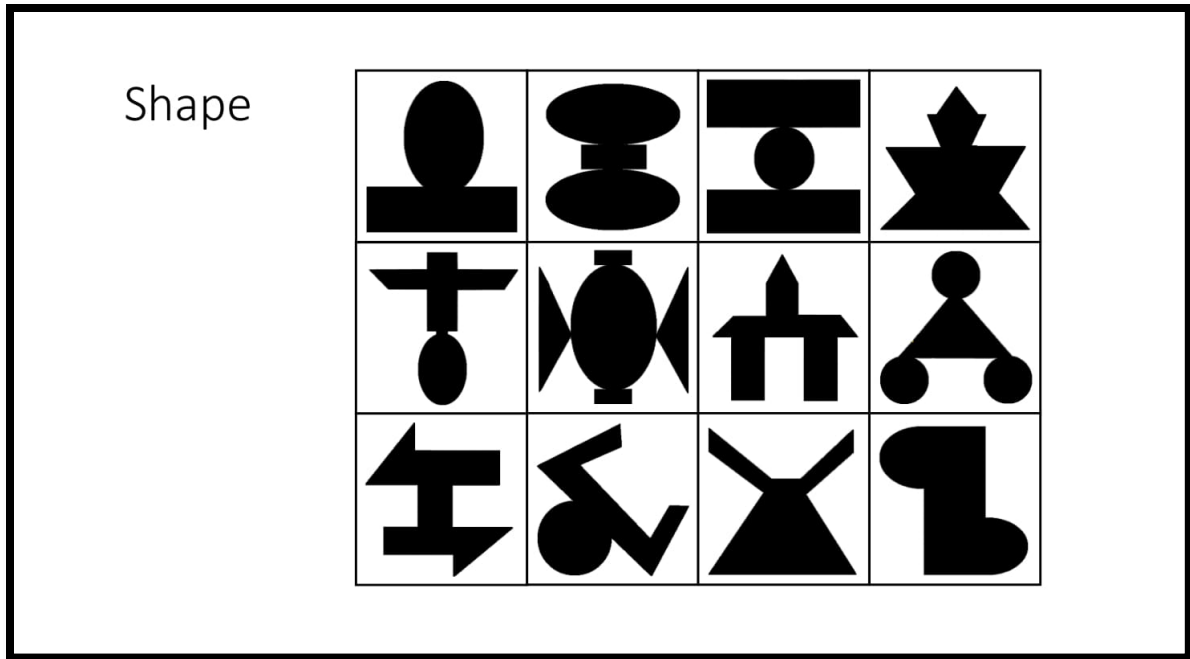


Figure 3.9. Shapes

The following pictures show two examples, one for the same and one for not the same, in each category.

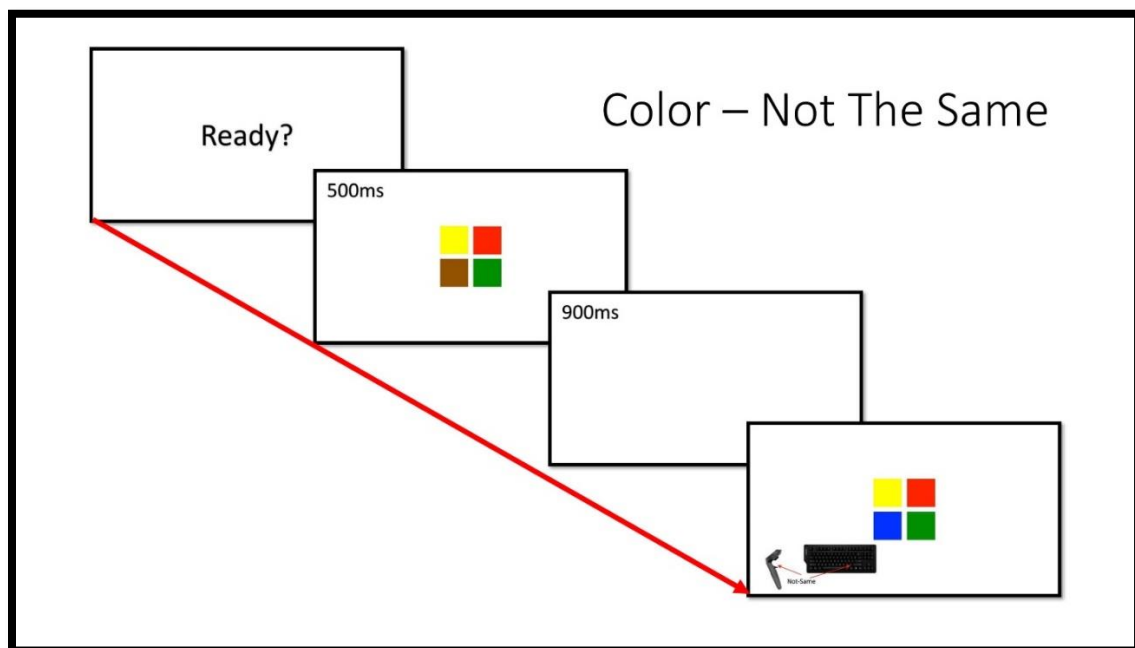


Figure 3.10. Color - Not The Same

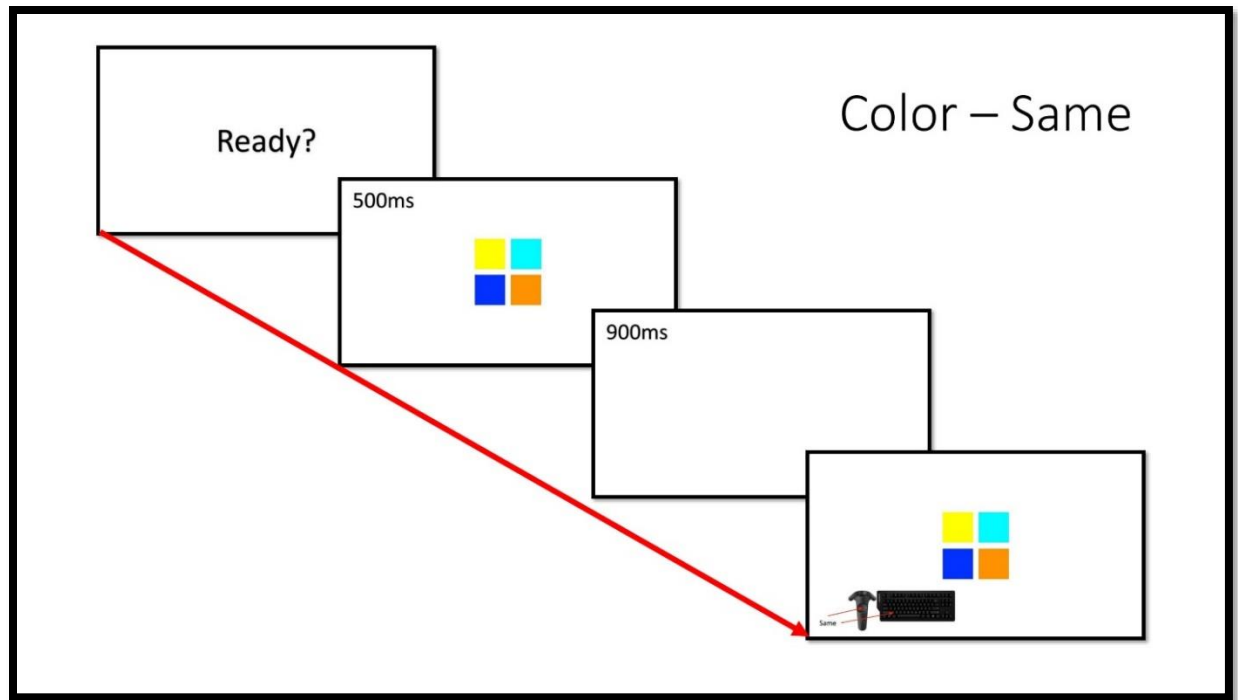


Figure 3.11. Color - Same

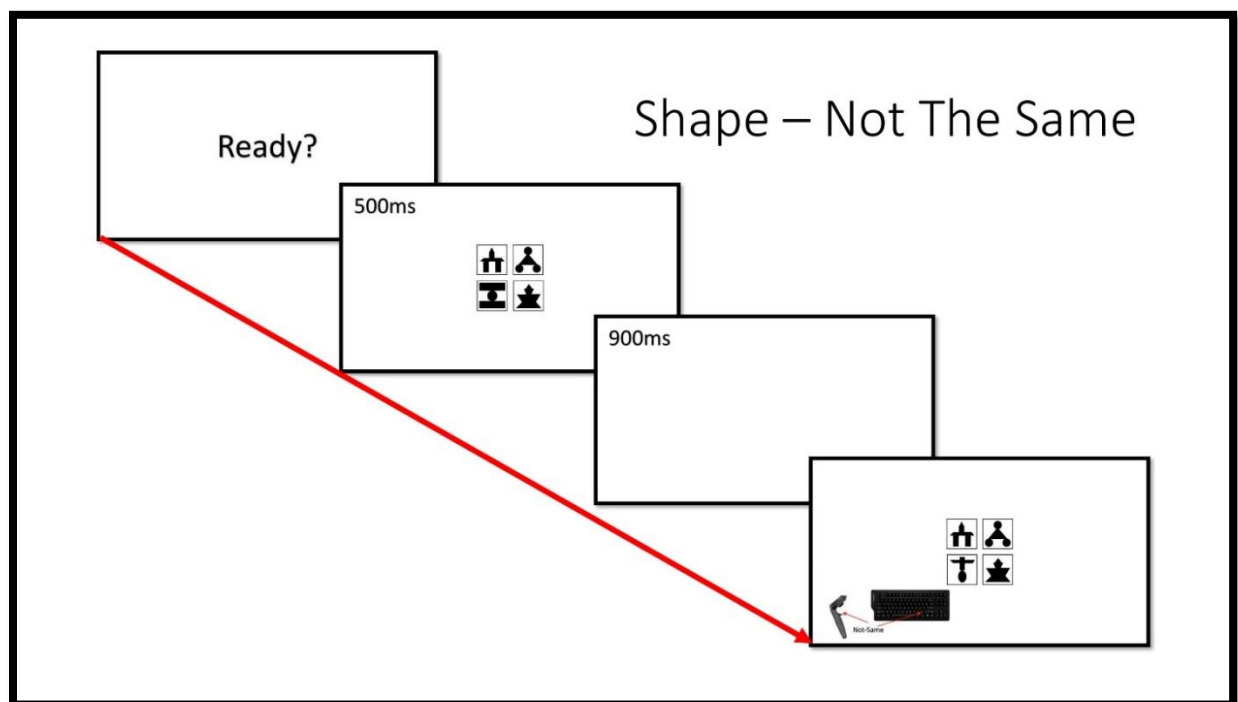


Figure 3.12. Shape - Not The Same

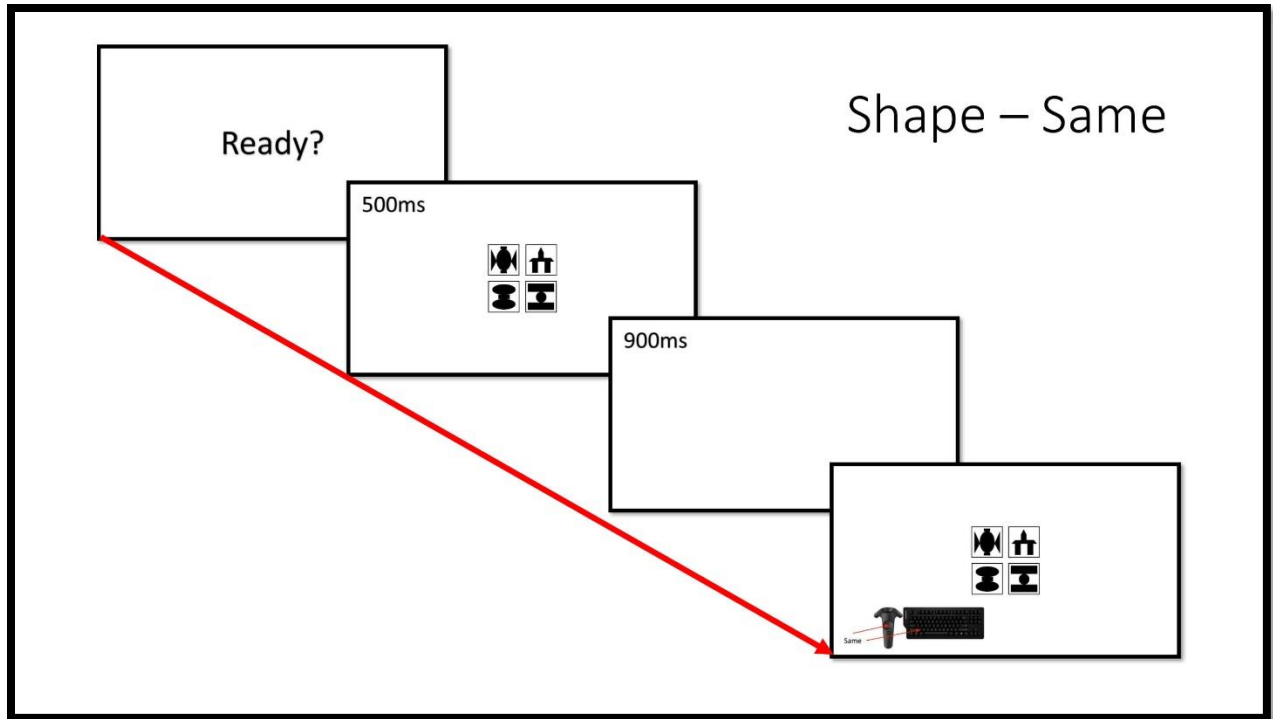


Figure 3.13. Shape - Same

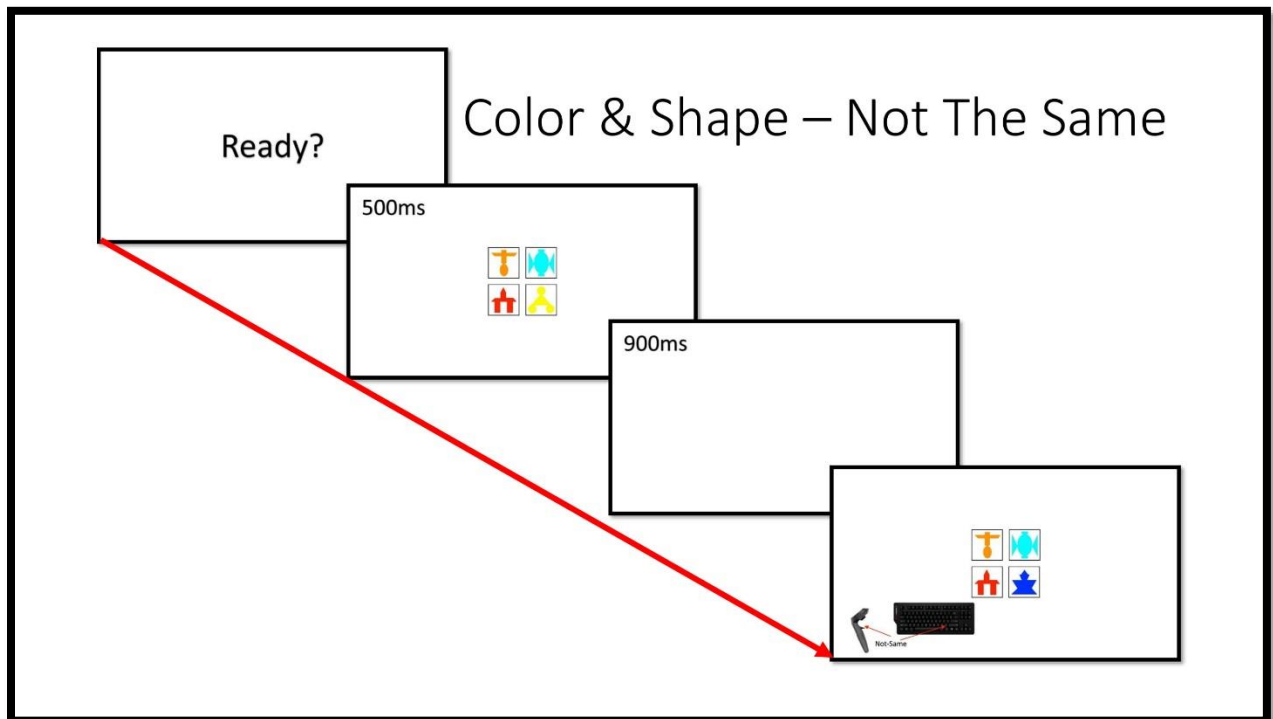


Figure 3.14. Color & Shape - Not The Same

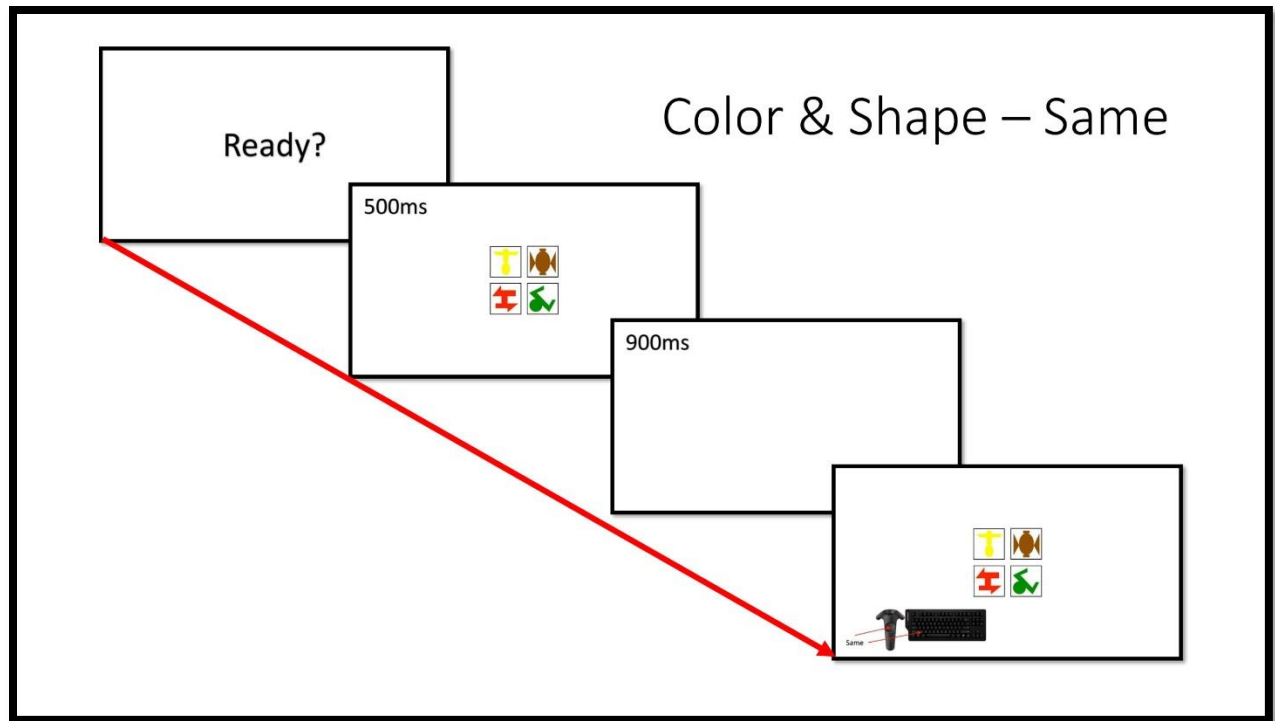


Figure 3.15. Color & Shape - Same

3.6. Statistical Analysis

I used SPSS and SAS to analyze the collected data. Paired-Samples T-test and mixed model were used to check reliability. To check the internal consistency in PANAS data, Cronbach's alpha was used.

3.6.2. Cronbach's alpha

Cronbach's alpha measures internal consistency to show how closely related a set of items are as a group. Cronbach's alpha checks the scale of reliability [77]. "Cronbach's alpha can be written as a function of the number of test items and the average inter-correlation among the items" [79].

Cronbach's alpha formula:
$$\alpha = \frac{K}{K-1} \left(1 - \frac{\sum_{i=1}^K \sigma_{y_i}^2}{\sigma_x^2} \right)$$

Where σ_x^2 is the variance of the observed total test scores, and $\sigma_{y_i}^2$ is the variance of component i for the current sample of persons.

Table 3.1. Cronbach's alpha [78]

Cronbach's alpha	Internal consistency
$0.9 \leq \alpha$	Excellent
$0.8 \leq \alpha < 0.9$	Good
$0.7 \leq \alpha < 0.8$	Acceptable
$0.6 \leq \alpha < 0.7$	Questionable
$0.5 \leq \alpha < 0.6$	Poor
$\alpha < 0.5$	Unacceptable

CHAPTER 4. DATA & ANALYSIS

4.1. Cronbach's alpha - PANAS

Cronbach's alpha indicates that internal consistency is good in negative affect, and it is excellent in positive affect.

NA (BIOPHILIC) IN-SITU		NA (BIOPHILIC) IVE		NA (NO BIOPHILIC) IN-SITU	
# of Question	10.00	# of Question	10.00	# of Question	10.00
sum of the item variances	1.68	sum of the item variances	1.67	sum of the item variances	3.27
variance of total score	6.26	variance of total score	6.87	variance of total score	14.89
Cronbach's alpha	0.81	Cronbach's alpha	0.84	Cronbach's alpha	0.87
NA (NO BIOPHILIC) IVE		PA (BIOPHILIC) IVE		PA (NO BIOPHILIC) IN-SITU	
# of Question	10.00	# of Question	10.00	# of Question	10.00
sum of the item variances	5.17	sum of the item variances	11.31	sum of the item variances	10.44
variance of total score	24.65	variance of total score	74.01	variance of total score	63.85
Cronbach's alpha	0.88	Cronbach's alpha	0.94	Cronbach's alpha	0.93
PA (BIOPHILIC) IN-SITU		PA (NO BIOPHILIC) IVE			
# of Question	10.00	# of Question	10.00		
sum of the item variances	12.55	sum of the item variances	13.35		
variance of total score	70.83	variance of total score	83.90		
Cronbach's alpha	0.91	Cronbach's alpha	0.93		

Figure 4.1. Cronbach's alpha Result

Result shows: NA: $0.8 \leq \alpha < 0.9$ = Good

PA: $0.9 \leq \alpha$ = Excellent

4.2. NA – PANAS

APPENDIX C provides negative affect data.

Table 4.1. Descriptive Statistics and t-test Results for Negative Affect in In-Situ

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
Negative Affect	11.73	2.55	12.80	3.93	30	-2.02 , -0.11	0.77	-2.28	20

* p < .05.

Table 4.2. Descriptive Statistics and t-test Results for Negative Affect in IVE

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
Negative Affect	12.00	2.67	13.53	5.05	30	-2.99 , -0.07	0.64	-2.15	29

* p < .05.

A paired samples t-test for In-Situ showed a statistically significant decrease in negative affect (NA) scores from biophilic (M = 11.73, SD = 2.55) to no biophilic (M = 12.80, SD = 3.93), $t(29) = -2.28$, $p = 0.03$ (two-tailed). The mean decrease in NA scores was 1.07 with a 95% confidence interval ranging from -2.02 to -0.11. These results suggest that biophilic design influences negative affect in In-Situ. Specifically, our results suggest that biophilic design decreases negative affect in In-Situ.

A paired samples t-test for IVE showed a statistically significant decrease in negative affect (NA) scores from biophilic (M = 12.00, SD = 2.67) to no biophilic (M = 13.53, SD = 5.05), $t(29) = -2.15$, $p = 0.04$ (two-tailed). The mean decrease in Negative Affect scores was 1.53 with a 95% confidence interval ranging from -2.99 to -0.07. These results suggest that biophilic design influences negative affect in IVE. Specifically, our results suggest that biophilic design decreases negative affect in IVE.

Mixed Model- SAS

NA

Model Information	
Data Set	WORK.TEST
Dependent Variable	NA
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Kenward-Roger
Degrees of Freedom Method	Kenward-Roger

Number of Observations	
Number of Observations Read	120
Number of Observations Used	120
Number of Observations Not Used	0

Iteration History			
Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	645.75275030	
1	1	624.62785885	0.00000000

Fit Statistics	
-2 Res Log Likelihood	624.6
AIC (Smaller is Better)	628.6
AICC (Smaller is Better)	628.7
BIC (Smaller is Better)	631.4

Class Level Information		
Class	Levels	Values
subject	30	1 10 11 12 13 14 15 16 17 18 19 2 20 21 22 23 24 25 26 27 28 29 3 30 4 5 6 7 8 9
Virtual	2	0 1
Biophilic	2	0 1

Dimensions	
Covariance Parameters	2
Columns in X	9
Columns in Z	30
Subjects	1
Max Obs per Subject	120

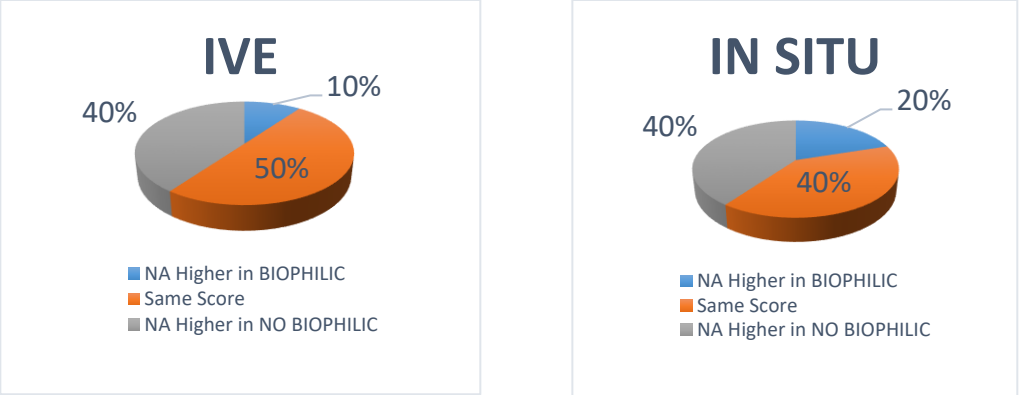
Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Virtual	1	87	0.91	0.3425
Biophilic	1	87	6.16	0.0150
Virtual*Biophilic	1	87	0.20	0.6571

Figure 4.2. Mixed model Negative Affect

Mixed model also approved this result as seen in the above figure (4.2); the p-value for IVE is 0.34, which is higher than 0.05, which means IVE does not significantly change negative moods. It also shows the p-value for biophilic is 0.01, which is less than 0.05, which means biophilic significantly changes negative moods.

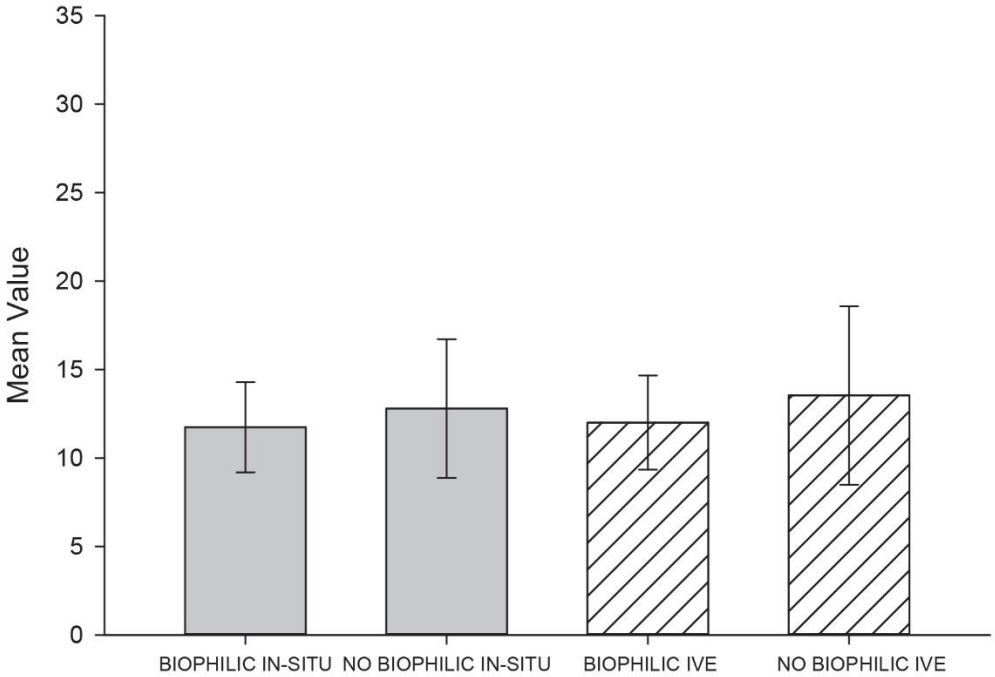
Graph 1 compares the number of people who made a higher negative affect score in two conditions: biophilic and no biophilic.

Graph 2 compares the mean value of negative affect in four conditions: biophilic In-Situ, no biophilic In-Situ, condition biophilic IVE, and no biophilic IVE.



Graph 4.1 Population Who Made Higher Negative Affect Score in Each Condition In Each Approach

Negative Affect



Graph 4.2 Mean Negative Affect Value in Each Condition

4.2. PA – PANAS

APPENDIX D provides positive affect data

Table 4.3. Descriptive Statistics and t-test Results for Positive Affect in In-Situ

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
Positive Affect	27.57	8.59	23.90	8.26	30	1.74 , 5.59	0.81	3.90	29

* $p < .05$.

Table 4.4. Descriptive Statistics and t-test Results for Positive Affect in IVE

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
Positive Affect	28.97	8.78	26.97	9.32	30	-0.13 , 4.13	0.80	1.92	29

* $p < .05$.

A paired samples t-test showed a statistically significant increase in positive affect (PA) scores from biophilic ($M = 27.57$, $SD = 8.59$) to no biophilic ($M = 23.90$, $SD = 8.26$), $t(29) = 3.90$, $p = 0.001$ (two-tailed). The mean increase in positive affect scores was 3.67 with a 95% confidence interval ranging from 1.74 to 5.59. These results suggest that biophilic design changes positive affect in In-Situ. Specifically, our results suggest that biophilic design increases positive affect in In-Situ.

A paired samples t-test showed marginally statistically significant increases in positive affect (PA) scores from biophilic ($M = 28.97$, $SD = 8.78$) to no biophilic ($M = 26.97$, $SD = 9.32$), $t(29) = 1.92$, $p = 0.065$ (two-tailed). The mean increase positive affect scores was 2.00 with a 95% confidence interval ranging from -0.13 to 4.13. These results

suggest that biophilic design has a marginal effect on positive affect in IVE. Specifically, our results suggest that biophilic design increases positive affect in IVE.

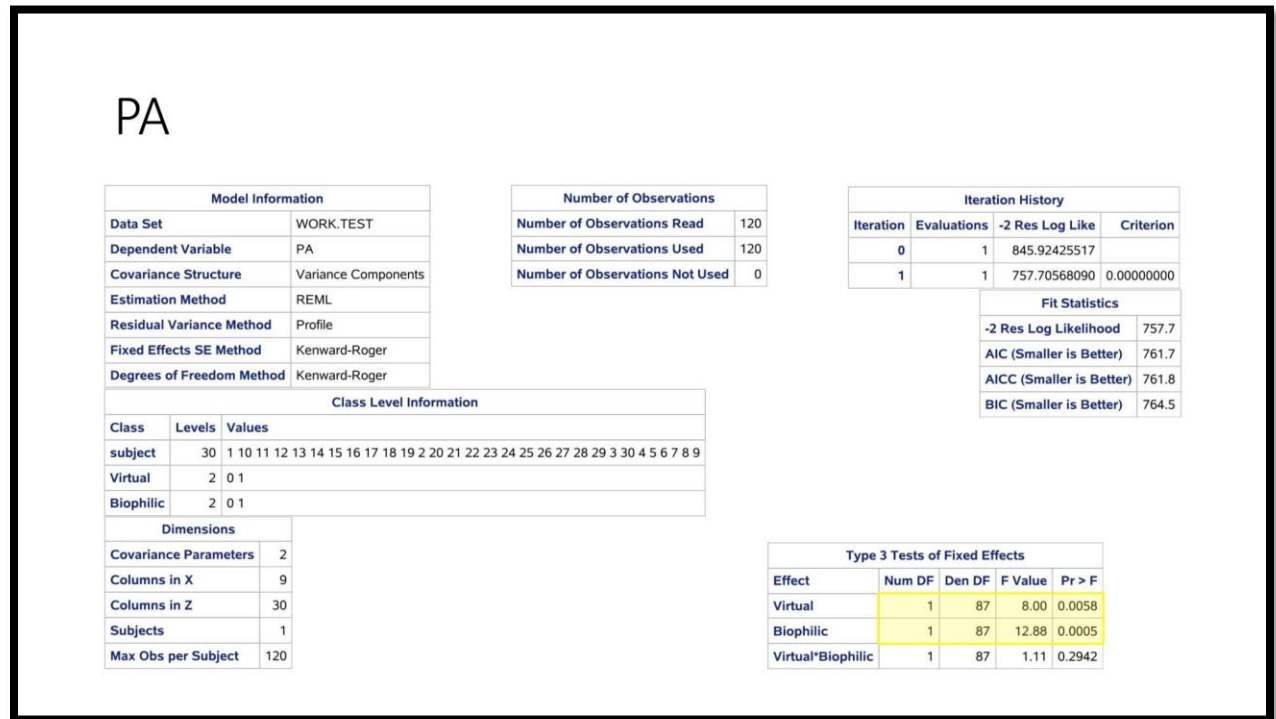
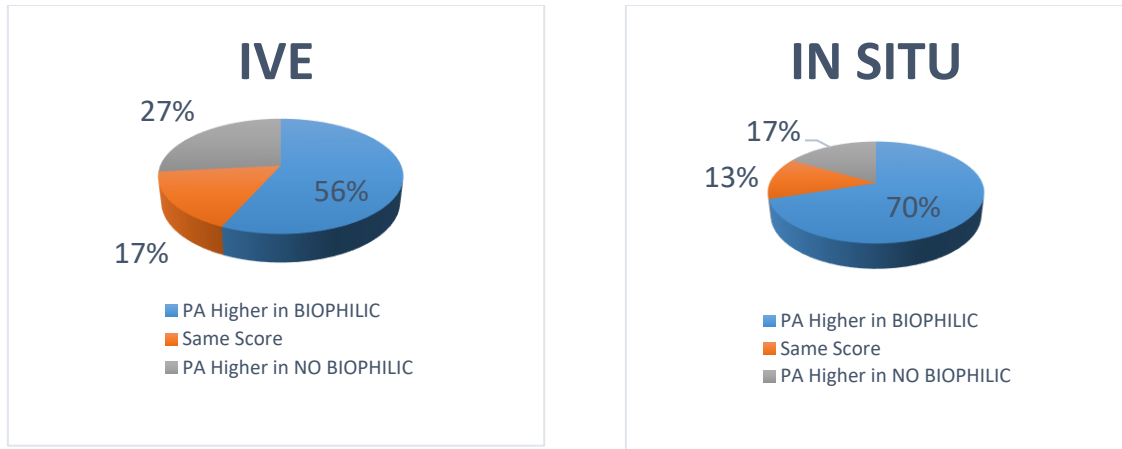


Figure 4.3. Mixed model Positive Affect

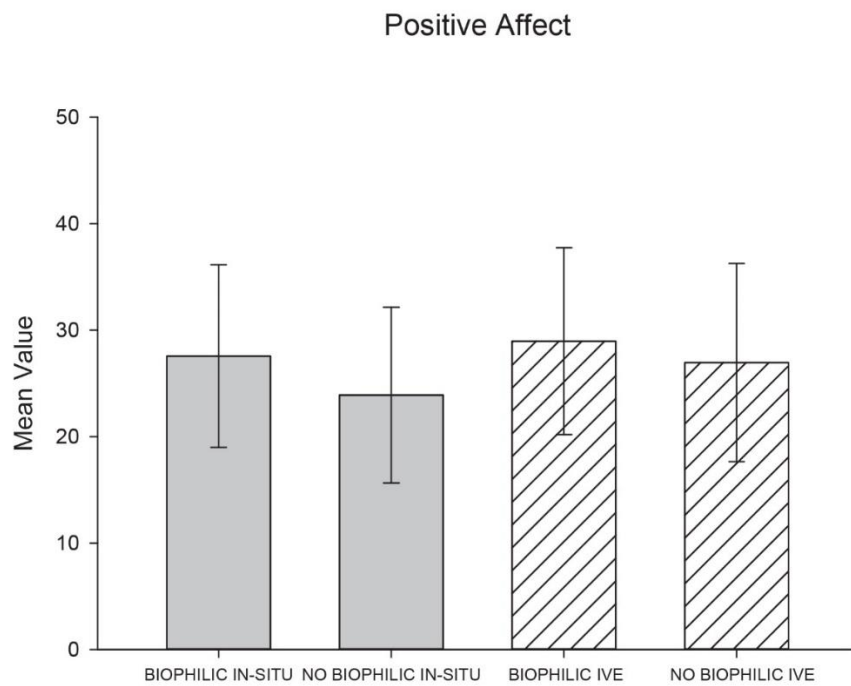
Mixed model also approved this result as seen in the above figure (4.3); the p-value for IVE is 0.0058, which is less than 0.05, which means IVE significantly changes positive moods. It also shows p-value for biophilic is 0.0005, which is less than 0.05, which means biophilic significantly changes positive moods.

Graph 3 compares the number of people who made a higher positive affect score in two conditions: biophilic and no biophilic.

Graph 4 compares the mean value of positive affect in four conditions: biophilic In-Situ, no biophilic In-Situ, condition biophilic IVE, and no biophilic IVE.



Graph 4.3 Population Who Made Higher Positive Affect Score In Each Condition In Each Approach



Graph 4.4. Mean Positive Affect Value in Each Condition

4.4. Presence

APPENDIX I, J, K, and L include data for presence. Pairwise t-test for presence data indicates that in three categories of presence, general, spatial, and realness, there is no

significant difference between biophilic environments versus no-biophilic environments. However, there is a statistically significant difference between involvements in biophilic versus no-biophilic environments.

Table 4.5. Descriptive Statistics and t-test Results for General Presence in IVE

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
IPQ - General	70.67	17.21	70.67	19.46	30	-6.79 , 6.79	0.51	0.00	29

* $p < .05$.

There was not a significant difference in the scores for general biophilic ($M = 70.67$, $SD = 17.21$) and general no biophilic ($M = 70.67$, $SD = 19.46$) conditions; $t(29) = 0.00$, $p = 1.00$.

Table 4.6. Descriptive Statistics and t-test Results for Spatial Presence in IVE

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
IPQ - Spatial Presence	73.07	8.85	73.87	9.02	30	-4.67 , 3.07	0.33	-0.42	29

* $p < .05$.

There was not a significant difference in the scores for Spatial Presence biophilic ($M = 73.07$, $SD = 8.85$) and Spatial Presence no biophilic ($M = 73.87$, $SD = 9.02$) conditions; $t(29) = -0.42$, $p = 0.676$.

Table 4.7. Descriptive Statistics and t-test Results for Involvement Presence in IVE

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
IPQ - Involvement	59.50	7.47	65.33	11.29	30	-9.05 , -2.62	0.65	-3.70	29

* p < .05.

There was a significant difference in the scores for Involvement biophilic (M = 59.50, SD = 7.47) and Involvement no biophilic (M = 65.33, SD = 11.29) conditions; $t(29) = -3.70$, $p = 0.001$.

Table 4.8. Descriptive Statistics and t-test Results for Realness Presence in IVE

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
IPQ – Realness	62.00	12.43	59.67	14.62	30	-1.85 , 6.51	0.67	1.14	29

* p < .05.

There was not a significant difference in the scores for Spatial Presence biophilic (M = 62.00, SD = 12.43) and Spatial Presence no biophilic (M = 59.67, SD = 14.62) conditions; $t(29) = 1.14$, $p = 0.263$.

4.5. Working Memory

Working Memory data can be found in APPENDIX E, F, G, and H.

Table 4.9. Descriptive Statistics and t-test Results for Working Memory in In-Situ

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					

Working Memory	84.28	6.20	81.72	6.10	30	0.25 , 4.86	0.50	2.27	29
----------------	-------	------	-------	------	----	-------------	------	------	----

* $p < .05$.

Table 4.10. Descriptive Statistics and t-test Results for Working Memory in IVE

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
Working Memory	82.33	5.58	81.72	6.42	30	-1.74 , 2.96	0.46	0.53	29

* $p < .05$.

A paired samples t-test showed a statistically significant increase in working memory (WM) scores from biophilic ($M = 84.28$, $SD = 6.20$) to no-biophilic ($M = 81.72$, $SD = 6.10$), $t(29) = 2.27$, $p = 0.031$ (two-tailed). The mean increase in working memory scores was 2.56 with a 95% confidence interval ranging from 0.25 to 4.86. These results suggest that biophilic design affects working memory in In-Situ. Specifically, our results suggest that biophilic design increases cognitive performance in In-Situ.

A paired samples t-test did not show a statistically significant increase in working memory (WM) scores from biophilic ($M = 82.33$, $SD = 5.58$) to no-biophilic ($M = 81.72$, $SD = 6.42$), $t(29) = 0.53$, $p = 0.599$ (two-tailed). The mean increase working memory scores was 0.611 with a 95% confidence interval ranging from -1.74 to 2.96. These results suggest that biophilic design does not affect working memory in IVE.

WM

Model Information	
Data Set	WORK.TEST
Dependent Variable	WM
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Kenward-Roger
Degrees of Freedom Method	Kenward-Roger

Number of Observations	
Number of Observations Read	120
Number of Observations Used	120
Number of Observations Not Used	0

Iteration History			
Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	760.62140038	
1	1	726.29296336	0.00000000

Fit Statistics	
-2 Res Log Likelihood	726.3
AIC (Smaller is Better)	730.3
AICC (Smaller is Better)	730.4
BIC (Smaller is Better)	733.1

Class Level Information		
Class	Levels	Values
subject	30	1 10 11 12 13 14 15 16 17 18 19 2 20 21 22 23 24 25 26 27 28 29 3 30 4 5 6 7 8 9
Virtual	2	0 1
Biophilic	2	0 1

Dimensions	
Covariance Parameters	2
Columns in X	9
Columns in Z	30
Subjects	1
Max Obs per Subject	120

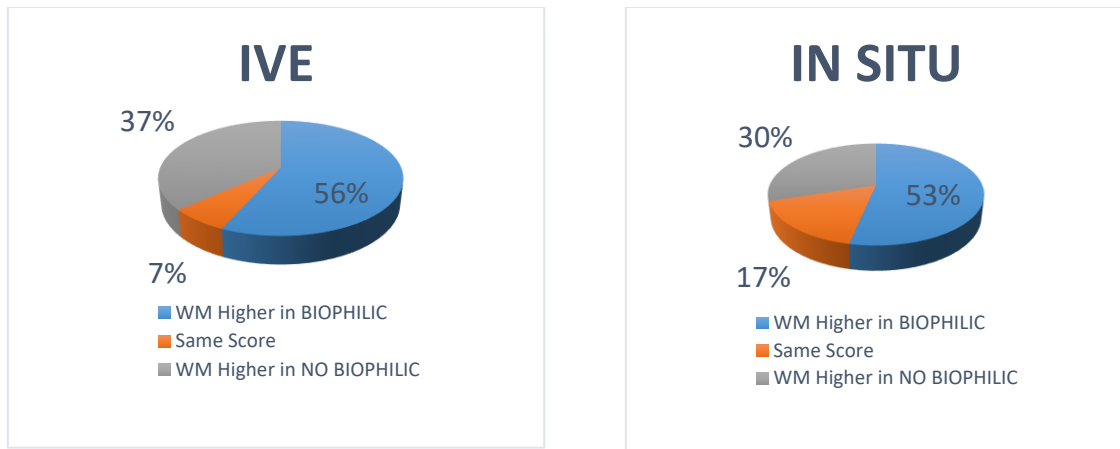
Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Virtual	1	87	1.84	0.1787
Biophilic	1	87	4.58	0.0351
Virtual*Biophilic	1	87	1.30	0.2567

Figure 4.4. Mixed model Working Memory

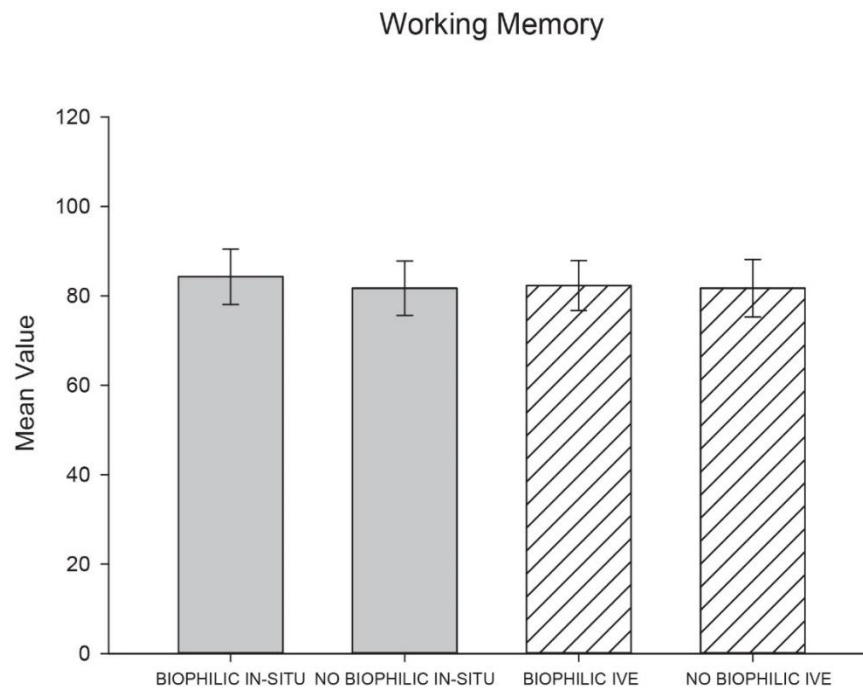
Mixed model also approved this result as seen in the above Figure (4.4); the p-value for IVE is 0.1787, which is higher than 0.05, which means IVE does not significantly change cognitive performance. It also shows p-value for biophilic is 0.0351, which is less than 0.05, which means biophilic design significantly varies cognitive performance. Mixed model information shows the p-value for both virtual reality and biophilic is 0.2567, which is not significant.

Graph 5 compares the number of people who made a higher working memory score in two conditions: biophilic and no biophilic.

Graph 6 compares the mean value of working memory in four conditions: biophilic In-Situ, no biophilic In-Situ, condition biophilic IVE, and no biophilic IVE.



Graph 4.5. Population Who Made Higher Working Memory Score In Each Condition In Each Approach



Graph 4.6. Mean Working Memory Score Value in Each Condition

4.6. Heart Rate

APPENDIX I provides Heart Rate data. Autonomic nervous systems (ANS), which includes Sympathetic Nervous System (SNS) and parasympathetic nervous systems (PNS), are reflected in the LF and HF bands in heart rate variability (HRV) [80]. Since the participant was not doing a task and they were in resting position, LF was chosen. But comparing LF in four conditions did not show a statistically significant difference between data.

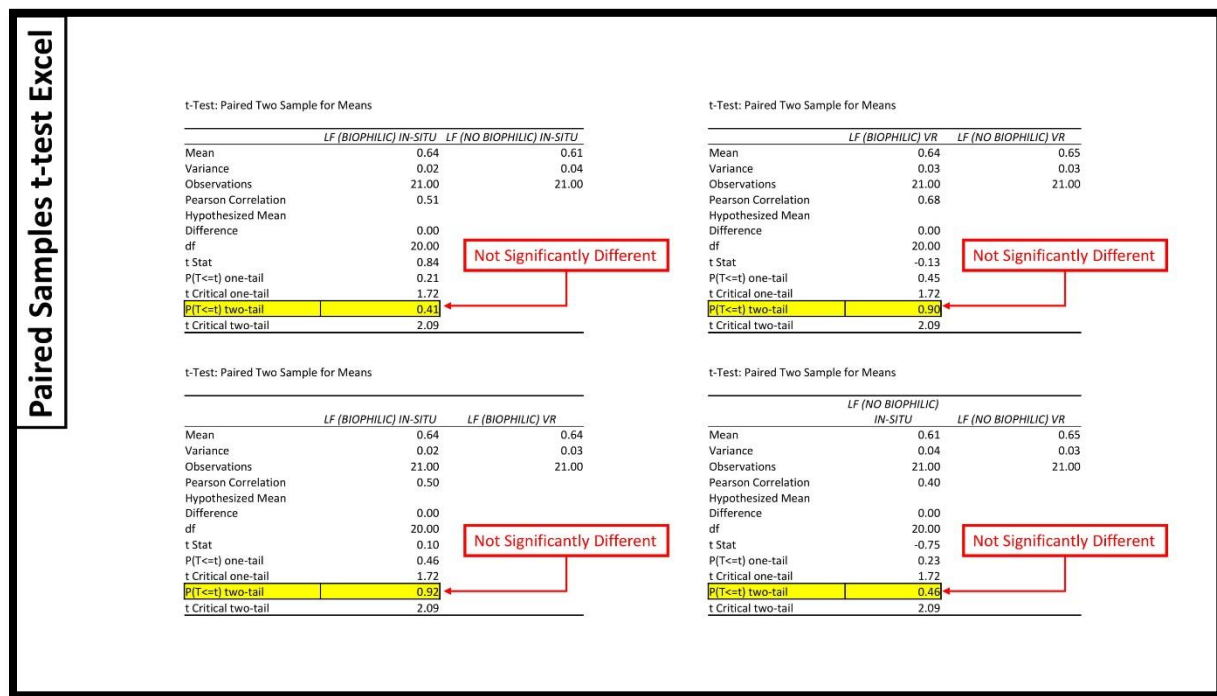


Figure 4.5. T-test LF

4.7. Discussion

In this section, three hypotheses that were mentioned in chapter one will be analyzed based on data that were previously presented.

Table 4.11. Descriptive Statistics and t-test Results for Negative Affect, Positive Affect, and Working Memory in In-Situ

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
Negative Affect	11.73	2.55	12.80	3.93	30	-2.02 , -0.11	0.77	-2.28	20
Positive Affect	27.57	8.59	23.90	8.26	30	1.74 , 5.59	0.81	3.90	29
Working Memory	84.28	6.20	81.72	6.10	30	0.25 , 4.86	0.50	2.27	29

* $p < .05$.

Table 4.12. Descriptive Statistics and t-test Results for Negative Affect, Positive Affect, Working Memory, and Presence in IVE

Outcome	Biophilic		No-biophilic		n	95% Confidence Interval of the Difference	r	t	df
	M	SD	M	SD					
Negative Affect	12.00	2.67	13.53	5.05	30	-2.99 , -0.07	0.64	-2.15	29
Positive Affect	28.97	8.78	26.97	9.32	30	-0.13 , 4.13	0.80	1.92	29
Working Memory	82.33	5.58	81.72	6.42	30	-1.74 , 2.96	0.46	0.53	29
IPQ - General	70.67	17.21	70.67	19.46	30	-6.79 , 6.79	0.51	0.00	29
IPQ - Spatial Presence	73.07	8.85	73.87	9.02	30	-4.67 , 3.07	0.33	-0.42	29
IPQ - Involvement	59.50	7.47	65.33	11.29	30	-9.05 , -2.62	0.65	-3.70	29
IPQ – Realness	62.00	12.43	59.67	14.62	30	-1.85 , 6.51	0.67	1.14	29

* $p < .05$.

4.7.1. Natural element exposure in IVE reduces negative mood in the same way as natural element exposure in In-Situ

Based on the result, I must accept the first hypothesis; natural element exposure in IVE reduces negative mood in the same way as natural element exposure in In-Situ.

4.7.2. Natural element exposure in IVE creates more positive moods in the same way as natural element exposure in In-Situ

Natural element exposure creates more positive moods in In-Situ, but the difference that natural element creates in IVE is marginal. It may be due to participant involvement.

Participants who had more involvement in a no-biophilic environment in IVE also had higher positive moods in the no-biophilic environment. This means involvement in IVE can change people's positive mood. Two participants who were more involved in no-biophilic environment and had more positive mood in no-biophilic environment said that the contrast between the video part versus model in the biophilic environment was continually reminding them that they are in an IVE environment, not a real environment. Perhaps this problem caused them to not be involved as much as they were in the no-biophilic environment. One participant also mentioned that he felt a sense of disorientation and did not feel connected in the biophilic IVE, because the day that he was doing the IVE part of the experiment was a rainy day while the light condition and video part of the model for the biophilic environment were set and recorded on a sunny day. He said this disconnection between reality and the IVE made the biophilic IVE model more unrealistic for him; he also said that in the no-biophilic environment, there

was no window to the outside, and light conditions were artificial, so he did not feel disconnection in the no-biophilic environment.

Table 4.13. Compare Individual Who with more involvement and Positive Affect Score in No-Biophilic

Subject	Involvement% Biophilic	Involvement% No Biophilic	PA (BIOPHILIC) VR	PA (NO BIOPHILIC) VR
person 2	70	75	40	40
person 7	50	65	19	23
person 14	35	45	33	34
person 18	50	50	47	43
person 20	60	70	34	38
person 23	65	70	26	33
person 27	65	65	23	29

5.7.3. Natural element exposure has the same impact on cognitive performance (working memory) in both VR and In-Situ

Working memory performance in the In-Situ biophilic environment was significantly different than in the In-Situ no-biophilic environment, and the mean value in the biophilic environment in In-Situ was higher, but in IVE the alpha is higher than 0.05, which means it is not significantly different. Thus, based on our data, I cannot accept the third hypothesis in this experiment.

This means Biophilic design in IVE does not have the same effect of Biophilic design in In-Situ. Although in another study short term memory has been improved in the biophilic environment and IVE did not affect cognitive performance [6], in this study, means of working memory is not significantly different in IVE. In the other study, they used a 3rd camera to record a built environment and played that for participants. In our study, everything was created by gaming program “real engine” so there can be the feeling of presence in the environment.

CHAPTER 5.CONCLUSION

This study shows a short-term exposure in In-Situ increases positive mood and working memory and decreases negative mood. It also indicates that an IVE can be used to create less negative moods. More studies need to be done to investigate the impact biophilic design has on positive moods in IVE. Participants had higher positive affect scores when they were in the biophilic environment in IVE, but those improvements were not statistically significant at the 95% confidence level. From my research I learned that when I apply a real video to the model, the contrast between the level of detail in the model and the video distracted some participants. More studies need to be done to investigate if not using real video can increase the confidence level.

The author decided to do this research to understand the capability of an immersive virtual environment for biophilic design because most of the investigations in this area are limited to videos or pictures of a built environment. This study is the first step to see what limitations and failures exist in measuring biophilic design impact in IVE in order to use them later in the design phase of a project.

The opportunities to do research in Immersive Virtual Reality and biophilic design are still numerous. For instance, current research studies are limited to using spaces that have already been built. To make experiments more flexible, it may be a better idea to make a small room that has biophilic elements by using materials like chipboard or cardboard that can be easily altered, instead of using existing spaces. Thus, it would be easier to manipulate some design aspects of the environments and examine the impact of changes in IVEs versus in-situ.

Other future studies that can be helpful in IVE could be about merging existing photos and videos to the designed model. Architects usually use pictures of existing landscapes to create renderings; image editing software like Photoshop enables designers to make their rendering very similar to real pictures so that their design is part of the whole image or scene, but there are limitations to use videos and photos and make them part of the IVE model. In this study, some participants claimed that disconnection between videos and models was bothering them. Future studies can investigate if making the outside environment in the model creates positive feelings in people. How significantly different can a video of a natural component in IVE versus a model of a natural component in IVE be?

More work needs to be done to see the impact of other attributes of biophilic design. In this study, attributes from two categories, direct experience of nature and indirect experience of nature, were used. There are limited studies that consider the third category, experience of space and place, for designing in IVE.

Finally, this research is the first step to investigate the advantage of the connection between human and nature in Immersive Virtual Reality, and more research needs to be done in this field.

REFERENCES

- [1] J. P. Simaika and M. J. Samways, "Biophilia as a universal ethic for conserving biodiversity," *Conserv. Biol.*, vol. 24, no. 3, pp. 903–906, 2010.
- [2] D. W. Orr, "Love it or Lose it: The Coming Biophilia Revolution," *The Biophilia Hypothesis*, pp. 415–440, 1993.
- [3] E. O. Wilson, *Biophilia*. Harvard University Press, 1984.
- [4] S. R. Kellert and E. O. Wilson, *The biophilia hypothesis*. Washington, D.C: Island Press, 1993.
- [5] S. R. Kellert, J. Heerwagen, and M. Mador, *Biophilic design : the theory, science, and practice of bringing buildings to life*. Hoboken, N.J. : Wiley, 2008.
- [6] J. Yin, S. Zhu, P. MacNaughton, J. G. Allen, and J. D. Spengler, "Physiological and cognitive performance of exposure to biophilic indoor environment," *Build. Environ.*, 2018.
- [7] L. Bragança, S. M. Vieira, and J. B. Andrade, "Early stage design decisions: the way to achieve sustainable buildings at lower costs.," *ScientificWorldJournal.*, vol. 2014, p. 365364, Jan. 2014.
- [8] W. Browning, C. Ryan, and J. Clancy, "14 Patterns of Biophilic Design," *Terrapin Bright Green, LLC*, pp. 1–60, 2014.
- [9] O. In, "Biophilic Design : Enhancing the Human-Nature Relationship in the Built Environment," pp. 1–5, 2016.
- [10] E. Fromm, *Babylon*. Lantern Books, 2010.
- [11] E. Fromm, *The heart of man, its genius for good and evil*. Harper & Row, 1964.
- [12] "U.S. Urban Population Is Up ... But What Does 'Urban' Really Mean? - CityLab." [Online]. Available: <https://www.citylab.com/equity/2012/03/us-urban-population-what-does-urban-really-mean/1589/>. [Accessed: 28-Feb-2019].
- [13] S. R. Kellert, E. O. Wilson, S. McVay, K. Aaron, and C. McCarthy, *The Biophilia Hypothesis*. Island Press.
- [14] S. R. Kellert, *Building for Life: Designing and Understanding the Human-Nature Connection*. Washington, DC: Island Press, 2005.
- [15] E. O. Wilson, *Biophilia*. 1984.
- [16] K. Gillis and B. Gatersleben, "A Review of Psychological Literature on the Health and Wellbeing Benefits of Biophilic Design," *Buildings*, vol. 5, no. 3, pp. 948–963,

2015.

- [17] Q. Li, "Effect of forest bathing trips on human immune function," *Environ. Health Prev. Med.*, vol. 15, no. 1, pp. 9–17, 2010.
- [18] R. Of and A. From, "The PracTice of BioPhilic Design," no. October 2001.
- [19] W. Irons, "Adaptively Relevant Environments Versus the Environment of Evolutionary Adaptedness," pp. 194–204.
- [20] E. Of, A. N. Outdoor, O. Program, and O. N. Biophilic, "An Investigation of the Effect of an Outdoor Orientation Program on Participants ' Biophilic Expressions Nathan W . Meltzer Submitted in partial fulfillment of the requirements for the degree of Master of Arts from Prescott College in Adventure Educatio," 2014.
- [21] C. B. Crawford and D. L. Krebs, *Handbook of evolutionary psychology: Ideas, issues, and applications*. Psychology Press, 1998.
- [22] R. Matt, *Encyclopedia of Sciences and Religions*. Springer Science+Business Media, 2013.
- [23] M. Moore, P. Gould, and B. S. Keary, "Global urbanization and impact on health," vol. 278, 2003.
- [24] D. (CUNY) Sharp and H. (UNDP) Kristoffersen, "The Nexus of Urbanization, Violence and Conflict : Linking SDG Goal 11 and SDG Goal 16," p. 32, 2016.
- [25] S. Friel *et al.*, "Addressing the Social and Environmental Determinants of Urban Health Equity : Evidence for Action and a Research Agenda," vol. 88, no. 5, pp. 860–874, 2011.
- [26] N. E. Klepeis *et al.*, "The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants," no. February 2001.
- [27] P. W. Shultz, *Inclusion with Nature: The Psychology Of Human-Nature Relations*. 2002.
- [28] G. G. Patil, "Biophilia : Does Visual Contact with Nature Impact on Health and Well-Being ?" pp. 2332–2343, 2009.
- [29] R. Berto, "sciences The Role of Nature in Coping with Psycho-Physiological Stress :." pp. 394–409, 2014.
- [30] G. Pereira *et al.*, "The association between neighborhood greenness and cardiovascular disease : an observational study," 2012.
- [31] Y. Joye, "Architectural Lessons From Environmental Psychology : The Case of Biophilic Architecture," vol. 11, no. 4, pp. 305–328, 2007.

- [32] M. G. Berman *et al.*, “Interacting with nature improves cognition and affect for individuals with depression,” *J. Affect. Disord.*, vol. 140, no. 3, pp. 300–305, 2012.
- [33] A. Q. Nyrud, T. Bringslimark, and K. Bysheim, “Benefits from wood interior in a hospital room : a preference study,” vol. 8628, 2014.
- [34] C. C. Marcus and M. Barnes, *Healing Gardens: Therapeutic Benefits and Design Recommendations*. New York : Wiley, 1999.
- [35] I. Alcock, M. P. White, B. W. Wheeler, L. E. Fleming, and M. H. Depledge, “Longitudinal Effects on Mental Health of Moving to Greener and Less Green Urban Areas,” 2014.
- [36] R. Mitchell and F. Popham, “Effect of exposure to natural environment on health inequalities : an observational population study,” *Lancet*, vol. 372, no. 9650, pp. 1655–1660.
- [37] J. C. Pruessner, M. Rietschel, M. Deuschle, and A. Meyer-lindenbergl, “City living and urban upbringing affect neural social stress processing in humans,” pp. 2–6, 2011.
- [38] E. Orsega-smith, A. J. Mowen, L. L. Payne, E. Orsega-smith, and G. Godbey, “The Interaction of Stress and Park Use on Psycho- physiological Health in Older Adults The Interaction of Stress and Park Use on Psycho-physiological Health in Older Adults,” vol. 2216, 2017.
- [39] N. Feature, “Stress and resilience,” 2012.
- [40] A. Abbott, “Stress and the city: Urban decay,” *Nature*, vol. 490, no. 7419, pp. 162–164, Oct. 2012.
- [41] L. Tyrväinen, A. Ojala, K. Korpela, T. Lanki, and Y. Tsunetsugu, “The influence of urban green environments on stress relief measures : A field experiment,” *J. Environ. Psychol.*, vol. 38, pp. 1–9, 2014.
- [42] A. C. Model, “The Significance of Parks to Physical Activity and,” vol. 28, 2005.
- [43] “View through a Window May Influence Recovery from Surgery Author (s): Roger S. Ulrich Published by American Association for the Advancement of Science Stable URL : <https://www.jstor.org/stable/1692984>,” vol. 224, no. 4647, pp. 420–421, 2019.
- [44] T. Gray, C. Birrell, and F. L. Wright, “Are Biophilic-Designed Site Office Buildings Linked to Health Benefits and High Performing Occupants ?” pp. 12204–12222, 2014.
- [45] M. G. Berman, J. Jonides, and S. Kaplan, “The Cognitive Benefits of Interacting With Nature,” vol. 19, no. 12, pp. 1207–1213, 2008.

- [46] B. Grinde and G. G. Patil, "Biophilia: Does visual contact with nature impact on health and well-being?," *International Journal of Environmental Research and Public Health*. 2009.
- [47] T. R. Herzog and A. G. Bryce, "Mystery and Preference in Within-Forest Settings," pp. 779–796, 2007.
- [48] K. Wang and R. B. T. Å, "Simulated walks through dangerous alleys : Impacts of features and progress on fear," vol. 26, no. 2006, pp. 269–283, 2007.
- [49] P. Grahn and U. K. Stigsdotter, "Landscape and Urban Planning The relation between perceived sensory dimensions of urban green space and stress restoration," vol. 94, pp. 264–275, 2010.
- [50] "Restorative Effects of Natural Environment Experiences.pdf."
- [51] T. Daysimeter, "Measuring circadian light and its impact on adolescents," pp. 201–215, 2011.
- [52] J. O. Barton and J. Pretty, "What is the Best Dose of Nature and Green Exercise for Improving Mental Health ? A Multi-Study Analysis," vol. 44, no. 10, pp. 3947–3955, 2010.
- [53] U. K. Stigsdotter and P. Grahn, "Experiencing a Garden : A Healing Garden for People Suffering from Burnout Diseases," no. January 2003.
- [54] T. Hartig, G. W. Evans, L. D. Jamner, D. S. Davis, and G. Tommy, "Tracking restoration in natural and urban field settings," vol. 23, pp. 109–123, 2003.
- [55] D. K. Brown, J. L. Barton, and V. F. Gladwell, "Viewing Nature Scenes Positively Affects Recovery of Autonomic Function Following Acute-Mental Stress," 2013.
- [56] O. Article, "Physiological effects in humans induced by the visual stimulation of room interiors with different wood quantities," pp. 11–16, 2007.
- [57] P. H. Kahn *et al.*, "A plasma display window ?— The shifting baseline problem in a technologically mediated natural world," vol. 28, pp. 192–199, 2008.
- [58] A. Kabanshi, H. Wigo, and R. Ljung, "Indoor and Built Human perception of room temperature and intermittent air jet cooling in a classroom," vol. 26, no. 4, pp. 528–537, 2017.
- [59] H. Jahncke, S. Hygge, N. Halin, A. Marie, and K. Dimberg, "Open-plan office noise : Cognitive performance and restoration," *J. Environ. Psychol.*, vol. 31, no. 4, pp. 373–382, 2011.
- [60] J. J. Alvarsson, S. Wiens, and M. E. Nilsson, "Stress Recovery during Exposure to Nature Sound and Environmental Noise," pp. 1036–1046, 2010.

- [61] R. J. De Dear and G. S. Brager, "Thermal comfort in naturally ventilated buildings : revisions to ASHRAE Standard 55," vol. 34, pp. 549–561, 2002.
- [62] S. Windhager, K. Atzwanger, F. L. Bookstein, and K. Schaefer, "Landscape and Urban Planning Fish in a mall aquarium — An ethological investigation of biophilia," *Landsc. Urban Plan.*, vol. 99, no. 1, pp. 23–30, 2011.
- [63] T. R. Herzog, P. Maguire, and M. B. Nebel, "Assessing the restorative components of environments," vol. 23, pp. 159–170, 2003.
- [64] K. Han, "A reliable and valid self-rating measure of the restorative quality of natural environments," vol. 64, no. 14, pp. 209–232, 2003.
- [65] S. Lichtenfeld, A. J. Elliot, M. A. Maier, and R. Pekrun, "Fertile Green : Green Facilitates Creative Performance," 2012.
- [66] R. J. Pheasant, M. N. Fisher, G. R. Watts, D. J. Whitaker, and K. V Horoshenkov, "The importance of auditory-visual interaction in the construction of ' tranquil space,'" *J. Environ. Psychol.*, vol. 30, no. 4, pp. 501–509, 2010.
- [67] M. White, A. Smith, K. Humphries, S. Pahl, D. Snelling, and M. Depledge, "Blue space : The importance of water for preference, affect, and restorativeness ratings of natural and built scenes," *J. Environ. Psychol.*, vol. 30, no. 4, pp. 482–493, 2010.
- [68] J. Gershon, E. Zimand, L. Hodges, B. O. Rothbaum, and R. Lemos, "Use of Virtual Reality as a Distractor for Painful Procedures in a Patient with Pediatric Cancer: A Case Study," *CyberPsychology Behav.*, vol. 6, no. 6, pp. 657–661, 2004.
- [69] S. Mosadeghi, M. W. Reid, B. Martinez, B. T. Rosen, and B. M. R. Spiegel, "Feasibility of an Immersive Virtual Reality Intervention for Hospitalized Patients: An Observational Cohort Study.," *JMIR Ment. Heal.*, vol. 3, no. 2, p. e28, Jun. 2016.
- [70] J. Yin, S. Zhu, P. MacNaughton, J. G. Allen, and J. D. Spengler, "Physiological and cognitive performance of exposure to biophilic indoor environment," *Build. Environ.*, vol. 132, no. January, pp. 255–262, 2018.
- [71] U. I. and Environment, "Sustainable building and construction : facts and figures," *April-September*, no. September, pp. 1–98, 2003.
- [72] J. Whyte and R. Fellow, "INDUSTRIAL APPLICATIONS OF VIRTUAL REALITY IN ARCHITECTURE AND CONSTRUCTION/4 EDITOR: Kalle Kahkonen," vol. 8, no. July 2002, pp. 43–50, 2003.
- [73] J. R. Crawford and J. D. Henry, "The Positive and Negative Affect Schedule (PANAS): Construct validity, measurement properties and normative data in a large non-clinical sample," *Br. J. Clin. Psychol.*, vol. 43, no. 3, pp. 245–265, Sep. 2004.

- [74] "igroup presence questionnaire (IPQ) overview | igroup.org – project consortium." [Online]. Available: <http://www.igroup.org/pq/ipq/index.php>. [Accessed: 28-Feb-2019].
- [75] A. E. van Lamsweerde, M. R. Beck, and J. S. Johnson, "Visual working memory organization is subject to top-down control," *Psychon. Bull. Rev.*, vol. 23, no. 4, pp. 1181–1189, 2016.
- [76] J. Fiser and R. N. Aslin, "Unsupervised Statistical Learning of Higher-Order Spatial Structures From Visual Scenes," *Psychol. Sci. Res. Artic.*, vol. 12, no. 6, pp. 499–504, 2001.
- [77] "Cronbach's Alpha - Statistics Solutions." [Online]. Available: <https://www.statisticssolutions.com/cronbachs-alpha/>. [Accessed: 28-Feb-2019].
- [78] "Cronbach's Alpha: Simple Definition, Use and Interpretation - Statistics How To." [Online]. Available: <https://www.statisticshowto.datasciencecentral.com/cronbachs-alpha-spss/>. [Accessed: 15-Mar-2019].
- [79] "What does Cronbach's alpha mean? | SPSS FAQ." [Online]. Available: <https://stats.idre.ucla.edu/spss/faq/what-does-cronbachs-alpha-mean/>. [Accessed: 14-Mar-2019].
- [80] W. von Rosenberg, T. Chanwimalueang, T. Adjei, U. Jaffer, V. Goverdovsky, and D. P. Mandic, "Resolving Ambiguities in the LF/HF Ratio: LF-HF Scatter Plots for the Categorization of Mental and Physical Stress from HRV.," *Front. Physiol.*, vol. 8, p. 360, 2017.

APPENDIX A. PANAS - SURVEY

This scale consists of a number of words that describe different feelings and emotions. Indicate to what extent you feel this way right now.

	Very Slightly or Not at All	A Little	Moderately	Quite a Bit	Extremely
1-Interested	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2-Distressed	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3-Excited	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4-Upset	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5-Strong	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6-Guilty	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7-Scared	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8-Hostile	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9-Enthusiastic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10-Proud	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
11-Irritable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
12-Alert	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
13-Ashamed	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
14-Inspired	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
15-Nervous	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
16-Determined	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
17-Attentive	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
18-Jittery	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
19-Active	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
20-Afraid	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

APPENDIX B. IPQ - SURVEY

General

1- In the computer-generated world, I had a sense of "being there."

- None at all
- A little
- A moderate amount
- A lot
- A great deal

Spatial Presence

1- Somehow, I felt that the virtual world surrounded me.

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

2- I felt like I was just perceiving pictures.

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

3- I did not feel present in the virtual space.

- Did not feel present
- Neutral
- Felt present

4- I had a sense of acting in the virtual space, rather than operating something from outside.

- Strongly disagree
- Somewhat disagree

- Neither agree nor disagree
- Somewhat agree
- Strongly agree

5- I felt present in the virtual space.

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Involvement

1- How aware were you of the real world surrounding while navigating in the virtual world? (i.e., sounds, room temperature, other people, etc.)?

- Extremely unaware
- Somewhat unaware
- Neutral
- Somewhat aware
- Extremely aware

2- I was not aware of my real environment.

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

3- I still paid attention to the real environment.

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

4- I was completely captivated by the virtual world.

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Experienced Realism

1- How real did the virtual world seem to you?

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

2- How much did your experience in the virtual environment seem consistent with your real world experience?

- A great deal
- A lot
- A moderate amount
- A little
- None at all

3- How real did the virtual world seem to you?

- Extremely unreal
- Somewhat unreal
- Neutral
- Somewhat real
- Extremely real

4- The virtual world seemed more realistic than the real world.

- Strongly disagree
- Somewhat disagree

- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Each item is rated on a 5-point scale as follows:

1	Strongly disagree	Extremely unreal	None at all	Extremely unaware
2	Somewhat disagree	Somewhat unreal	A little	Somewhat unaware
3	Neither agree nor disagree	Neutral	A moderate amount	Neutral
4	Somewhat agree	Somewhat real	A lot	Somewhat aware
5	Strongly agree	Extremely real	A great deal	Extremely aware

APPENDIX C. NEGATIVE AFFECT

Subject	NA (BIOPHILIC) IN-SITU	NA (NO BIOPHILIC) IN-SITU	NA (BIOPHILIC) VR	NA (NO BIOPHILIC) VR
person 1	13	10	10	11
person 2	22	28	10	13
person 3	11	12	12	11
person 4	11	12	11	11
person 5	10	10	10	10
person 6	12	11	11	11
person 7	10	10	11	10
person 8	11	15	12	15
person 9	11	12	17	22
person 10	11	15	11	14
person 11	11	20	13	33
person 12	10	10	10	10
person 13	10	10	13	13
person 14	10	10	10	10
person 15	13	13	11	15
person 16	11	10	12	12
person 17	10	14	10	10
person 18	11	11	14	14
person 19	14	16	14	11
person 20	11	17	13	16
person 21	17	16	23	25
person 22	10	10	10	10
person 23	10	10	13	13
person 24	10	10	11	11
person 25	12	11	11	11
person 26	10	10	10	10
person 27	15	16	14	14
person 28	12	11	10	12
person 29	11	11	11	12
person 30	12	13	12	16

APPENDIX D. POSITIVE AFFECT

Subject	PA (BIOPHILIC) IN-SITU	PA (NO BIOPHILIC) IN-SITU	PA (BIOPHILIC) VR	PA (NO BIOPHILIC) VR
person 1	18	10	14	13
person 2	26	22	40	40
person 3	21	16	22	16
person 4	17	18	28	24
person 5	20	20	25	22
person 6	20	19	18	17
person 7	19	18	19	23
person 8	26	28	30	24
person 9	22	22	26	25
person 10	23	18	22	13
person 11	40	22	34	18
person 12	27	24	23	23
person 13	22	23	29	29
person 14	40	37	33	34
person 15	21	18	27	19
person 16	34	30	33	31
person 17	36	32	31	29
person 18	43	45	47	43
person 19	31	31	41	42
person 20	36	35	34	38
person 21	30	25	29	26
person 22	21	14	19	16
person 23	24	16	26	33
person 24	15	12	13	11
person 25	37	32	32	38
person 26	28	28	26	27
person 27	18	13	23	29
person 28	31	32	37	37
person 29	47	26	47	28
person 30	34	31	41	41

APPENDIX E. WORKING MEMORY - (BIOPHILIC) IN-SITU

	C (BIOPHILIC) IN-SITU	CS (BIOPHILIC) IN-SITU	S (BIOPHILIC) IN-SITU	WM (BIOPHILIC) IN-SITU	WM % (BIOPHILIC) IN-SITU
person 1	17.00	14.00	14	45.00	75.00
person 2	18	17	13	48.00	80.00
person 3	18	17	18	53.00	88.33
person 4	18	18	14	50.00	83.33
person 5	17	15	13	45.00	75.00
person 6	18	18	16	52.00	86.67
person 7	20	19	12	51.00	85.00
person 8	19	19	15	53.00	88.33
person 9	19	17	14	50.00	83.33
person 10	19	19	15	53.00	88.33
person 11	18	19	12	49.00	81.67
person 12	19	19	11	49.00	81.67
person 13	20	18	17	55.00	91.67
person 14	17	16	13	46.00	76.67
person 15	19	20	15	54.00	90.00
person 16	19	17	15	51.00	85.00
person 17	16	14	16	46.00	76.67
person 18	14	19	11	44.00	73.33
person 19	18	14	12	44.00	73.33
person 20	19	17	14	50.00	83.33
person 21	19	17	18	54.00	90.00
person 22	18	18	17	53.00	88.33
person 23	18	17	16	51.00	85.00
person 24	20	18	18	56.00	93.33
person 25	18	20	13	51.00	85.00
person 26	19	19	17	55.00	91.67
person 27	20	19	17	56.00	93.33
person 28	17	16	13	46.00	76.67
person 29	18	18	15	51.00	85.00
person 30	19	20	17	56.00	93.33

APPENDIX F. WORKING MEMORY - (NO BIOPHILIC) IN-SITU

	C (NO BIOPHILIC) IN-SITU	CS (NO BIOPHILIC) IN-SITU	S (NO BIOPHILIC) IN-SITU	WM (NO BIOPHILIC) IN-SITU	WM % (NO BIOPHILIC) IN-SITU
person 1	18	13	15	46	76.67
person 2	18	15	14	47	78.33
person 3	16	14	13	43	71.67
person 4	18	16	12	46	76.67
person 5	19	14	12	45	75.00
person 6	20	18	18	56	93.33
person 7	19	20	11	50	83.33
person 8	16	14	13	43	71.67
person 9	18	20	12	50	83.33
person 10	18	18	11	47	78.33
person 11	19	18	13	50	83.33
person 12	17	19	13	49	81.67
person 13	20	20	15	55	91.67
person 14	19	16	12	47	78.33
person 15	19	20	15	54	90.00
person 16	19	16	12	47	78.33
person 17	15	16	16	47	78.33
person 18	18	17	13	48	80.00
person 19	19	14	13	46	76.67
person 20	17	15	16	48	80.00
person 21	18	15	15	48	80.00
person 22	15	17	14	46	76.67
person 23	20	18	17	55	91.67
person 24	19	19	17	55	91.67
person 25	17	19	12	48	80.00
person 26	19	19	16	54	90.00
person 27	19	18	14	51	85.00
person 28	18	19	11	48	80.00
person 29	17	17	14	48	80.00
person 30	17	19	18	54	90.00

APPENDIX G. WORKING MEMORY - (BIOPHILIC) VR

	C (BIOPHILIC) VR	CS (BIOPHILIC) VR	S (BIOPHILIC) VR	WM (BIOPHILIC) VR	WM % (BIOPHILIC) VR
person 1	17	16	12	45	75.00
person 2	19	20	18	57	95.00
person 3	17	15	16	48	80.00
person 4	18	17	13	48	80.00
person 5	15	16	9	40	66.67
person 6	18	19	15	52	86.67
person 7	18	19	14	51	85.00
person 8	18	17	13	48	80.00
person 9	19	17	15	51	85.00
person 10	19	18	11	48	80.00
person 11	17	16	16	49	81.67
person 12	18	17	14	49	81.67
person 13	16	18	17	51	85.00
person 14	16	18	14	48	80.00
person 15	20	18	13	51	85.00
person 16	18	15	14	47	78.33
person 17	16	18	14	48	80.00
person 18	15	16	14	45	75.00
person 19	16	17	18	51	85.00
person 20	15	18	12	45	75.00
person 21	18	17	12	47	78.33
person 22	14	20	17	51	85.00
person 23	19	15	16	50	83.33
person 24	19	20	15	54	90.00
person 25	19	19	10	48	80.00
person 26	17	20	13	50	83.33
person 27	19	20	13	52	86.67
person 28	18	19	13	50	83.33
person 29	18	19	16	53	88.33
person 30	20	19	16	55	91.67

APPENDIX H. WORKING MEMORY - (NO BIOPHILIC) VR

	C (NO BIOPHILIC) VR	CS (NO BIOPHILIC) VR	S (NO BIOPHILIC) VR	WM (NO BIOPHILIC) VR	WM % (NO BIOPHILIC) VR
person 1	13	16	14	43	71.67
person 2	14	19	13	46	76.67
person 3	14	19	13	46	76.67
person 4	19	18	15	52	86.67
person 5	18	19	11	48	80.00
person 6	19	19	15	53	88.33
person 7	18	20	13	51	85.00
person 8	14	19	13	46	76.67
person 9	19	20	11	50	83.33
person 10	19	19	14	52	86.67
person 11	15	16	15	46	76.67
person 12	17	18	17	52	86.67
person 13	17	14	15	46	76.67
person 14	17	14	16	47	78.33
person 15	20	20	15	55	91.67
person 16	17	14	16	47	78.33
person 17	16	16	15	47	78.33
person 18	12	14	16	42	70.00
person 19	18	16	13	47	78.33
person 20	18	14	15	47	78.33
person 21	19	17	12	48	80.00
person 22	15	18	14	47	78.33
person 23	16	16	15	47	78.33
person 24	20	19	17	56	93.33
person 25	17	19	13	49	81.67
person 26	20	19	16	55	91.67
person 27	19	17	14	50	83.33
person 28	17	19	12	48	80.00
person 29	15	18	16	49	81.67
person 30	20	19	20	59	98.33

APPENDIX I. IPQ - GENERAL

	General Biophilic	General% Biophilic	General No Biophilic	General% No Biophilic
person 1	5	100	4	80
person 2	4	80	4	80
person 3	2	40	3	60
person 4	4	80	4	80
person 5	4	80	4	80
person 6	3	60	4	80
person 7	2	40	3	60
person 8	4	80	4	80
person 9	5	100	5	100
person 10	3	60	3	60
person 11	3	60	2	40
person 12	3	60	5	100
person 13	3	60	2	40
person 14	3	60	3	60
person 15	3	60	2	40
person 16	4	80	4	80
person 17	2	40	3	60
person 18	3	60	4	80
person 19	3	60	2	40
person 20	5	100	5	100
person 21	4	80	3	60
person 22	3	60	4	80
person 23	4	80	4	80
person 24	4	80	4	80
person 25	4	80	5	100
person 26	4	80	5	100
person 27	3	60	2	40
person 28	5	100	3	60
person 29	3	60	3	60
person 30	4	80	3	60

APPENDIX J. IPQ - SPATIAL PRESENCE

	Spatial Presence Biophilic	Spatial Presence% Biophilic	Spatial Presence No Biophilic	Spatial Presence% No Biophilic
person 1	17	68	19	76
person 2	19	76	20	80
person 3	13	52	19	76
person 4	19	76	19	76
person 5	21	84	21	84
person 6	20	80	19	76
person 7	18	72	19	76
person 8	17	68	18	72
person 9	20	80	22	88
person 10	18	72	19	76
person 11	16	64	19	76
person 12	18	72	17	68
person 13	16	64	18	72
person 14	18	72	15	60
person 15	18	72	19	76
person 16	21	84	20	80
person 17	17	68	17	68
person 18	18	72	16	64
person 19	14	56	19	76
person 20	18	72	20	80
person 21	21	84	21	84
person 22	21	84	18	72
person 23	17	68	20	80
person 24	21	84	21	84
person 25	20	80	22	88
person 26	21	84	17	68
person 27	15	60	12	48
person 28	16	64	17	68
person 29	19	76	14	56
person 30	21	84	17	68

APPENDIX K. IPQ - INVOLVEMENT

	Involvement Biophilic	Involvement% Biophilic	Involvement No Biophilic	Involvement% No Biophilic
person 1	15	75	14	70
person 2	12	60	14	70
person 3	11	55	12	60
person 4	7	35	9	45
person 5	10	50	13	65
person 6	13	65	13	65
person 7	12	60	13	65
person 8	14	70	15	75
person 9	13	65	14	70
person 10	12	60	12	60
person 11	12	60	13	65
person 12	11	55	11	55
person 13	11	55	10	50
person 14	11	55	14	70
person 15	12	60	11	55
person 16	11	55	11	55
person 17	13	65	14	70
person 18	10	50	9	45
person 19	12	60	11	55
person 20	14	70	15	75
person 21	12	60	12	60
person 22	13	65	16	80
person 23	13	65	18	90
person 24	12	60	13	65
person 25	12	60	18	90
person 26	13	65	14	70
person 27	12	60	14	70
person 28	10	50	10	50
person 29	12	60	15	75
person 30	12	60	14	70

APPENDIX L. IPQ - REALNESS

	Realness Biophilic	Realness% Biophilic	Realness No Biophilic	Realness% No Biophilic
person 1	18	90	14	70
person 2	12	60	11	55
person 3	9	45	8	40
person 4	14	70	13	65
person 5	13	65	13	65
person 6	13	65	14	70
person 7	10	50	9	45
person 8	14	70	13	65
person 9	13	65	14	70
person 10	13	65	13	65
person 11	10	50	9	45
person 12	13	65	14	70
person 13	8	40	6	30
person 14	11	55	9	45
person 15	13	65	13	65
person 16	10	50	12	60
person 17	13	65	9	45
person 18	12	60	13	65
person 19	6	30	9	45
person 20	15	75	19	95
person 21	12	60	13	65
person 22	15	75	15	75
person 23	12	60	14	70
person 24	13	65	13	65
person 25	13	65	16	80
person 26	14	70	12	60
person 27	9	45	6	30
person 28	16	80	10	50
person 29	13	65	10	50
person 30	15	75	14	70

APPENDIX M. LF HEART RATE

Subject	LF (BIOPHILIC) IN-SITU	LF (NO BIOPHILIC) IN- SITU	LF (BIOPHILIC) VR	LF (NO BIOPHILIC) VR
person 1	65.90%	65.80%	68.60%	68.30%
person 2	61.00%	65.80%	68.60%	68.30%
person 3	70.90%	54.00%	68.20%	68.90%
person 4	51.10%	55.40%	70.30%	57.30%
person 5	63.10%	68.40%	45.30%	49.00%
person 6	53.60%	53.00%	83.40%	84.10%
person 7	75.10%	73.60%	77.80%	73.30%
person 8	75.60%	86%	87.20%	79.80%
person 9	56.20%	32.80%	56.20%	51.10%
person 10	45.10%	38%	59.70%	40.20%
person 11	54.60%	44.20%	54.60%	44.20%
person 12	63.80%	27.50%	66.50%	35.70%
person 13	58.70%	54.50%	58.20%	68.30%
person 14	86.40%	79.20%	86.40%	79.20%
person 15	90.40%	86.10%	69.70%	74.60%
person 16	50.00%	44%	27.90%	48.00%
person 17	77.30%	21%	56.60%	66.10%
person 18	23.50%	49.50%	56.60%	66.10%
person 19	55.30%	56%	56.40%	52.00%
person 20	86.10%	88.00%	80.50%	82.30%
person 21	72.20%	78.10%	78.70%	82.30%
person 22	58.10%	64.70%	80.00%	91.30%
person 23	34.40%	60.10%	38.60%	52.00%
person 24	49.70%	35%	34.70%	35.70%
person 25	56.10%	77%	34.70%	35.70%
person 26	76.90%	78%	78.80%	43.90%
person 27	34.60%	69%	56.30%	66.40%
person 28	90.50%	90.60%	87.20%	83.40%
person 29	54.60%	41.50%	43.50%	46.60%
person 30	71.90%	58.10%	45.30%	72.90%

APPENDIX N. IRB FORM

ACTION ON PROTOCOL APPROVAL REQUEST



Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu
lsu.edu/research

TO: Yimin Zhu
Construction Management

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: October 30, 2018

RE: IRB# 4138

TITLE: Design and Engineering for Human Wellbeing: Understanding the Potential of Immersive Virtual Environments (IVEs) for Biophilic Design

New Protocol/Modification/Continuation: New Protocol

Review type: Full ☐ Expedited ☒ **Review date:** 10/29/2018

Risk Factor: Minimal ☒ Uncertain ☐ Greater Than Minimal ☐

Approved ☒ **Disapproved** ☐

Approval Date: 10/30/2018 **Approval Expiration Date:** 10/29/2019

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 35

LSU Proposal Number (if applicable): 48052

By: Dennis Landin, Chairman 

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: When emailing more than one recipient, make sure you use bcc.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at <http://www.lsu.edu/irb>*

APPENDIX O. INFORMED CONSENT

CONSENT TO PARTICIPATE IN THE RESEARCH STUDY (INFORMED CONSENT)

1- Title of Study: Design and Engineering for Human Wellbeing: Understanding the Potential of Immersive Virtual Environments (IVEs) for Biophilic Design

We give you this consent form so that you may read about the purpose, risks and benefits of this research study.

- The main goal of a research studies is to collect data that may help to validate the effectiveness of Immersive Virtual Environments (IVE) in replicating Biophilic Architectural Design
- You have the right to refuse to take part, or agree to take part now and change your mind later on.
- Please review this consent form carefully and ask any questions before you make a decision.
- Your participation is voluntary.
- By signing this consent form, you agree to participate in the study as it is described.

2- Investigators:

The following investigator will be available for questions about this study:

Principal Investigator: Dr. Yimin Zhu, Ph.D.
Phone: (225)578-5373
Email: yiminzhu@lsu.edu

Co-Investigators: Sanaz Saeidi, PhD. Candidate
Phone: (225)573-2510
Email: ssaeidl@lsu.edu

Asalsadat Emamjomeh, Graduate Student
Phone: (760)580-4779
Email: aemamj1@lsu.edu

Asalsadat Emamjomeh will take care of conducting the experiments. We expect about 35 participants will be enrolled in this pilot study. The study will take place over a period of 2 visits.

3- Performance Site:

This study will take place at Louisiana State University-Baton Rouge Campus, Patrick F. Taylor Hall.

4- Purpose of the Study:

This study aims at investigating Biophilic design in IVE platforms, and figuring out if they have similar impact on participants as in similar *in-situ* cases. The biophilic design features in the experimental settings will be laid down through natural elements exposure. This research will

quantify your physiological and cognitive responses while being exposed to the natural patterns of Biophilic design in IVEs and will compare those measures to the equivalent *in-situ*.

5- Participant Inclusion:

Study staff will discuss with you the requirements for participation in this study. It is important that you are completely truthful with the staff about your health history. You should not participate in this study if you do not meet all the qualifications.

You are eligible for this study if you are:

- Capable and willing to give written informed consent, understand exclusion criteria and accept the randomized assignment
- Male or female age 18-35 years
- Healthy (no uncontrolled health problems)

You are **NOT eligible** for this study if you have any of the following conditions:

- Any type of uncontrolled physical health disorder (controlled = 6 months of medication)
- Mental illness within the past 5 years or currently undergoing treatment for any kind of mental illness.
- Severe headaches, migraine, eye strain, nauseous,
- Any other medical, psychiatric or behavioral factors that in the judgment of the Principle Investigator that may interfere with study participation or the ability to follow the protocol

6-Study Procedures:

The pilot study for which you are volunteering will take about 2 weeks to complete and will include 2 main phases:

- Recruitment and Screening, Trial 1, performing the experiment in a physical setting (In-situ)
- Trial 2, performing the experiment in an Immersive Virtual Environment (IVE)

Recruitment and Screening

At the first visit, the informed consent will be explained to you by our study staff and procedures are performed. If you choose to sign the informed consent, the following tests and procedures will be performed. If the inclusion criteria is met, the pre-experiment questionnaires will be administered, questions about the below items will be asked:

- Demographics
- Immersive Tendencies

Trial 1 and 2

The consent form will be read to you and your signature will be obtained. The research assistant will also sign and date the form. Every participant will perform both the experiments of the physical setting (*in-situ*) and the Immersive Virtual Environment (IVE). To minimize the order effect, the two trials will be randomized. That is, half of the participants will perform the IVE test in their first visit, and the *in-situ* test in their second visit. While the other half will do the *in-situ* test in their first visit, and the IVE test in their second visit. The test will be started by device set up (i.e. Heart rate sensor, GSR sensor) and a short orientation. The purpose of the orientation

process is to let you become familiar with the experimental setting, content, and the instruments. Once ready, you will be asked to be seated on a chair and explore the room in which the experiment is happening (for about 5 minutes). The *in-situ* experiment will occur at two different locations, one with the biophilic design pattern and one without any biophilic feature. After each exposure you will be asked to complete some questionnaires (i.e. PANAS, and short memory). On your next visit, you will be asked to put on virtual reality (VR) headset (if the previous visit was an *in-situ*) and explore an IVE setting which has biophilic design, for about 5 min. Then, you will be asked to take off the VR headset and complete the same questionnaires as in the *in-situ* test. Next, an IVE which does not have a biophilic design will be demonstrated through the VR headset and same questionnaires will be administered. In addition to randomizing the *in-situ* and IVE trials, the exposure to the biophilic environment and non-biophilic environment will also be randomly assigned to the participants. Figure 1 summarizes the steps of each trial and the approximate time each step will take.

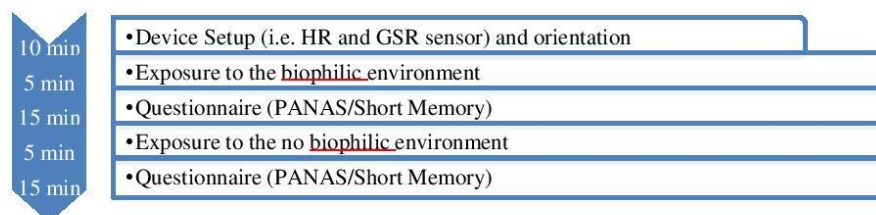


Figure 1. Steps of each trial of the experiment

7- Risks/Discomforts:

Using the head mounted display might pose some physical risks such as disorientation, dizziness, eyestrain, nausea and headache, however, risks in this experiment will be the minimum possible because the test duration will not last longer than few minutes and the players' movements are entirely controlled. Besides, all the participants will take some time to become adapted with the virtual environment and the equipment and those who are not comfortable with the IVE setting, will be excluded from the experiment.

8- Benefits:

We cannot promise any benefits from your being in the study. However, you can acquire some knowledge in a recent technology, IVE, and its great potential and contribution to various fields of study such as, health care, science, education and engineering.

9-Alternatives to Participation:

There are no alternatives to the study described in this consent. You have the choice at any time not to participate in this research study. If you choose not to participate, any benefits to which you are entitled will not be affected in any way.

10- Injury/Illness or Questions:

If you have any questions about your rights as a research volunteer, you should call Dr. Dennis Landin, Institutional Review Board Office at 225-578-8692. If you have any questions about the

research study or think you have a research-related injury or medical illness, contact Dr. Yimin Zhu, at 225-578-2453 during regular working hours.

11-Privacy:

No personally identifiable information (like the name and address of the subjects) will be collected through the use of questionnaire and interview. Once the survey data has been input into an electronic database, the original survey forms will be destroyed along with any information linking the electronic data with the original survey.

12-Early Study Withdrawal:

You can be withdrawn from the study for any reason or for no reason. You may withdraw from the study at any time without penalty. Possible reasons for withdrawal include injury, the presence of an old or existing injury that may be deemed risky, sufficient medical history deemed too risky for testing. The sponsor of the study may end the study early.

13-Additional Information:

During the other research that may affect your willingness to continue participation. Information concerning any such new findings will be provided to you.

14-Charges for Participation:

None

15-Payments for Participation:

There is no payment for participation in the study.

16- Compensation for study-related injury or medical illness:

No form of compensation for medical treatment or for other damages (i.e., lost wages, time lost from work, etc.) is available from Louisiana State University. In the event of injury or medical illness resulting from the research procedures in which you participate, you will be referred to a treatment facility. Medical treatment may be provided at your own expense or at the expense of your health care insurer (e.g., Medicare, Medicaid, Blue Cross-Blue Shield, Dental Insurer, etc.) which may or may not provide coverage.

17- Signatures:

The study has been discussed with me and all my questions have been answered. I understand that additional questions regarding the study should be directed to the study investigators. I agree with the terms above and acknowledge that I have been given a copy of the consent form.

Printed Name of Volunteer _____

Signature of Volunteer _____

Date _____

Date of Birth of Volunteer _____

Signature of Person Administering Informed Consent _____

Date _____

Version Date 10/25/2018

Volunteer's initials _____

VITA

Asal Sadat Emamjomeh was born in Tehran, Iran. She moved to the United States in 2010. She started Architecture school at Louisiana State University in 2012. She obtained her Bachelor's degree in Architecture in 2016. Later, she decided to pursue higher education and was accepted into Master of Science in Construction Management program at Louisiana State University. While she was graduate student, she worked in three architecture firms; Coleman Partners Architects, O'Brien Hughes Architects, and Coleman Brown Architects. She became interested in sustainable design and potential of virtual reality in design phase. She conducted a research about the potential of Immersive Virtual Environment for Biophilic Design for her master research. She plans to apply her knowledge in the construction and architecture industry.