ARCHITECTURE WITH AESTHETICS: MEASURING PSYCHOLOGICAL AND NEURAL RESPONSES TO CURVED ARCHITECTURAL BOUNDARIES

A Ph.D. Dissertation

by

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Ankara
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The Graduate School of Economics and Social Sciences

of

İhsan Doğramacı Bilkent University

by

TUĞÇE ELVER BOZ

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DOCTOR OF PHILOSOPHY IN INTERIOR ARCHITECTURE AND ENVIRONMENTAL DESIGN

THE DEPARTMENT OF
INTERIOR ARCHITECTURE AND ENVIRONMENTAL DESIGN
İHSAN DOĞRAMACI BİLKENT UNIVERSITY
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I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy in Interior Architecture and Environmental Design.

…………………………………..
Halime Demirkan
Advisor

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Burcu A. Ürgen
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Yasemin Afacan
Examining Committee Member

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ABSTRACT

ARCHITECTURE WITH AESTHETICS:

MEASURING PSYCHOLOGICAL AND NEURAL RESPONSES

TO CURVED ARCHITECTURAL BOUNDARIES

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Ph.D., Department of Interior Architecture and Environmental Design

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June 2024

This interdisciplinary study, covering neuroscience and architecture, conducted a systematic, empirically-directed qualification of human aesthetic experience and explored the effects of architectural spatial characteristics on human aesthetic experience. The first phase of the study was a comprehensive framework for studying and characterizing the aesthetic experience of spaces with curvilinear boundaries (horizontal and vertical) and specific properties (different levels of size, light, texture, and color) in virtual reality environments. A wide list of scales widely used in literature was then compiled, where participants evaluated the spaces and identified the core components of the aesthetic judgments. The findings showed that human aesthetic judgments consist of three primary components: ‘familiarity,’ ‘excitement,’ and ‘fascination.’ Each of these components is influenced by various architectural features that reveal their differences. In the second phase of the study, spaces with inclined architectural boundaries and specific properties, known as architecture variables, were designed as a whole, and the three primary aesthetic judgments in both immersive virtual environment and desktop-based virtual environment were studied. In two virtual environments, the subjects assessed how much they felt inside the space present. At this stage, the objective is to test the basic components of aesthetic judgments in spaces designed as a whole, such as places perceived in real life, and to reference to the third research stage. In the third and final phase of the study, the three primary aesthetic judgments in space with architectural variables by electrical monitoring of brain wave activity (EEG) and brain neural relationships were investigated. The results show that alpha and beta waves distinguish space with architectural variables, but do not distinguish theta waves. The study is a collaborative study in the fields of architecture and neuroscience, which provides a new contribution to the literature regarding the methods used and the research questions it tries to answer.

Keywords: Aesthetic Judgments, Architectural Boundaries, Neuro-architecture, Virtual Environment

ÖZET

ESTETİK İLE MİMARLIK:

EĞİMLİ MİMARİ SINIRLARDA PSİKOLOJİK VE NÖRAL TEPKİLERİN ÖLÇÜLMESİ

Elver Boz, Tuğçe

Doktora, İç Mimarlık ve Çevre Tasarımı Bölümü

Tez Danışmanı: Prof. Dr. Halime Demirkan

2. Tez Danışmanı: Dr. Öğr. Üyesi Burcu A. Ürgen

Haziran 2024

Nörobilim ve mimariyi kapsayan bu disiplinler arası çalışmada, insan estetik deneyimini ampirik olarak yönlendiren sistematik bir nitelendirilmesi yapılmış ve mimari mekân özelliklerinin insan estetik deneyimi üzerindeki etkileri araştırılmıştır. Çalışmanın ilk aşaması, sanal gerçeklik ortamında eğimli (yatay ve dikey) mimari sınırları ve belirli mimari özellikleri olan (farklı düzeyde boyut, ışık, doku ve renk) mekanlar incelenerek, estetik deneyimin nitelendirilmesi için kapsamlı bir çerçeve oluşturulmuştur. Ardından literatürde yaygın olarak kullanılan ölçeklerden oluşan geniş bir liste derlenerek, estetik deneyimin temel bileşenleri saptanmıştır. Bulgular,

insan estetik deneyiminin ‘aşinalık’, ‘heyecan verici’, ve ‘etkileyici’ olmak üzere üç temel bileşenden oluştuğunu göstermiştir. Bu bileşenlerin her biri, farklılıklarını ortaya çıkaran çeşitli mimari özelliklerden etkilenmektedir. Çalışmanın ikinci aşamasında, mimari değişkenler adı verilen eğimli mimari sınırlara sahip ve çeşitli mimari özellikler içeren mekanlar bir bütün olarak tasarlanarak, hem sürükleyici hem de masaüstü bilgisayar tabanlı sanal ortamlarda estetik deneyimin üç temel birleşeni incelenmiştir. İki sanal ortamda deneklerin kendilerini mekan içerisinde ne kadar var hissettikleri değerlendirilmiştir. Bu aşamada gerçek yaşamda algılanan mekanlar gibi, bir bütün olarak tasarlanmış mekanlarda estetik deneyimin temel bileşenlerinin test edilmesi ve üçüncü araştırma aşamasına referans sağlaması hedeflenmiştir. Çalışmanın üçüncü ve son aşamasında, beyin dalgaları aktivitesinin elektriksel yöntemle izlenmesiyle (EEG) mimari değişkenlere sahip mekanlarda, estetik deneyimin üç temel birleşeni ve beyin sinirsel ilişkileri araştırılmıştır. Sonuçlar, alfa ve beta dalgalarının mimari değişkenlere sahip mekanlar üzerinde ayırt edildiğini, ancak theta dalgaları üzerinde ayırt edilmediğini göstermektedir. Yapılan çalışma, mimarlık ve nörobilim alanlarında iş birliği içerisinde yürütülen bir çalışma olarak, kullanılan metotlar ve cevaplamaya çalıştığı sorular açısından literatüre yeni bir katkı sunmuştur.

Anahtar Kelimeler: Estetik Değerler, Mimari Sınırlar, Nöro-mimari, Sanal Ortam

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LIST OF ABBREVIATIONS

DTVE	Desktop Computer Virtual Environment
EEG	Electroencephalogram
fMRI	Functional Magnetic Resonance
HB	Horizontal Boundaries
HMD	Head Mounted Display
IVE	Immersive Virtual Environment
PC	Principal Component
PQ	Presence Questionnaire
RE	Real Environment
SLTC	Size, Light, Texture, and Color
VB	Vertical Boundaries
VE	Virtual Environments
VR	Virtual Reality

CHAPTER 1

INTRODUCTION

Humans typically allocate around 90% of their daily routines within built environments characterized by enclosure, engaging in close and direct interactions with those physical areas (Vartanian et al., 2013). Until now, most cognitive science research has concentrated on how humans view and engage with the individuals and objects inside structures (DiCarlo et al., 2012) instead of focusing on the buildings themselves. An increasing corpus of research explores people's aesthetic judgments in built spaces and bridges the fields of architecture and cognitive science (Chatterjee & Vartanian, 2014; 2016). An aesthetic perception refers to a collection of emotional and cognitive reactions triggered by the characteristics of a designed environment that lead to conduct driven by action (Schubert et al., 2016).

The thesis discusses several empirical and theoretical investigations that aim to define the primary aesthetic judgment components of humans in their architectural surroundings. The researcher analyzes the primary characteristics of architectural environments and their impact on aesthetic judgments. In conclusion, the research elucidates the constraints of prior studies. It presents an exhaustive structure for defining the aesthetic judgment inside the constructed world, accentuating some of its most significant attributes. The study was also conducted on various architectural environments in different virtual reality (VR) environments to test the main aesthetic components that were found to be primary dimensions of aesthetic judgments. As a result, the impact of spaces with architectural variables on human perception and different VR environments on people was thoroughly analyzed. In addition, the study brought the research on architectural sites to a more comprehensive dimension by studying the neural foundations.

1.1. Problem Statement

Many research studies focused on analyzing human aesthetic perception in constructed spaces utilize individual ratings or scales to alter different aspects of the architectural environment (Osgood et al., 1957). These studies provided valuable insights into people's experiences in these environments, but they lacked a comprehensive understanding of aesthetic judgments due to their reliance on a limited number of rating scales for assessing architectural stimuli. They concentrated on only a limited number of areas within the realm of aesthetic measurement. Conversely, research indicates that aesthetic judgments are intricate and encompass various dimensions, such as cognitive, emotional, and behavioral aspects. What framework, considering the variables of the architectural surroundings, is proposed?

After examining the effect of certain architectural variables of space on aesthetic judgments, the thesis aims to enhance existing spaces and to be a reference for future designs. Since human beings spend most of their time in enclosed spaces, designing and organizing these spaces according to their aesthetic judgments is significant for improving the quality of life and understanding the behavioral and neurological bases of their aesthetic perception. This thesis makes contributions to the fields of neuro-architecture and neuro-aesthetics as an interdisciplinary study of neuroscience, psychology, and architecture. This research examines how different architectural variables impact human aesthetic judgments and methodically describes it in space properties with curved boundaries. Also, the study uses neuroimaging techniques to look into the brain underpinnings of aesthetic judgments while subjects experience architectural settings.

1.2. Aim and Scope of the Thesis

The main objective of the present thesis is to suggest an aesthetic framework that considers the characteristics of the architectural surroundings. Secondly, the thesis seeks to shed light on the ways in which different built environment properties combine to influence human aesthetic judgments. A third aim of the thesis is to demonstrate which part of the neural correlates is related to the presented architectural environment and how. The thesis mainly contributes to the interdisciplinary work between neuroscience and architecture. The objective of the thesis is to demonstrate architectural variables that evoke human behavioral responses and their neural bases within the scope of aesthetic assessments in a virtual environment (VE) as follows, as shown in Figure 1.

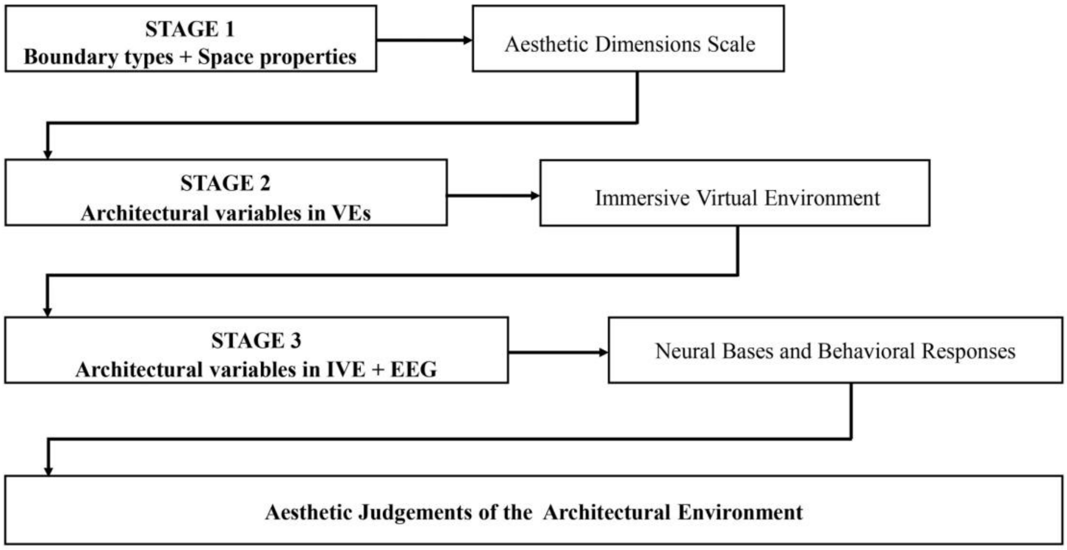


Figure 1. Conceptual framework of the thesis (drawn by the author, 2024).

- The thesis examines curved boundaries and specific space properties systematically. The rationale behind investigating the curved boundaries with space properties lies in the fact that individuals typically allocate a significant portion of their time within built environments, engaging closely with the internal spaces (Stage 1).
- The thesis compiles the relevant aesthetic adjectives from the literature and includes them in this research. This research introduces a framework focused on aesthetic judgments in the built environment, incorporating psychological aspects. The influence of interior spaces on human psychology can be assessed through the utilization of the aesthetic judgment scale. These aesthetic adjectives can be used

in studies of different boundary types and space properties. However, this research examines the boundary type as curved horizontal boundaries (HB) and vertical boundaries (VB) and the space properties as size, light, texture, and color (SLTC). Accordingly, the aim is to understand how people perceive the interior space as having curved boundaries and space properties within the scope of aesthetic assessments in a VE (Stage 1).

- According to the literature on aesthetic evaluations, it is highlighted as a multi-dimensional phenomenon. Hence, the study (stage 1) needs dimension reduction to measure this phenomenon comprehensively in the neuroimaging study as the 3rd stage. Numerous adjective scales cannot be tested simultaneously in neural studies; the research generated the primary aesthetic judgments absent from the literature and added to the third stage. (Stage 1)
- The curved boundaries and space properties are examined separately in the 1st stage, and the study examines the new architectural variables (curved boundaries + space properties) investigated in the 2nd stage. Accordingly, the 2nd stage investigates the primary aesthetic judgments and the similarities and differences between the study's first and second stages in the VR environment field. In this stage, the study investigates how aesthetic judgements change as a function of curved boundaries and space properties when combined rather than in isolation (Stage 2).
- Also, architectural variables were investigated in immersive virtual environments (IVE) and desktop computer virtual environments (DTVE) to understand the relationship between immersive and non-immersive VEs relationship (Stage 2).

- Besides, in order to conduct the 3rd stage methodology, in the 2nd stage, the study examines IVE and DTVE presence scores in terms of aesthetic judgments. Deciding to use functional magnetic resonance imaging (fMRI) or electroencephalogram (EEG) instruments in the 3rd stage depends on the result of the 2nd stage presence score.
- The thesis delves further into the psychology of architecture to develop a stronger foundation for future research on the neuroscience of architecture (Stage 3).
- The relationship between neural correlates of interest (theta, alpha, and beta waves) and architectural variables was investigated to understand the neural reactions of the built environment (Stage 3).
- The thesis examines the representational properties of neural correlates involved in the scene's visual perception. In particular, the stage would investigate the theta, alpha, and beta waves code for architectural variables (Stage 3).
- There is an emerging "neuroscience of architecture" that promises an empirical foundation for investigating the experiential components of architecture that have been mostly ignored in modern building science.

The doctoral thesis was supported by TÜBITAK (see Appendix A). The first part of the study was also published as an article.

Elver Boz, T., Demirkan, H., & Urgen, B. A. (2022). Visual perception of the built environment in virtual reality: A systematic characterization of human aesthetic experience in spaces with curved boundaries. *Psychology of Aesthetics, Creativity, and the Arts.* https://doi.org/10.1037/aca0000504

1.3. Structure of the Thesis

The thesis was arranged in the following manner. In Chapter 2, the aesthetic perception in architectural environments was given with grounded theory. First, the components of aesthetic measurement literature were categorically described. Then, the idea of aesthetic and neuroscience literature was explored. Subsequently, the concept of VR for neurological architectural research was studied in light of the work being done.

In Chapter 3, the significance of the curvilinear form was supported by literature interpretations. The shape of the space boundaries was analyzed using various architectural settings. In this thesis, the properties of architectural variables were determined using the curved form of boundaries. The various space properties of the architectural surroundings were investigated with the SLTC parameters. VR was introduced as an architectural design support tool as a prelude.

In Chapter 4, the conceptual framework of the thesis was formed with three methodological stages. The stages of the thesis were explained in detail, and they were interrelated. In light of the aim of the stages, the research questions, participants, environmental stimuli, instruments and procedures, data analysis, results, and discussion of the related stages were presented.

In Chapter 5, the discussion of the three stages and the interpretation of the stage's relationships are conducted. Behavioral and neural data were gathered, and inferences were made.

In Chapter 6, the conclusion of the thesis is mentioned as a general summary of the thesis. It was followed by contributions to the thesis, implications of architectural and psychological aspects, limitations, and suggestions for further research.

CHAPTER 2

AESTHETICS, ARCHITECTURE, AND NEUROSCIENCE

This chapter describes the evolutionary process of aesthetic judgments over architecture. The concept of architectural aesthetics has emerged, and how it has been approached by researchers. Results from previous studies have been associated with contextual concepts. Also, the chapter investigates the role of neuroscience in providing a basic understanding of perception in architectural surroundings. This interdisciplinary study focuses on establishing environments that facilitate the advancement of individuals in the realms of psychology and behavior. Through, rapidly evolving area of neuroscience has grown to be a significant component of neurology. This section describes how neuro-architecture has become an experimental knowledge, the concept of neuro-aesthetics, and the neuro-architectural studies used with emerging technology.

2.1 The Aesthetic Perception in Architectural Surroundings

According to Roman architect Vitruvius, two millennia ago, beauty was one of the three fundamental elements of architectural design. As to Vitruvius et al.'s (1914) breakthrough Vitruvian trinity, a building needs to fulfill three requirements for its users: it should be sturdy and structurally safe (firmitas), service its users' utilitarian needs (utilitas), and satiate their aesthetic perceptions (venustas) (Morgan, 2010). The great attention this topic has received throughout history and culture is indicative of the widespread perception that the building's aesthetic attributes have a significant affect on the human encounters.

Plenty of studies conducted in the early 1900s revealed that people's perceptions of architecture's aesthetic value had a significant influence on their emotional states, cognitive abilities, and behavioral patterns (Adams, 2014; Cooper et al., 2014; Gifford, 2002; Hartig, 2008; Joye, 2007). Several theoretical models have been put forth to describe aesthetic experience in architectural environments. The following is how Leder et al. (2004) defined the five stages of aesthetic experience based on their psychological model: 1) perception, 2) explicit classification, 3) implicit classification, 4) cognitive mastery/interpretation, and 5) evaluation. The connection between emotions and aesthetic experience is notably highlighted in this concept, wherein emotions are the foundation of the aesthetic experience, the former phenomenon emerges as a consequence of affective and emotional conditions (see Figure 2).

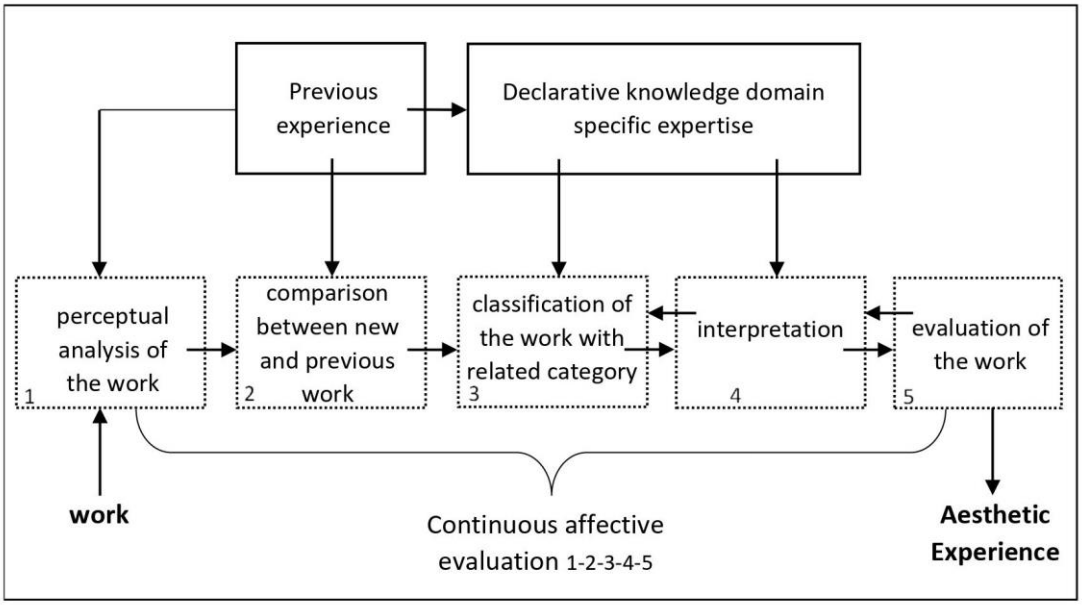


Figure 2. Schematic model of aesthetic experience (adapted from Leder et al., 2004: 492).

In line with Leder et al. (2004), Hekkert (2006) proposes that affective assessment is comprised of two processes: an automatic process that is mapped to stages 1, 2, and 3 of Leder et al. (2004) model and entails deciding whether an item is novel or well-known, as well as a cognitive-emotional process that involves the dominance of cognitive and emotional processes over the experience. These processes are linked to stages 3, 4, and 5 of Leder et al.'s (2004) model. It is thought that aesthetic sensations are produced when these two processes come together.

In order to give a more comprehensive framework for the topic, Chatterjee and Vartanian (2014) build on these prior studies by putting out an *aesthetic triad model* of architectural experience. This paradigm states that there are three basic components that make up an individual's perception of aesthetics in the built environment, each of which corresponds to a different brain system. Stages 3, 4, and 5 are believed to be connected to Leder et al.'s (2004) psychological model of aesthetic evaluation. As stated by Chatterjee and Vartanian (2014), these components include *knowledge-meaning, emotion-valuation, and sensory-motor.* This methodology's knowledge-meaning component is impacted by personal experiences, education, exposure to the constructed world, and cultural experiences. It is hypothesized that the *emotion-valuation* factor influences the feelings and emotions that urban environments and architectural design evoke (Leder et al., 2004). The visual, auditory, somatosensory, olfactory, and vestibular systems are thought to be stimulated by the *sensory-motor* component, which also elicits motor responses (approach-avoidance) (Chatterjee & Vartanian, 2014, 2016).

Coburn et al. (2020) build upon the Chatterjee and Vartanian (2014) aesthetic triad model, incorporating three significant areas of information processing associated with the three components in this model: *behavior* about the sensorimotor system, *cognition* about the knowledge-meaning element, and *emotion* about the emotion-valuation component. The empirical studies that address each of these aspects of information processing and assess aesthetic perception on various scales are discussed below, considering the three components of human aesthetic evaluations.

2.1.1. Cognitive Responses

Upon entering a building, people typically form an initial cognitive judgment of the area. People make cognitive judgments, or top-down assessments, of the external characteristics of their environment rather than reflecting on their interior states. The difference is based on extrospective and introspective judgments, which are expected to include dissociable neural circuitry, according to Coburn et al. (2017).

The initial part of the aesthetic perception consists of cognitive judgments, which are considered congruent with the initial evaluation of the external features of the architectural surroundings. Put another way, the goal of tackling the cognitive component of aesthetic perception is to respond to the query, *"How does the architectural space look?"*. Devlin and Nasar (1989) divided cognitive architectural assessments into interpretive and affective assessments. To characterize these ratings, they ranked the architectural places according to safety, femininity, mystery, and complexity attributes.

Lang (1992), who concentrates on the cognitive part of aesthetic perception, classifies the assessment factors into three categories: *affective, formal*, and *symbolic*. Affective factors quantify an architectural feature's level of aesthetic appeal or stimulation. Conversely, the formal elements assess the architectural surrounding's complexity (e.g., how complicated the surroundings look?), rhythms, forms, and visual word sequences. Lastly, the symbolic elements assess the setting's associational meanings, such as how enigmatic or safe the architectural surroundings appear.

Russell (1992), following Lang (1992), divides the affective variables into two primary categories: pleasantness and arousal. People were asked to score how interesting or relaxing they believed the surroundings looked in several empirical research (Cetintahra & Cubukcu, 2014; Hanyu, 2000; Nasar 1983, 1992a, 1992b, 1992c, 1992d; Nasar et al., 1992; Russell, 1992). Parallel to Lang (1992), Nasar (1998) suggests the two primary semantic scales of coherence and complexity to describe the formal factors. Numerous research works have examined the impact of complexity and coherence on the aesthetic experience of surroundings (Cetintahra & Cubukcu, 2014; Hanyu, 2000; Kaplan, 1992; Nasar, 1992a, 1992c) and have discovered that these two semantic scales differ significantly about space size, shapes, and attributes. Moreover, several studies considered safety a symbolic variable (Cetintahra & Cubukcu, 2014; Hanyu, 2000; Kaplan & Kaplan, 1989; Nasar et al., 1992; Nasar, 1992c).

2.1.2. Emotional Responses

Architectural surroundings can change and impact emotions and other inner states of being (Coburn et al., 2017). Alexander (2002) emphasized the importance of evaluating a building by looking at how much it "touches us in our humanity" (Alexander, 2002, p. 300) and "stirs our feelings, our passion" (Alexander, 2002, p. 302) in addition to evaluating it based on an objective examination of its appearance. According to Hekkert (2006), states that the definition of the product experience is “the entire set of effects that is elicited by the interaction between a user and a product, including the degree to which all our senses are gratified (aesthetic perception), the meanings we attach to the product (experience of meaning), and the feelings and emotions that are elicited (emotional experience)” (p.160).

The second part of the aesthetic encounter is characterized by the sentiments and psychological responses that may be elicited in a person by the tangible characteristics of a setting. In other words, the emotional aspect of the aesthetic perception is tackled by responding to the question, *"How does the architectural space make me feel?"*. Emotion is defined by Mehrabian and Russell (1974) as pleasure and arousal. Thus, the key to comprehending aesthetic evaluation is determining how content or aroused a person is in a certain setting. Mehrabian and Russell (1974) asserted that facial expressions (e.g., frowning and smiling) convey pleasure. Human behavior and alertness, including skin reactions, are indicators of arousal (Mehrabian & O'Reilly, 1980).

2.1.3. Behavioral Responses

The psychological evaluations of motivation, movement, and behavior linked to the brain's sensorimotor processing comprise behavioral reactions (Coburn et al., 2017). The aesthetic perception's final aspect is conduct, measured by scales that characterize behavioral objectives and approach-avoidance patterns. These behaviors are occasionally referred to as dominance patterns, according to Mehrabian and O'Reilly (1980). For example, Russell and Mehrabian (1977) discovered that an environment's capacity to arouse strong emotions in people affects their attitudes toward it. Russell (1992) illustrates in a similar way how people's reactions to an environment are influenced by its emotive quality.

The aesthetic adjectives from earlier research are displayed in Table 1, along with their domains and sources.

Table 1. In each domain of the aesthetic adjectives and the relevant literature sources.

Source	Domain	Aesthetic Experience
Devlin & Nasar (1989) Lang (1992) Russell (1992)	**Affective**	Sleepy-Arousal, Unpleasant-Pleasant, Gloomy-Exciting, Distressing-Relaxing
	Formal	Simple-Complex, Incoherent-Coherent
	Symbolic (Interpretive)	Unsafe-Safe, Nonmysterious-Mysterious, Masculine-Feminine
Mehrabian and Russel (1974) Russell & Mehrabian (1977)	**Pleasure**	Annoyed-Pleased, Unhappy-Happy, Bored-Relaxed, Unsatisfied-Satisfied, Melancholic-Contended, Despairing-Hopeful
	Arousal	Unaroused-Aroused, Calm-Excited, Sluggish-Frenzied, Dull-Jittery, Sleepy-Wide awake, Relaxed-Stimulated
	Dominance	Prefer to live, Like to spend time, Enjoy exploring, Feel friendly and talkative

Table 2 shows how the study's triad model was first designed by Chatterjee and Vartanian (2014) and expanded by Coburn et al. (2020), which assumed that these aesthetic adjectives would be classified as cognition, emotion, and behavior.

Table 2. The components related to aesthetic measures with low-high values.

Domain	Aesthetic scale	Low	High
Cognition (thought; space looks; how … is it)			
Affective	Arousing	sleepy	arousing
	Pleasant	unpleasant	pleasant
	Exciting	gloomy	exciting
	Relaxing	distressing	relaxing
Formal	Complex	simple	complex
	Coherent	incoherent	coherent
Symbolic	Safe	unsafe	safe
	Mysterious	not mysterious	mysterious
	Feminine	masculine	feminine
Emotion (feelings; space makes me feel)			
Pleasure	Pleased	annoyed	pleased
	Happy	unhappy	happy
	Relaxed	bored	relaxed
	Satisfied	unsatisfied	satisfied
	Contended	melancholic	contended
	Hopeful	despairing	hopeful
Arousal	Aroused	unaroused	aroused
	Excited	calm	excited
	Frenzied	sluggish	frenzied
	Jittery	dull	jittery
	Wideawake	sleepy	wideawake
	Stimulated	relaxed	stimulated
Behavior (interactions; behavioral intentions)			
Dominance	Prefer to live	How much would you prefer to live this place?	
	Like to spend time	How much time would like to spend in this space?	
	Enjoy exploring	How much would you enjoy exploring space?	
	Feel friendly and talkative	To what extend does this place make you feel friendly and talkative to a stranger who happens to be near you?	

2.2. Neuroscience and Architecture

The architectural discipline has broadened its scope to include multidisciplinary studies that extend beyond the domains of architecture and science. This expansion aims to comprehend the intricate connection between people and the environment (Lee et al., 2022). Attempts to integrate architecture and cognitive science, such as environmental behavior and spatial analysis, have been made since the 1960s. This is essentially comparable to the recent endeavors to integrate neuroscience and architecture (Lee et al., 2022). Eberhard (2009) emphasized that there is a prevailing movement in the area of architecture to seek a more scientific method of understanding how people and the constructed environment interact. This involves integrating the disciplines of neuroscience and architecture. Thus, neuro-architecture is an emerging multidisciplinary topic of research that integrates the disciplines of neuroscience and architecture. A rising collection of work labeled the "neuroscience of architecture" provides an empirical foundation for investigating the mostly disregarded experiential components of design in modern constructed building science.

Recently, many scholars have linked environment-behavior investigations to neuroscience (Dobkins & Heyman, 2013; Dzebic et al., 2013; Jelić et al., 2016; Jelić, 2015; Martínez-Soto et al., 2013; Nanda et al., 2013). The link between architecture and neuroscience is examined using diverse scientific methodologies, and the distinct neurological correlates with activation in various architectural contexts are examined (Eberhard, 2009; Mallgrave, 2010; Pallasmaa et al., 2013; Papale et al., 2016; Robinson & Pallasmaa, 2015; Sternberg & Wilson, 2006).

Neuro-architecture, which combines architectural elements and neuroscientific methods, has greatly enhanced the current understanding of how the brain and neural systems respond to different environmental conditions. Various methodologies, including diverse data measures, are used to comprehend the effects of stimuli on human states (Karakas & Yildiz, 2020). Neuroimaging methods have been extensively used as a primary tool in this multidisciplinary area. Improved neuroimaging methods enable investigators to directly examine brain processes during the performance of diverse tasks by participants. Brain imaging, when used in conjunction with advanced experimental designs and data processing techniques, allows for the examination of the functions of different brain areas and how they interact with one another (Xue et al., 2010). The thesis examined EEG neuroimaging techniques in architectural fields in different manners.

2.3. Neuroscience and Aesthetics

The neuroscience of architecture is explored, drawing in neuro-aesthetics, a field that studies the neurological foundations of aesthetic evaluations. The aesthetics in the built environment are studied using these concepts and techniques (Eberhard, 2009). In the 2000s, the concept of neuro-aesthetics reached a very important point in its development, both empirically and theoretically. Chatterjee (2004a; 2004b) published the first papers that used fMRI to identify neural responses to art and to critically review the art’s neuropsychology. Leder et al. (2004), and Chatterjee and Vartanian (2014) presented cooperatively and notably early models defining important cognitive and neural systems involved in the aesthetic field. Previous research has been dealt with as a descriptive study. Only qualitative and observational studies associated neural results with aesthetic fields. Studies producing empirical hypotheses began to emerge after the study of the descriptive hypothesis. They helped the neuroscientific discipline to become the mainstream of scientific research.

Many studies examined how people who use space and have cognitive brain processes interpret aesthetics concerning curved space boundaries. Vartanian et al. (2013) used an fMRI scanner to examine three architectural factors at two runs (beauty judgment and approach-avoidance): curved versus rectilinear contours, openness, and ceiling height. They examined how the built environment affects human decision-making and, in a related vein, the functioning of the brain. The results showed that people were more inclined to think that curved places were beautiful than rectilinear ones and that when curvilinear spaces were considered beautiful, two significant areas of the visual cortex -the lingual and calcarine gyrus- were activated along with an effective response associated with pleasantness. Other studies revealed that the approach-avoidance decision was not significantly influenced by contour. The findings imply that studies of the built environment may benefit from the aesthetic preference for curved designs. Vartanian et al. (2015) also used an fMRI scanner to examine how perceived enclosure and ceiling height affected people's aesthetic assessments and approach-avoidance choices in curved architecturally conceived rooms. The findings explained why people were more inclined to find higher ceiling rooms lovely and why they stimulated the dorsal stream's attention and visuospatial exploration regions. Open rooms elicited increased feelings of attraction and stimulated the structures below perceived visual motion. Furthermore, the anterior midcingulate cortex (aMCC) of the cingulate gyrus, which gets direct inputs from the amygdala, was active in confined spaces and linked to a higher inclination for making escape decisions. Using fMRI, Coburn et al. (2017) and Coburn et al. (2020) examined the neurological and psychological reactions to the coherence, attractiveness, and hominess components of interior design images. These investigations showed a connection between curiosity level and brain activity in the right lingual gyrus. On the other hand, coherence was only associated with left inferior occipital gyrus brain activity when participants evaluated beauty, and hominess was only associated with left cuneus neural activity when people decided to avoid approaches.

Research using fMRI is restricted by related literature that uses two-dimensional stimuli. Researchers can only encounter two-dimensional stimuli because of the movement constraint on the fMRI instrument. Coburn et al. (2020) noted in their publications' limitations that numerous studies also may use of more immersive technology. While fMRI studies are informative about which brain regions are involved in aesthetic judgments, EEG studies provide complementary information using oscillatory activity

Brainwaves are sequences of electrical activity generated by the brain. The brain comprises many millions of neurons that communicate via electrical impulses. Brainwaves are created when a set of neurons fires in a specific sequence to relay signals to different sets of neurons. These electrical sequences are linked to distinct types of brain activity and states of consciousness. Brainwaves are extremely precise electrical impulses representing variations in brainwave frequency that arise during various mental states. Understanding brainwaves is essential to comprehend the functioning of the human mind and brain and the connections between the primary brain regions and neurological processes. In actuality, the sum of the activities of brain cells is what is known as the electrical activity of the brain. Even though every brain cell has a unique frequency wave, we can measure the total activity of all brain cells. The constant motion obtained from the brain is divided into frequency bands. These frequency band spans are employed in many investigations, with minor variances in different domains (Newson & Thiagarajan, 2019). Brainwaves are classified into three major types in this study: theta, alpha, and beta.

Alpha waves, which range from 8 to 12 Hz, have a significant role in attentional processes and, in this study, are particularly related to environmental perception (Klimesch, 2011). Klimesch (2011) highlights that these waves are commonly linked with feelings of calm and relaxation despite their importance in tasks requiring spatial awareness. Alpha oscillations are hypothesized to govern the suppression of unnecessary sensory input, increasing the processing efficiency of relevant environmental cues (Klimesch et al., 2007; Jensen & Mazaheri, 2010). Jensen (2024) emphasizes that alpha waves adjust attention by blocking noisy details, allowing individuals to focus more efficiently on certain areas of their environmental surroundings.

On the other hand, the cognitive processes of the brain, including active thinking, problem-solving, and decision-making, are associated with beta waves. Their frequency range is between 12 and 30 Hz. Beta activity is linked to environmental perception when it comes to processing visual and proprioceptive information needed for anticipating and interacting with physical obstacles or changes in the environment (Di Dona & Ronconi, 2023). It is responsible for segregation or integration and the reorganization of visual inputs. These tasks play a major role in understanding scenes' spatial layout and dynamics. Prior studies have shown that higher beta power correlates with better performance in visual crowding tasks, which require participants to distinguish a target from surrounding distractors. These findings demonstrate that beta waves resolve visual clutter and enhance perceptual clarity. New studies involving transcranial magnetic stimulation provide causal evidence for beta waves involved in scene perception and visuospatial processing (Di Dona & Ronconi, 2023).

Theta waves, spanning frequency bands lower than 8 Hz and higher than 4 Hz, are associated with memory load. Theta waves have been shown to increase with the complexity of memory load. Regarding scene perception, theta waves are crucial for scene-related information in short-term memory (Busch & Herrmann, 2003). Theta oscillations are predominant for binding items to their context during encoding, helping effectively perceive and recall complex scenes (Summerfield & Mangels, 2005).

2.4. Neuro-architecture and Immersive Virtual Environment

With the rapid development of technology, different instruments are used in the neural calibration. Utilizing VE creates a more dynamic and engaging environment than other studies. Researchers can maintain consistent design aspects while regulating pertinent variables by using VEs. Recently, researchers investigated neuro-architecture with VR. The use of VR technology with neuropsychological tests, such as EEG, simultaneously to assess an architectural environment's aesthetic perception has recently been covered in the literature. With the development of immersive VR technology, various studies in the literature use VEs to perform EEG analysis (Banaei et al., 2017b; Jung et al., 2023; Kober et al., 2012; Mostafavi et al., 2023; Shemesh et al., 2016; Shemesh et al., 2021; 2022; Slobounov et al., 2015; Taherysayah et al., 2024; Vecchiato et al., 2015a, 2015b). Modern scientific tools like the EEG are employed in neuroscience to study the neurological correlates of architectural settings. Participants can experience the simulations by tilting their heads in the VE, even though the EEG device does not restrict movement. The growth of the study of neuro-architecture into an experimental science may be facilitated by further methodological approach development. Vartanian et al., (2013) suggested that multidisciplinary research combining neuroscience and environment-behavior is crucial.

EEG signals acquired during the perception of three IVEs (empty room, modern furniture, and cutting edge) were studied by Vecchiato et al. (2015b). Participants were directed to rate the familiarity, novelty, comfort, pleasantness, arousal, and presence of their experience while using a rated scale. These findings demonstrate that when participants reported feeling more present, familiar, comfortable, and pleasurable, frontal-midline theta is engaged. Human responses to various geometric spaces, including square, round (domed), sharp-edged, and curved environments, were studied by Shemesh et al. (2016). Participants, both design and non-design students, examined the settings with various geometries in a VR setting and answered a thought and emotion questionnaire about their observations. Additionally, the EEG data collected throughout the study was used to determine the neurophysiological correlates of the individuals' experiences in a VR setting. The findings showed that whilst non-design students preferred curved areas, design students preferred rooms with sharp angles. Banaei et al. (2017a) investigated the neurophysiological connections between perceived affect and brain activity in respect to the different interior types of affects. EEG was utilized to monitor human brain activity while the viewer actively explored a 3D architectural scene, and researchers examined the 3D architectural designs. The result showed that curved geometries strongly affected human perception and brain activity, raising pleasure and arousal ratings. Furthermore, anterior cingulate cortex (ACC) activity is strongly influenced by curvature geometries. Shemesh et al. (2021; 2022) examined the connection between emotions of humans and the architectural environment while utilizing EEG to explore different geometrical forms in VR. The results showed that an architectural space's unique geometric form has a significant effect on people's emotions. This outcome demonstrates that it is possible to assess and quantify the emotional reactions that architectural settings elicit.

In conclusion, the aesthetic concept and the components of the literature have been analyzed in detail in architectural surroundings. The formation of the concepts of aesthetics and neural maize and related previous studies are then presented. However, VR studies used as a design support tool have been studied, and development processes have been covered. VR is a popular and useful technology in architectural study. The thesis used VR to alter the variables systematically to regulate several architectural variables and examine their impacts on human aesthetic judgments. It also provides information on better synthesizing the VE and VR techniques. In the final phase, VR studies in neuro-architecture are discussed. The main work of this thesis is to explore the interactions of neural correlates using VR of spaces with different architectural variables. In the next chapter, the features of the architectural environment are discussed in detail. The interaction of architectural boundaries in different shapes on humans has been studied from a psychological point of view. Furthermore, architectural surroundings with different specific properties have been analyzed by previous literature.

CHAPTER 3

PROPERTIES OF ARCHITECTURAL SURROUNDINGS

This chapter describes the different variables of the architectural surroundings. The influence of curved forms on human psychology and curved boundaries in the architectural surroundings was studied. Moreover, space properties are conducted systematically. The SLTC of the space properties that do not change easily in the architectural surroundings were investigated in the related literature.

In this thesis, in an interior area, boundary type and SLTC comes together to form a composition. Regarding space unity, these features differ from others, such as furniture, openness, and murals (Bokharaei & Nasar, 2016). The SLTC are easily modified characteristics in the living environment. Many significant factors that affect people's attitudes and sentiments about space also affect people's quality of life, and these factors are hard to change in a living area. According to Nasar (1992d), cognitive and affective evaluations of the quality of life are related to how well one's expectations align with the features of physical space. Consequently, an interior architect designs spaces that highlight these qualities. Many aspects of architectural spaces influence people's perceptions of aesthetics in the built environment. Among these essential qualities are the form of space boundaries and SLTC.

3.1. The Shape of the Space Boundaries

One of the fundamental aspects of space perception is the shape of the space boundary. Studies have repeatedly demonstrated that when it comes to architectural settings, people prefer curved boundaries over other types of boundaries (Van Oel & Van Den Berkhof, 2013). In contrast to abrupt changes in an interior region, curved borders, also known as curvilinear forms, are typically defined by smooth transitions between curves (for instance, walls) (Elver, 2018).

A growing amount of research has used a range of scales to examine how individuals understand curvilinear patterns in the built world. The choices of participants in various indoor VR environments featuring curved, rectilinear, angled, and mixed geometries were investigated by Hobbs et al. (2015). According to their research, curved boundary spaces are perceived by people as more relaxing, pleasant, and inviting than straight boundary spaces (Hobbs et al., 2015). Other researches indicates that people perceive curved spaces as more pleasant and safer than straight ones (Bar & Neta, 2006; Silvia & Barona, 2009). According to Pearson (2001), curves make more sense since they are associated with the body in the human mind. As per Salingaros (1998), structures possessing organic and natural features seem to be perceived differently and psychologically more suitable than other conventional forms. Interior spaces with curved forms elicit sentiments of happiness, harmony, and well-being, according to Papanek (1995). Furthermore, research by Madani Nejad (2007) has showed that curvilinear patterns likely to increase viewers' perceptions of the space as more private, enjoyable, and stress-free, as well as their sense of safety. Additionally, Dazkir and Read (2012) found that curved patterns evoked noticeably stronger feelings than rectilinear forms (measured using the "pleasurable" scale) and were associated with feelings of calmness, tranquility, and relaxation.

Studies have also researched how people perceive curved boundaries differently on an aesthetic evaluation. Vartanian et al. (2019) discovered that specialists (self-identified designers and architects) deemed curvilinear areas more appealing than rectilinear environments. In contrast, non-experts' beauty assessments were unaffected by the contour's (boundary's) shape. However, specialists' approach-avoidance decisions were unaffected by the contour's shape, whereas non-experts were more likely to enter rectilinear than curved surroundings. Shemesh et al. (2016) researched both design and non-design students responded to VR spaces with varying geometries, including square, rounded (domed), sharp-edged, and curved places. It was found that non-design students typically prefer curvaceous spaces, but design students prefer regions with sharp angles. The results of this study demonstrate how knowledge affects the aesthetic and motivational significance of border shape, even though boundary shape is still recognized as a significant and potentially adaptive feature of architecture and design. Further, Banaei et al. (2017a) provided a framework for categorizing architectural forms inside structures. They put out 25 formal clusters for 343 pictures of living spaces with various architectural themes and interior design elements. Their work is groundbreaking in the field of architectural studies since it uses form as a measure to categorize interior spaces. Additionally, Banaei et al. (2017b) studied how perception and brain activity were affected by various interior forms. The findings revealed a significant relationship between curved shapes that impact human perception and brain function and the increased ratings of arousal and pleasure. Additionally, Banaei et al. (2020) investigated the ways in which various interior forms influenced emotions. Individual variations were assessed in addition to personality characteristics using assessments of dominance, arousal, and enjoyment. They found that different personality types have different relationships between interior architectural forms and emotional states.

People's preference for curving boundaries has been explained by several hypotheses. According to one of these explanations, curves are natural shapes that people are regularly exposed to in the built environment, they attract people's attention more than linear forms (Vartanian et al., 2013). Another explanation holds that people's aversion to angular objects is the source of their desire for curvature (Bar & Neta, 2006). Studies on neuropsychology also support this narrative. Research has shown that angularity, instead of curvature, evokes feelings of threat and uneasiness (Bar & Neta, 2007). Recent research indicates that people's preference for curved shapes results from both biological and cultural factors (Gómez-Puerto et al., 2016).

Moreover, studies have examined different curvatures concerning aesthetic perception (Blijlevens et al., 2012; Blijlevens et al., 2013; Ho et al., 2016). Each of this research indicates a quadratic relationship between expressed preference levels and product curvature; the association increases up to a point of significant curvature and then drops. Consequently, a modest curvature substantially correlates with the individuals' highest preference level. In conclusion, studies have proven that curved architectural environments lure people in. However, in other studies, different measures were used to quantify the aesthetic perception of these settings. Corradi and Munar (2020) contend that a complete understanding of aesthetic perception must still be included. The fundamental objective of this thesis is to analyze the human aesthetic judgments for curved boundaries across all these scale measurements and determine the underlying primary properties of these aesthetic judgments.

3.2. Space Properties of Architectural Surroundings

The different space properties have been adeptly merged and harmonized by designers over the course of history. Due to the essential and crucial nature of design components, they are extensively examined in almost every design book and in any context where design work is taught or assessed. Several scholars (Adams, 2013; Ching, 2007; Kilmer & Kilmer, 2014; Nielson & Taylor, 2011) investigated design properties in the field of interior architecture. Several elements, including boundary shape and SLTC (see Figure 3 variations), impact an architectural space's composition in this thesis.

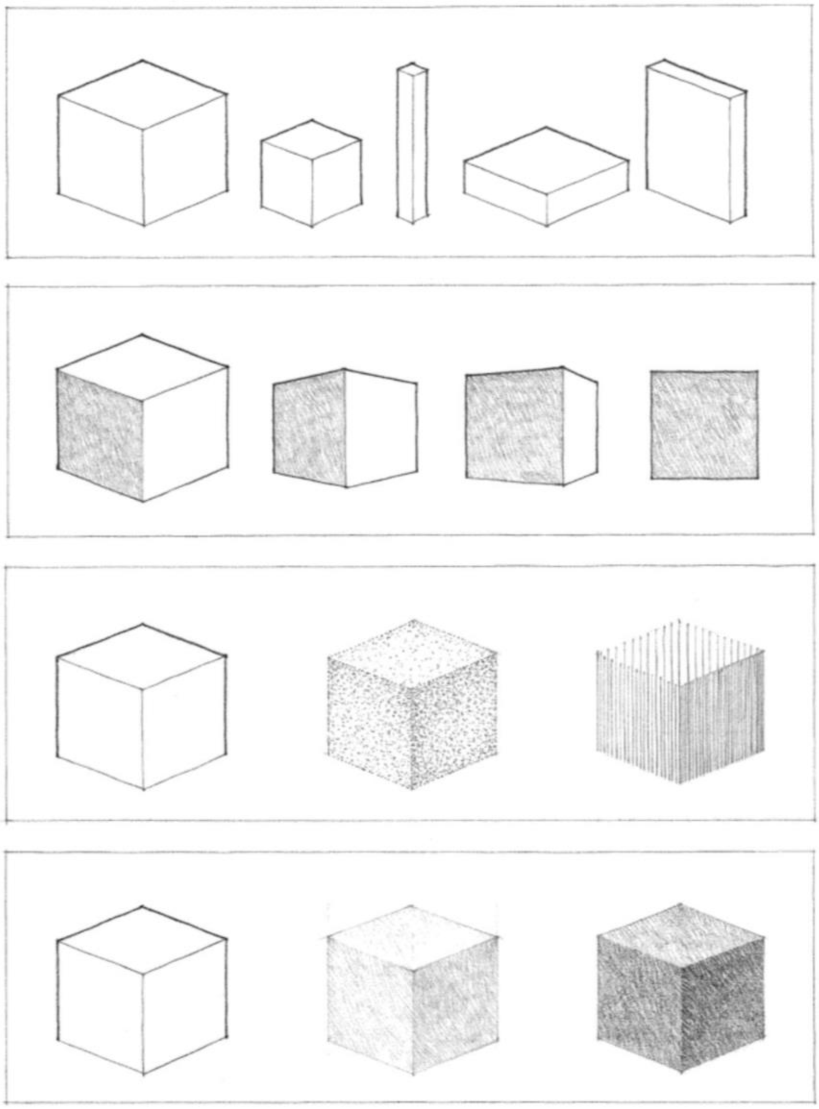


Figure 3. SLTC Variations (adapted from Ching, 2007: 34)

3.2.1. Size

The physical proportions of a location can impact on an aesthetic perception, according to research on how people interpret the scale of architectural spaces. Particularly, individuals perceive spaces with rectangle shapes are roomier and more expansive compared to those with square forms, even when two spaces have the same physical dimensions. Stamps (2007, 2009, 2010) has proven to be knowledgeable in this area through his research, which has covered several studies related to the form of architectural space. In other words, it has been found that an architectural space's horizontal distance, or length, affects people's perception of it (Bokharaei & Nasar, 2016; Franz & Wiener, 2005; Franz, 2006; Franz et al, 2005). However, Al-Zamil (2017) emphasized that a room's perception of space increases with its ceiling height.

3.2.2. Light

The aspect of space that also affects how something is perceived as beautiful is light (Bokharaei & Nasar, 2016; Knez, 2001; Kuller et al., 2006; Odabasioglu & Olgunturk, 2015; Ulusoy et al., 2021). Several studies indicate that the range of aesthetic measures that can occur in an architectural space depends on the quantity of light present (Durak et al., 2007; Kuller, 1986; Odabasioglu & Olgunturk, 2015; Stamps, 2007). Ozdemir (2010) and Stamps (2010) additionally discovered that individuals perceive space with bright illumination as larger than spaces with dim illumination. Although Stamps (2009) reveals that individuals view night views as more spacious than day ones, the difference disappears when one considers the intensity of light.

3.2.3. Texture

The texture indicates the degree of smoothness or roughness of the surface. It gets detected by visual or tactile perception. According to Bokharaei and Nasar (2016), texture is an attribute of an interior space that causes a particular amount of reflection or absorption on the surface of a space, resulting in variations in how individuals perceive and assess architectural environments. Vertical patterns are related with the vertical dimension of the boundary surface, whereas horizontal patterns are associated with depth (Bokharaei & Nasar, 2016). Ishikawa et al. (1998) observed that individuals tend to regard environments with horizontal textures and increased depth as more spacious and visually appealing. In contrast, Stamps (2011) identified that people tend to view spaces as narrower if they exhibit greater height and vertical patterns. Also, Al-Zamil (2017) emphasized that by utilizing both horizontal and vertical lines, the space may appear larger and more expansive.

3.2.4. Color

Another aspect of a space that influences aesthetic perception is its color. Color is a visual phenomenon that is influenced by how one sees light, including factors such as shadow, intensity, and the specific hue of the color. Many studies show that people perceive warm and cool colors differently (Bokharaei & Nasar, 2016). Interior spaces are perceived as larger when painted in light cool colors like blue or green instead of warm colors like red or orange, according to Yildirim et al. (2007). The reason is that light is diffused by surfaces with light cool colors that expand people's perspective of space. Cooler or lighter hues give the impression that it is farther away (Al-Zamil, 2017). Researchs indicates that utilization of warm and saturated color schemes leads to decrease in the evaluating in aesthetic judgment while using cool color schema and desaturated colors produces a favorable aesthetic judgment (Franz, 2006; Odabasioglu & Olgunturk, 2015). Al-Zamil (2017) demonstrates how using natural tones and bright colors on walls and ceilings can create the illusion of more space.

Despite a wealth of research on how architectural variables affect people's aesthetic perceptions, it still needs to be determined how these elements interact with the different architectural surroundings that define and influence people's perceptions of aesthetic judgment as a holistic approach. One of the thesis objectives is to create this primary dimension of aesthetic judgment as a holistic approach and better understand the factors influencing aesthetic judgment.

3.3. Immersive Virtual Environments as an Architectural Design Support Tool

Recent technology adoption is a successful tactic for streamlining, integrating, and assisting architectural construction processes (Eastman et al., 2008; Paes, 2019). VR is a prominent research support tool in several architectural areas that focus on spatial cognition, behavior, and perception. It has advantages over RE, as demonstrated by the several literatures (Luck & Aylett, 2000).

Firstly, VR enables systematic alterations of the surroundings that are not feasible to execute in REs. For example, Kuliga et al. (2015) noted that although it would be difficult to significantly change a real building's spatial configuration, using VR could make it feasible to test the impact of various designs on the behaviors of users without interfering with the structure's ongoing use. Most importantly, VR enables researchers to control some architectural aspects while concentrating on their impacts. For example, much VR research uses simplified models of architectural interiors, such as vacant or sparsely furnished areas. In this manner, a great deal of the interior spaces can be controlled, including the arrangement of furniture, its shape, and color, the view via window openings, natural light coming in from the outside, mural compositions, and the impact of the architectural factors. By utilizing spherical wide-angle projection technology with 360-degree panoramic images, Franz et al. (2005), for example, employed 16 empty rectangular rooms and varied the types of windows and doors to examine their influence on emotional evaluations. Franz (2006) examined how architectural features, size, and color affected how people felt about these 16 vacant areas as a follow-up to earlier research. Furthermore, human figures, carpets, wall textures, and bookcases were methodically added to empty rectangular rooms as Stamps and Krishnan (2006) studied the link between spaciousness and rugged edges of architectural areas in VEs. They deduced that interior spaces appear larger when boundaries are rough. Additionally, using a variety of blank rooms (no décor) with a various proportion of plan, Stamps (2011) examined the impacts of space, height, length, and color on the impression of space. Stamps (2011) limited his analysis to altering the architectural characteristics of the unfurnished interior areas. Through two tests, Von Castell et al. (2014) examined how the interior environment's furnishings affected the sense of its experienced dimensions of space and degree of spaciousness. The initial experiment employed model rooms in scale 1:10 to examine the impact of the height that one perceives and spaciousness. The furnished rooms were seen as more spacious, but they were also thought to be taller. Spaces with varying surfaces and continuous physical heights were examined in the second experiment. According to their investigation, decorating did not influence how roomy or large the interior surroundings were assessed to be. Bokharaei and Nasar (2016) used size, light, texture, mural, window size, and furniture manipulation to independently study the degree of perception of preference and spaciousness in a constrained online workspace setting.

They concluded that a previously seen room's size, lighting, and window size influenced the perception of preference level and spaciousness.

In an immersive VE, Shemesh et al. (2016) examined how people reacted to several geometrically planned environments that were intended to be colorless, soundless, and devoid of any objects (aside from a single, plain chair that serves as a human scale reference in the middle of every room). Utilizing empty spaces in VR, Carreiro et al. (2017) measured the aesthetic perception for architectural settings with different levels of geometric surroundings. They discovered that moderate curvature rates were more precise than radical ones. Utilizing an empty VR environment, Simpson et al. (2018) investigated the impact of wallpaper patterns on evaluations of spaciousness and action-oriented metrics. According to Von Castell et al.'s (2020) investigation of the stripe wall patterns, perception was influenced by the stripes' density (stripe count per viewing angle degree) and direction (horizontal vs. vertical). In a similar vein, Wang et al. (2020) examined how perception and assessments of spaciousness in an empty virtual space were affected by wall texture. VR enabled scientists to regulate some architectural aspects while manipulating others in the abovementioned studies.

Also, VR allows researchers to dynamically model the entire life cycle of a building to assess the effectiveness of possible designs (Tasli & Ozguc, 2001). This finding is a significant advantage because, in a way, structures are living things. Notably, VR technologies allow consumers to immerse themselves in architectural areas virtually. VR simulations have become popular because of the advantages of representing scale, depth, and volume, particularly for design reviews (Paes et al., 2021). Setting limits for an architectural immersive environment is similar to doing so for a visual living area. As a result, it makes it possible to move around the area as though one were truly there. Implementing the space's limits enhances the experience, and the spectator feels more immersed in the surroundings.

As VR becomes more widely used, one concern that has come up is whether the reactions of people in VE would be similar to those in RE. Numerous research studies have examined this issue by contrasting people's behavior in RE with VE. According to De Kort et al. (2003), VE has great potential to develop into important new research instruments for comprehending the way people behave in architectural surroundings. It may take the place of RE as the study lab for design studies in the future. In a study of theirs, 101 participants in either VE or RE examined the same space during the trial. The bipolar adjective factor analyses revealed that the major dimensions were comparable in both settings, indicating that the actions and experiences in VEs and REs are comparable. Furthermore, Kuliga et al. (2015) contrasted building users' experiences in VE and RE. They discovered that much of the behavior was similar in both settings. Significantly, they proposed that VR is even better since it allows for thorough observations, precise behavioral assessments, and methodical environment modifications in a lab setting. Brade et al. (2017) also extended user experience research by comparing the existence and usability of RE and VE. They assessed its effect on usability and user experience by comparing the presence of Cave Automatic VE and the real city center, in between-subject design. Whereas the RE displayed better reasonable standards of quality, the VE demonstrated much greater hedonic quality values regarding user experience. The user experience components and their existence showed some correlation in both VE and RE; as long as a high presence is attained, their findings suggest that VEs can serve as a viable substitute for REs in user experience research.

Moreover, Paes et al. (2017) examined how users perceived space when utilizing an immersive (VE) platform as opposed to a traditional workstation (screen). Their findings demonstrated enhanced spatial perception in immersive VE and indicated that VE may be helpful in modern design practices by enhancing experts' comprehension of spatial arrangements. Higuera-Trujillo et al. (2017) conducted a noteworthy study in which they examined the physiological and psychological reactions elicited by three distinct environments, namely actual photographs, 360-degree panoramas, and VR, along with how individuals experience a sense of being present in these environments. The researchers discovered that 360-degree panoramas yield the most realistic outcomes according to the psychological reactions of the participants, as well as compared to VR according to the physiological reactions. They determined that researchers could mimic experiences in real-world settings by using 360-degree VR surroundings.

In this context, VR is a popular and useful technology in architectural study. The thesis used VR to alter the architectural variables systematically to regulate several architectural elements and examine their impacts on human aesthetic judgments. In the next chapter, the methodology is presented in three different stages.

CHAPTER 4

METHODOLOGY

There are three methodological stages to the thesis. In the first stage, the main relevant aesthetic aspects were demonstrated, and the curved boundaries and space properties were the subjects of prior cognitive, emotional, and behavioral aesthetic judgment research. In the second stage, to comprehend the relationship between curvilinear boundary types + space properties (stage 1) and architectural variables (stage 2), these pertinent important aesthetic factors are evaluated to establish new architectural variables. In order to comprehend the differences or similarities between immersive and non-immersive experiences, IVE and DTVE correlations were also found. In the third stage, neuronal responses to architectural factors examined how neural correlates of interest of the brain are impacted by the surrounding environment in aesthetic perception (see Figure 4). The thesis stages were carried out in different time frames, and each stage involved different participants.

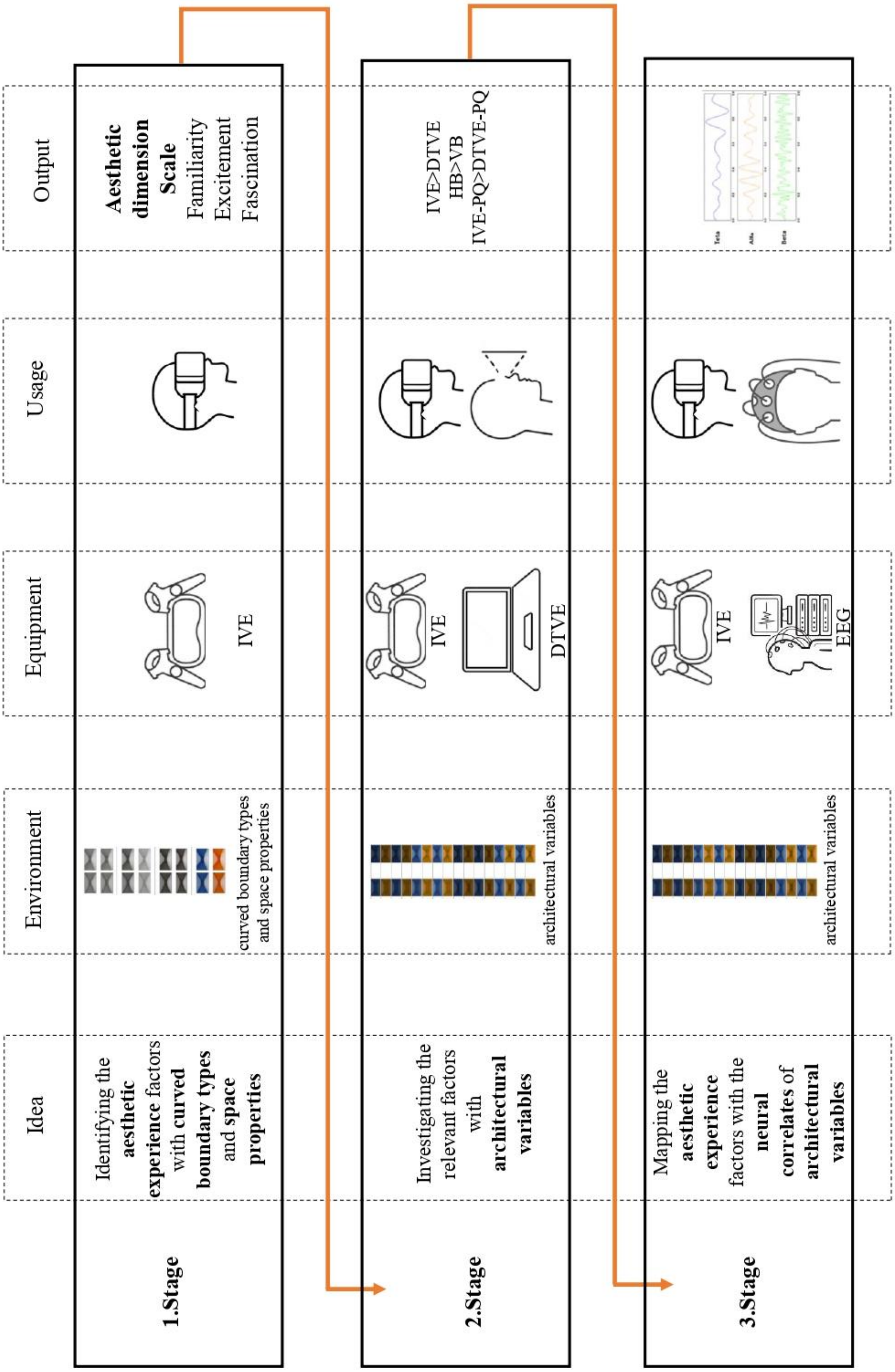


Figure 4. The framework of the proposed stages (drawn by the author, 2024).

4.1. Method of Stage 1

For stage 1, the study altered the SLTC of 16 architectural spaces with curved boundaries in IVE. Subsequently, participants evaluate these spaces by using every scale commonly employed in the literature to quantify the aesthetic adjectives of the built environment. Ultimately, the study identified the essential components of aesthetic judgments and described how different architectural space attributes influence each of these architectural properties by analyzing several data points. To this knowledge, this is the most comprehensive and methodical description of the aesthetic judgments for architectural spaces with curved boundaries. The following research questions (RQ) are posed for stage 1:

RQ1: Can aesthetic judgments be grouped into psychological dimensions in an architectural space?

RQ2: Are these psychological dimensions (aesthetic judgments) sensitive to the curved boundaries (HB/ VB) and space properties (SLTC)?

4.1.1. Participants

The experiment involved 128 graduate and undergraduate students from various departments of Bilkent University, 54 of whom were male and 74 of whom were female. The study was authorized by the Bilkent University Ethics Committee (No: 2018_01_18_04, see Appendix B1), and each participant signed the consent form (see Appendix C1), and. The study consists of four sections (S/L/T/C), and different individuals participated in the experiment. The Ishihara electronic color blindness test

(Color-blindness.com, 2019) was utilized to determine whether or not the participants' ability to perceive color was intact before the experiment (see Appendix D).

4.1.2. Environmental Stimuli

The immersive stimuli used in the VR have two essential qualities: (1) Boundary types and (2) Space properties. Curved horizontal boundaries (HB) and curved vertical boundaries (VB) are the two curved borders utilized. The HB region is surrounded by four walls, with horizontal concave connections connecting the edges of each wall (see Figure 5A). In contrast to standard room connections, the space's horizontal plane does not have a 90-degree edge. Vertically concave links connect the ceiling to the four walls that enclose the VB space (see Figure 5B). Unlike usual space connections, the vertical walls and ceiling do not meet at a 90-degree angle.

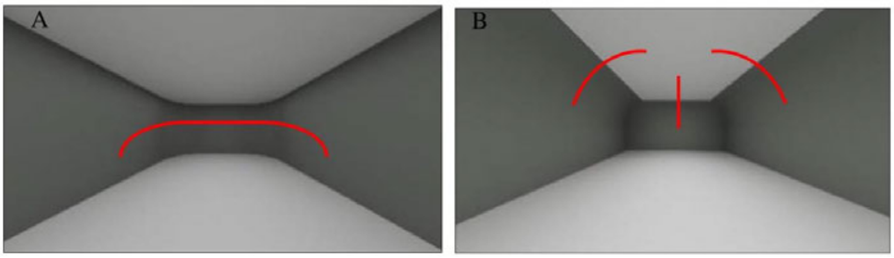
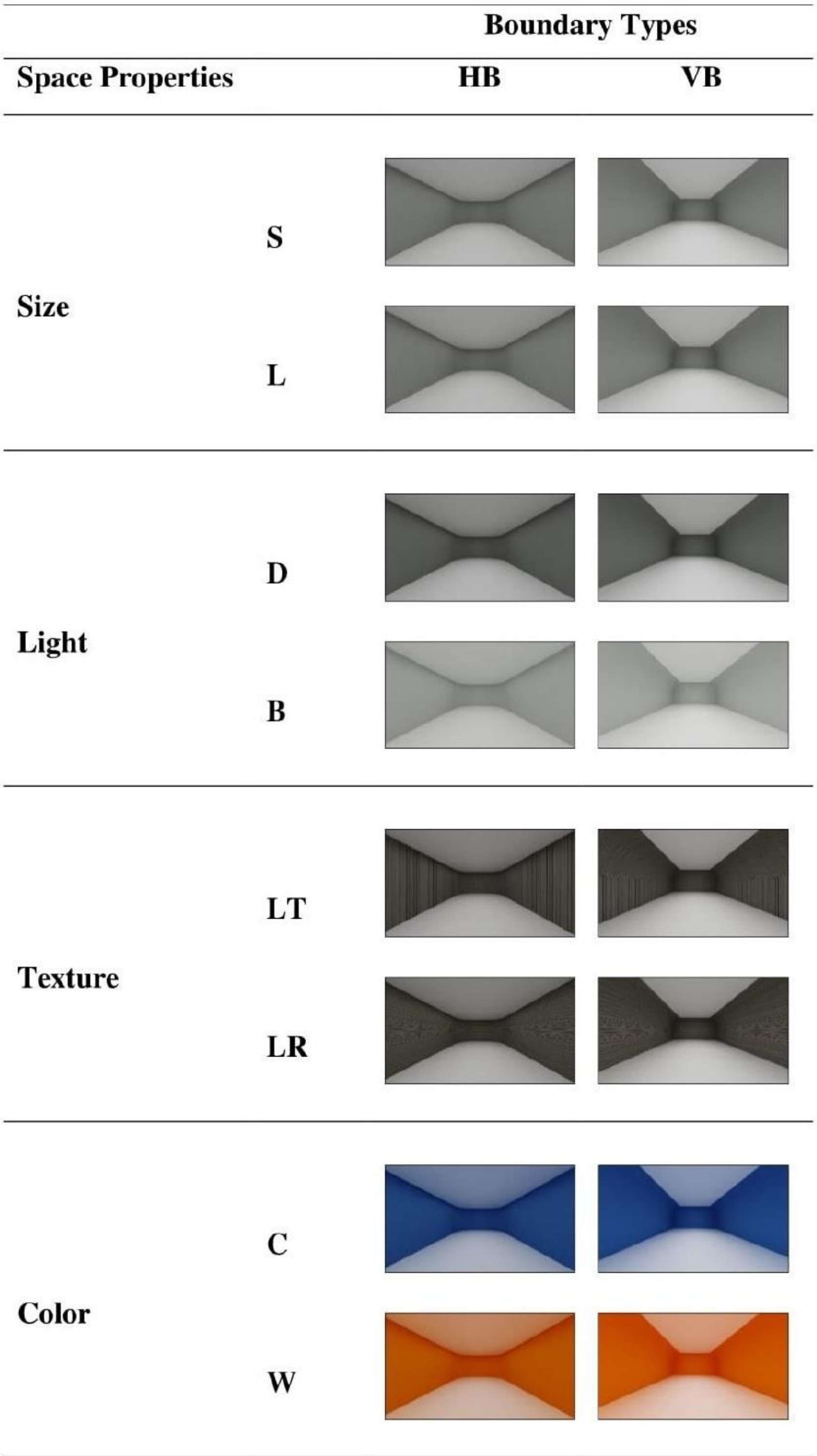


Figure 5. The stimuli in VR are designed using two distinct boundary types: (A) HB and (B)VB (designed by the author, 2019).

Every boundary type involved the four space properties of the surrounding surfaces: SLTC, each with two intensity levels: high and low. Figure 6 illustrates the SLTC levels. The participants perceive these zones at eye level.



Boundary Types: Horizontal boundary (HB) and Vertical boundary (VB)

Space Properties: Size; Small (S)-Large (L), Light; Dim (D)-Bright (B), Texture; Longitudinal (LT)-Lateral (LR), and Color; Cool(C)-Warm(W).

Figure 6. Curved boundaries with space properties visualizations (designed by the author, 2019).

4.1.3. Instruments and Procedures

Users of VR technologies can digitally enter architectural surroundings. An architectural immersive environment's boundaries are comparable to those of a visual living area. Consequently, it allows one to navigate the environment as if it were a real place. The boundaries of the place being used, which add to the viewer's sense of presence, improve their experience. Carefully setting VE boundaries can lead to the most accurate understanding of the spatial environment.

With dimensions of 4.5 meters in width, 9 meters in length, and 3 meters in height, each section was supposed to be the same middle size. Non-directional lighting was employed everywhere to ensure uniform lighting throughout. The floor areas (40.5 m2) of the areas are identical. Depending on the size criteria, spaces have a floor area of 25 m2 for small and 50 m2 for large versions. Furthermore, the moderate curve (4 ½ in.) was selected as the curvature of the horizontal and vertical limits based on the study of Hopkins et al. (1976). Additionally, Carreiro et al. (2017) found that reasonable curvature preferences are more reasonable than radical curvature rates. Additionally, during simulations in VEs, participant motions were predicated on an egocentric framework of perception (Sancaktar & Demirkan, 2008). These spaces, however, were intended to be silent in the absence of objects by the earlier research (Carreiro et al., 2017; Shemesh et al., 2016; Simpson et al., 2018; Von Castell et al., 2020; Von Castell et al., 2014; Wang et al., 2020).

Four 360-degree settings were evaluated for aesthetic adjective quality using a Head Mounted Display (HMD) device (SM-R325 Gear VR). The same layouts were used for the visual stimuli. In order to preserve the perception of the space property with boundary type, no materials or openings were included in the produced area. The study involved 32 participants in each of the four VR sessions. Participants observed and scored four environments with two levels of intensity and a single space feature (SLTC) that varied randomly during each session. Each participant experienced the 360-degree virtual space visualization for 10 seconds. Depending on how the virtual glasses were positioned and adjusted, the VR experience took 15-20 minutes to complete. During the experiment, participants can stand and turn their bodies around themselves as egocentric. After each space, participants respond to an evaluation in a VE with VR controllers. The Qualtrics survey is carried out in VE. ("Qualtrics XM - Experience Management Software," 2019). In the cognition and emotion domains, every visualization was rated by the participants using twenty-one distinct bipolar adjectives on a 5-point Likert scale (-2=represent low value, 0=neutral, 2=represent high value), and in the behavior domain, they used four items on a 5-point Likert scale (anchored by never/a few hours and not at all/very much) after viewing the visualizations (see Appendix E1 for survey set), which are distributed at random within Qualtrics. In every session, the experiment room in the Bilkent University FF building lacked windows, color, and furnishings. Only the VR gear was there.

The physical characteristics of the surroundings may impact the aesthetic measures that arise from the surroundings. Numerous studies evaluate interactions between people and their surroundings in respect of aesthetic measures. Rafaeli and Vilnai-

Yavetz (2004) highlighted the close connection between the physical characteristics of the surroundings and aesthetic measures. They looked into how people's descriptions of interior spaces are influenced by their usefulness, beauty, and the meanings they ascribe to them.

4.1.4. Data Analysis of Stage 1

Based on the scores of the 128 participants, the correlation matrix of the 25 aesthetic adjective pairs was conducted. The scores were then subjected to principal component (PC) analysis to determine if the metrics used to assess aesthetic adjectives could be categorized into any important characteristics. Subsequently, we performed a repeated measures ANOVA with two variables, 2(boundary type) x 2(space property), on the factor loadings of each PC for each of the four experiments.

4.1.5. Results of Stage 1

An evaluation of the 25 items' internal validity revealed good reliability, according to Cronbach's alpha (α= 0.933). Using the RStudio (2019), the correlation matrix was calculated over the 25 aesthetic adjectives (see Figure 7). The degree of association between the different aesthetic adjectives was displayed in the correlation matrix.

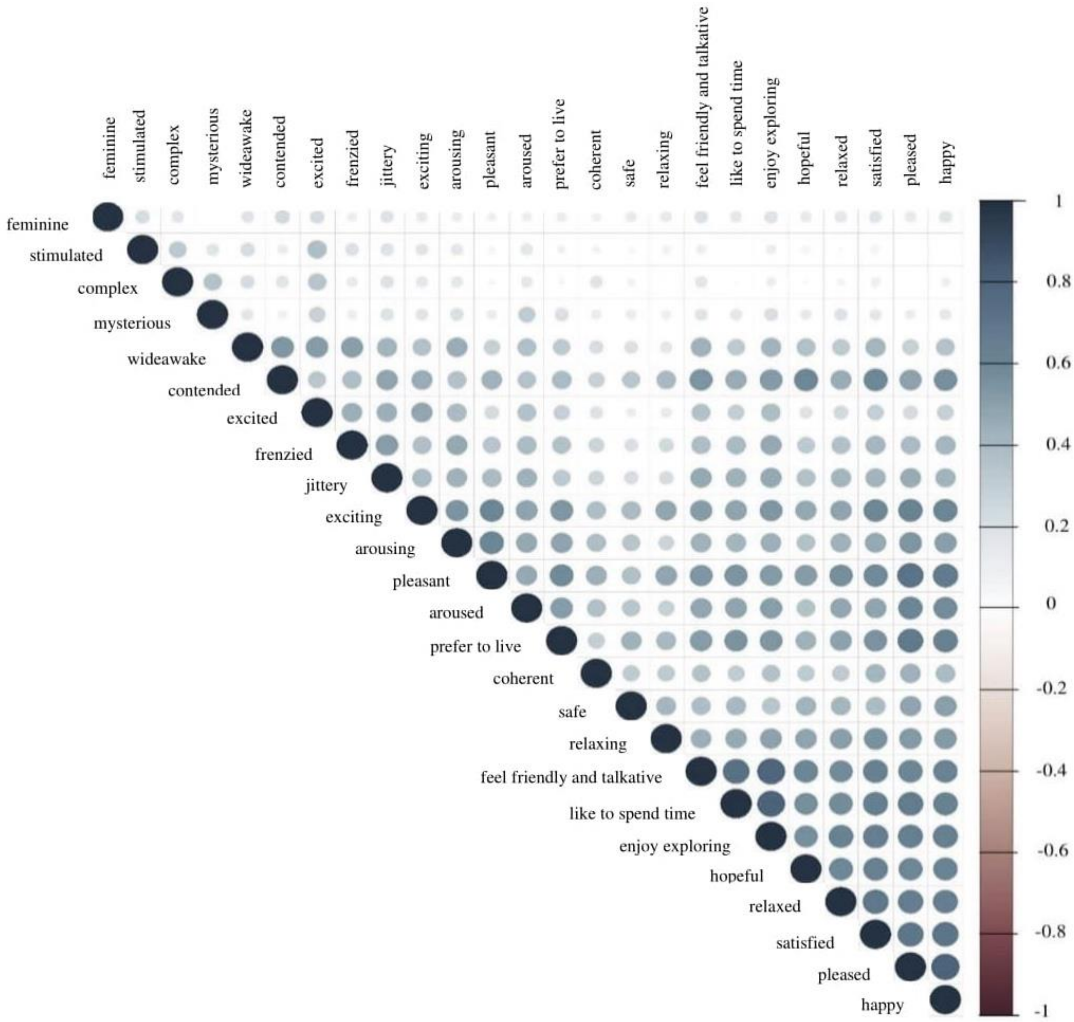


Figure 7. An analysis of the correlation between 25 aesthetic adjectives (drawn by the author, 2019).

PC analysis was utilized to ascertain the fundamental elements that underlie the 25 aesthetic adjectives. After a preliminary component analysis revealed that one of the aesthetic adjectives, feminine, was classified as a single adjective, it was excluded from the analysis. As a result, as Table 3 illustrates, PC was performed using 24 variables.

Table 3. Factor loadings pertaining to the three primary PC.

Aesthetic rating scale	PC 1 Familiarity	PC 2 Excitement	PC 3 Fascination
Pleased	.87		
Happy	.83		
Satisfied	.78		
Pleasant	.77		
Relaxed	.74		
Like to spend time	.73		
Prefer to live	.70		
Enjoy exploring	.70		
Hopeful	.70		
Relaxing	.69		
Feel friendly and talkative	.67		
Exciting	.65		
Safe	.62		
Aroused	.58		
Arousing	.53		
Coherent	.52		
Wideawake		.73	
Excited		.64	
Frenzied		.62	
Jittery		.59	
Contended		.58	
Mysterious			.68
Complex			.67
Stimulated			.54
Eigenvalue	8.42	3.54	2.01
Variance Explained	33%	14%	8%
Cumulative Variance	33%	47%	55%

The dataset was deemed acceptable for PCs based on the results of Bartlett's test of sphericity identity matrix (χ^2=7534.89, *df*=300, *p*<0.001) and the Kaiser-Meyer-Olkin measure of sampling adequacy (KMO= 0.942), which demonstrated a statistical link between the scales. According to three PC: the first, PC1, is made up of sixteen aesthetic adjectives that are referred to as the *familiarity* dimension; the second, PC2, is made up of five aesthetic adjectives that are representative of the *excitement* dimension; and the third, PC3, is made up of three aesthetic adjectives that are associated with the *fascination* dimension. Of the entire variation, the familiarity dimension accounts for 33%, the thrill dimension for 14 percent, and the curiosity dimension for 8 percent. Together, these three factors accounted for 55 percent of the variation in total.

As previously noted, identifying the primary components is difficult (Coburn et al., 2020). The three main PCs were named to develop a phrase that would describe anyone's experience in an architectural setting and be appropriate for the individual objects grouped under each component and the entire set. As a result, PC1 is called familiarity since everything under it may be related to one's visual perception of places with which one is familiar. People could spend time in a comfortable setting, find it calming, secure, and cohesive, and even feel joyful or content. Since it includes things that allude to good, elevated sensations about a certain location, such as being eager or agitated, the PC2 is dubbed excitement. PC3 is called fascination because all the elements included are mysterious, complicated, and exciting spaces.

After identifying the three main components, each PC's factor loadings for each trial were subjected to a 2x2 ANOVA (see Figure 8). Table 4 presents the findings from the ANOVAs.

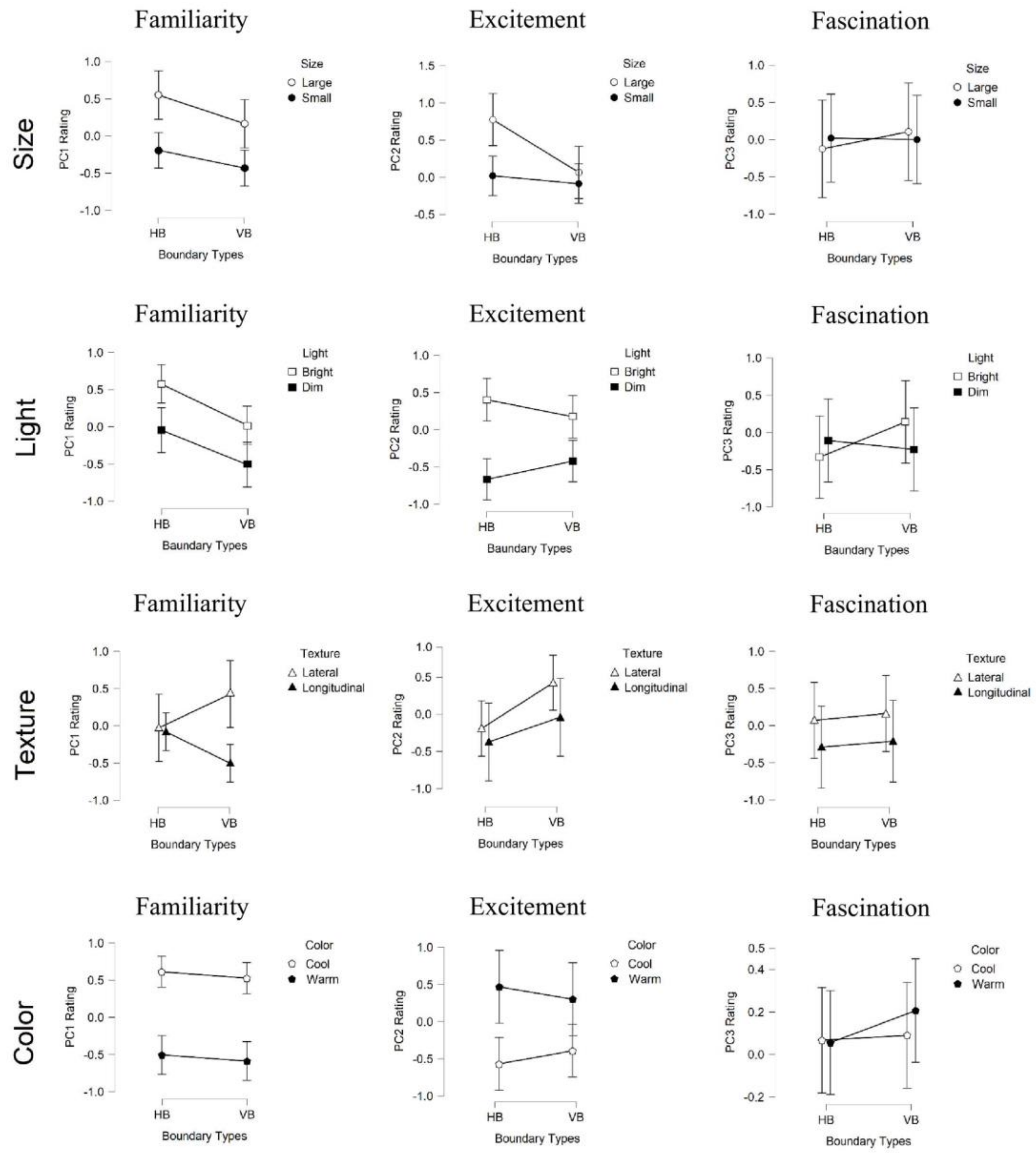


Figure 8. The impact of space properties and curved boundaries on the PC (drawn by the author, 2019).

Table 4. The primary dimensions of space properties and curved boundaries types on factorial ANOVA analyses.

	Familiarity	Excitement	Fascination
Size & Boundary			
Main effect of boundary	* $F(1,31)=4.75$, $p=0.037$ $\eta_p^2=0.13$	* $F(1,31)=4.39$, $p=0.044$ $\eta_p^2=0.12$	$F(1,31)=0.07$, $p=0.78$
Main effect of size	* $F(1,31)=30.03$, $p<0.001$ $\eta_p^2=0.49$	* $F(1,31)=6.19$, $p=0.018$ $\eta_p^2=0.17$	$F(1,31)=0.004$, $p=0.95$
Interaction of boundary & size	$F(1,31)=0.28$, $p=0.6$	* $F(1,31)=10.58$, $p=0.003$ $\eta_p^2=0.25$	$F(1,31)=0.36$, $p=0.55$
Light & Boundary			
Main effect of boundary	* $F(1,31)=12.43$, $p<0.001$ $\eta_p^2=0.29$	$F(1,31)=0.003$, $p=0.96$	$F(1,31)=0.31$, $p=0.58$
Main effect of light	* $F(1,31)=9.64$, $p=0.004$ $\eta_p^2=0.24$	* $F(1,31)=31.68$, $p<0.001$ $\eta^{2p}=0.50$	$F(1,31)=0.03$, $p=0.85$
Interaction of boundary & light	$F(1,31)=0.12$, $p=0.73$	* $F(1,31)=4.28$, $p<0.047$ $\eta_p^2=0.12$	$F(1,31)=1.82$, $p=0.18$
Texture & Boundary			
Main effect of boundary	$F(1,31)=0.002$, $p=0.96$	$F(1,31)=4.03$, $p=0.05$	$F(1,31)=0.08$, $p=0.78$
Main effect of texture	$F(1,31)=3.41$, $p=0.07$	$F(1,31)=1.50$, $p=0.23$	$F(1,31)=1.38$, $p=0.25$
Interaction of boundary & texture	* $F(1,31)=6.44$, $p=0.01$ $\eta_p^2=0.17$	$F(1,31)=0.45$, $p=0.50$	$F(1,31)=0.001$, $p=0.98$
Color & Boundary			
Main effect of boundary	$F(1,31)=0.65$, $p=0.43$	$F(1,31)=0.0001$, $p=0.98$	$F(1,31)=0.47$, $p=0.49$
Main effect of color	* $F(1,31)=19.37$, $p<0.0001$ $\eta_p^2=0.38$	* $F(1,31)=6.41$, $p=0.01$ $\eta_p^2=0.17$	$F(1,31)=0.07$, $p=0.79$
Interaction of boundary & color	$F(1,31)=0.0001$, $p=0.99$	$F(1,31)=1.22$, $p=0.28$	$F(1,31)=0.31$, $p=0.58$

* $p<0.05$ (Bonferroni corrected)

There was a main impact of boundary type and size in the 2x2 ANOVA on component 1 (familiarity). It was discovered that people were more familiar with horizontal boundaries than vertical ones (p=0.037, η_p^2=0.13). Similar findings showed that larger interior spaces were more familiar than smaller ones (p<0.001, η_p^2=0.49). Size and boundary type did not interact. Boundary type, size, and interaction were the major effects of the 2x2 ANOVA on component 2 (excitement). It was generally discovered that horizontal boundaries generated greater excitement than vertical boundaries (p=0.044, η_p^2=0.12). Similarly, it was discovered that larger interior spaces generate greater excitement than smaller ones (p=0.018, η_p^2=0.17). On the other hand, for large areas, the difference in excitement between the horizontal and vertical boundaries was significant (p=0.003, η_p^2=0.25). There were no major effects of interaction in the 2x2 ANOVA on component 3 (fascination) (Table 4 shows all factorial ANOVA results).

Boundary type and light were the major effects of the 2x2 ANOVA on component 1 (familiarity). It was discovered that people were more used to horizontal boundaries than vertical ones (p<0.001, η_p^2=0.29). Similarly, brighter interior areas were shown to be more familiar than dimmer ones (p=0.004, η_p^2=0.24). Light and boundary types did not interact. ANOVA on component 2 (excitement) with 2x2 revealed both the main impact of light and the interaction between boundary type and light. Brighter interior environments elicit higher excitement than dimmer ones (p<0.001, η_p^2=0.50). Furthermore, for bright regions only, the difference in excitement between horizontal and vertical boundaries was significant (p=0.047, η_p^2=0.12). There were no main effects or interactions in the 2x2 ANOVA on component 3 (fascination) (Table 4 shows all factorial ANOVA results).

An interaction between boundary type and texture was seen in the 2x2 ANOVA on component 1 (familiarity). For lateral spaces, but not longitudinal spaces, there were significant variations between horizontal and vertical boundaries (p=0.01, η_p^2=0.17).

There were no main effects or interactions found in the 2x2 ANOVA on component 2 (excitement) and component 3 (fascination) (Table 4 shows all factorial ANOVA results).

A major impact color was shown by the 2x2 ANOVA on component 1 (familiarity). Cooler interior color schemes were found to be more familiar than warmer ones (p<0.0001, η_p^2=0.38). Color and boundary type did not interact. A major effect color was displayed by the 2x2 ANOVA on component 2 (excitement). Warmer-colored interior areas were shown to elicit more excitement than cooler-colored ones (p=0.01, η_p^2=0.17). Color and boundary type did not interact. There were no main effects or interactions in the 2x2 ANOVA on component 3 (fascination) (Table 4 shows all factorial ANOVA results).

4.1.6. Discussion of Stage 1

The current study aims to offer a thorough, empirically based framework that describes how people experience architecture. The objective is to disclose the principal aspects of the aesthetic judgments and how different characteristics of the architectural surroundings impact these aspects. In order to achieve this, VR should be used to examine how architectural space properties with curved boundaries have been methodically altered. Participants in the study were asked to rate these areas using various scales frequently used in the literature. According to this research, there are three main aspects of human aesthetic judgments in spaces with curved boundaries: familiarity, excitement, and fascination. These aspects are influenced differently by various architectural features. The impact of primary aesthetic judgments on curved boundaries and space properties are discussed in detail.

Primary Dimensions of the Aesthetic Judgments with Curved Boundaries

The research indicates that familiarity, excitement, and fascination are the three primary qualities that best describe human aesthetic judgments in areas with curved boundaries. The “familiarity” dimensions comprise evaluations of how they *feel* in a given setting as pleasant, satisfied, or relaxed; how they think the setting *looks* to be as safe and coherent; and how they *behave* in this setting as whether they would like to spend time there or prefer to explore. With this structure in mind, the framework (triad model) proposed by Chatterjee and Vartanian (2014) and expanded upon by Coburn et al. (2020) takes a more holistic approach based on these broad domains in psychology, characterizing aesthetic judgments as distinct cognitive, emotional, and behavioral elements (see categorization in Table 2). However, research indicates that data-driven methods can change this predetermined classification, and the model might be more intricate for architectural areas with curved boundaries. More precisely, research demonstrates that three essential dimensions -aspects that intersect with the triad model's cognitive, affective, and behavioral components- can be used to describe the aesthetic judgments of architectural environments with curved boundaries. Figure 9 shows that the three main components identified in this study -cognition, emotion, and behavior-are represented by the a priori categories of aesthetic judgments.

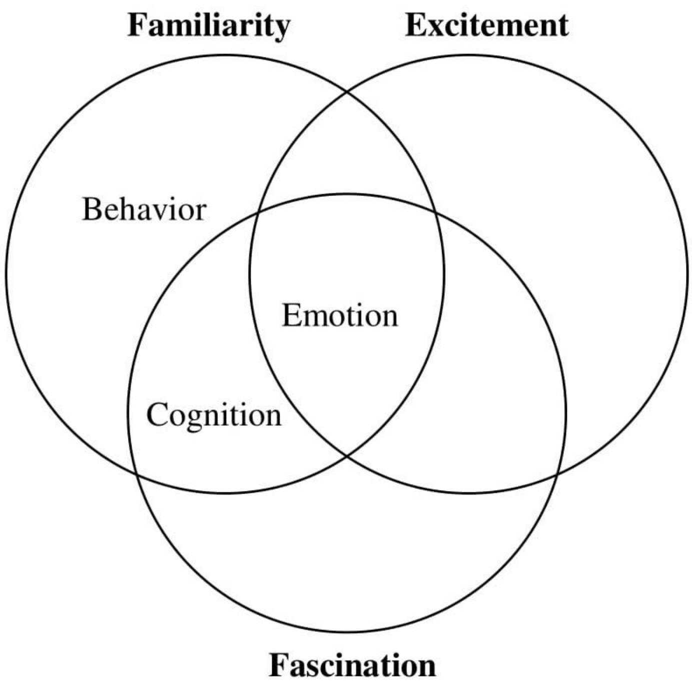


Figure 9. How the three a priori categories-the triad model of cognition, emotion, and behavior (Chatterjee & Vartanian, 2014)-relate to the main characteristics found in the current study (familiarity, excitement, and fascination) (drawn by the author, 2019).

The research demonstrates that, at least in environments with curved boundaries, elements presumptively classified as belonging to cognition, emotion, and behavior are covered by the “familiarity” dimension of aesthetic judgments. This finding aligns with the previous study that individuals perceive a location as familiar when they have a cognitive, affective, and behavioral connection (Meijering et al., 2019). Also, the results confirm Wickelgren's (1979) hypothesis, which states that people will interact more with an interior space as it becomes dominant and they become more accustomed to it. Conceptually, the familiarity dimension might connect to the hominess dimension put out by Coburn et al. (2020), who manipulate various architectural characteristics, such as curvature, to study how humans interpret aesthetics. Individuals may view their houses as safe and well-organized, experience happiness, contentment, and relaxation there, and want to spend more time there (see categorization in Table 2). Stated differently, the "familiarity" might signify a feeling of being a part of a place, such as a home.

The "excitement" is the second dimension identified in this study as a crucial aspect of human aesthetic judgments in environments with curved boundaries. This dimension encompasses evaluations of excitement, frenziedness, jitteriness, or contention in a given setting. According to the theoretical frameworks of previous studies (Coburn et al., 2020; Chatterjee & Vartanian, 2014), this dimension fits well with the triad model's emotional component (see categorization in Table 2). Stated differently, the "excitement" embodies the experience of feeling in an architectural environment.

The current study has identified "fascination" as the third dimension. This dimension covers evaluations of things like how complex or mysterious an environment *looks* or how stimulated one *feels* when in that environment. This dimension comprises the cognitive and emotional components of aesthetic judgments within the framework of the previous study (Chatterjee & Vartanian, 2014) triad model (see categorization in Table 2). In theory, it is also connected to the "fascination" dimension put out by Coburn et al. (2020), in which they manipulate architectural factors such as curvature, ceiling, and enclosure to study aesthetic judgments.

Ultimately, this VR research uncovered three major aspects of human aesthetic judgments in architectural spaces with curved boundaries. A detailed analysis of the composition of these dimensions reveals that the behavioral, emotional, and cognitive aspects of human aesthetic judgments -which have been postulated by previous research- might only sometimes manifest as distinct elements when describing human aesthetic judgments. This study, therefore, extends previous research by Marković (2012) and Polovina and Marković (2006), who postulate that aesthetic judgment is more strongly associated with interestingness- which this study expressed as a fascination dimension- than with other dimensions of subjective experience such as positive hedonic tone, which is conceptually associated with the excitement dimension, and regularity, which in this case corresponds to the familiarity dimension. The study explains how these dimensions vary in the following section by reviewing how various curved boundaries and specific properties affect them.

Primary Dimensions of the Aesthetic Judgments with Space Properties

In the current study, numerous architectural factors were adjusted, including the variety of curved boundaries, as well as the specific properties of the architectural spaces, and how these variables influenced the essential characteristics of human aesthetic judgments in VR. Based on various architectural factors, the results demonstrate how the three primary dimensions of aesthetic judgments in curved boundaries differ.

The dimension of familiarity is influenced by the architectural space properties, such as size, color, and light, in that order (following the magnitude of effect sizes). Larger rooms with brighter lighting and a colder color scheme are perceived as more familiar than smaller rooms with dimmer lighting and a warmer color scheme. Additionally, the familiarity dimension is impacted by the curved boundaries, particularly when the space is presented with varying sizes or lighting. More specifically, it has been observed that architectural spaces with horizontal boundaries are more familiar regardless of size or light level than those with vertical ones. On the other hand, how familiar people find a space depends on how the architectural texture interacts with the type of curved boundaries. Specifically, people find lateral patterns more familiar than longitudinal patterns within a vertically defined space, while within a horizontally defined space, people find both lateral and longitudinal patterns equally familiar.

The dimension of excitement is influenced by architectural space properties, light, size, and color, though in slightly different ways than how color and size. Larger areas with warmer colors, brighter lighting, and brighter lighting elicit more excitement than smaller areas with cooler colors, dimmer lighting, and smaller sizes. Furthermore, the excitement dimension is influenced by the kind of curved boundaries, particularly when the space is presented in varying sizes. Regardless of their size, areas with horizontal boundaries are particularly exciting than those with vertical boundaries. However, the excitement an architectural space evokes in people depends on its light and its curvature. To be more precise, areas with brighter lighting add more excitement than those with dimmer lighting when a HB separates them; conversely, areas with dimmer lighting create more excitement than those with brighter lighting when a VB separates them.

These results corroborate past studies showing that a larger space (Bokharaei & Nasar, 2016; Franz & Wiener, 2005; Franz et al., 2005; Franz, 2006; Stamps, 2007, 2009, 2010), more lighting (Durak et al., 2007; Odabasioglu & Olgunturk, 2015; Stamps, 2007), and colder colors (Franz, 2006; Odabasioglu & Olgunturk, 2015) all correlate with an increase in aesthetic judgments. The study makes a significant contribution to the body of literature by identifying the fundamental dimensions that underpin a variety of scales that have been used independently in prior research and by demonstrating how different architectural space properties, such as familiarity and excitement, affect these dimensions. In this way, this research offers a thorough, methodical, and data-driven description of the aesthetic judgments of humans.

None of the architectural space properties used in this study affect the fascination dimension. The results contradict certain earlier research that indicates the amount of stimulation in a space can be enhanced by its shape (Archea, 1977), size (Aiello, 1987; Baum & Paulus, 1987), texture (Evans & McCoy, 1998), color, and lighting (Berlyne, 1971; Mehrabian & Russell, 1974). For one thing, the stimuli employed in this study might have been too easy to make people fascinated. Stated differently, it is plausible that individuals find architectural spaces fascinating when they are more natural and complex and incorporate a variety of space attributes. Table 5 shows the summary of the findings of stage 1.

Table 5. Summary of the findings of Stage 1.

	Curved Boundary	Space properties			
		Size	Light	Texture	Color
Familiarity	HB>VB	Large>Small	Dim<Bright	ns	Cool>Warm
Excitement	HB>VB	Large>Small	Dim<Bright	ns	Cool<Warm
Fascination	ns	ns	ns	ns	ns

ns: non-significant

Therefore, in stage 2, new architectural variables are combined rather than studied separately as in stage 1. The next experiment, designed from a combined perspective, resembles a RE. The architectural environment that the individuals are in already includes many parameters in the same space. However, dealing with these combined parameters in experimental studies allows us to obtain more robust and consistent data. The findings of the three main aesthetic judgments are being tested in newly designed architectural variables and two different VR environments.

4.2. Method of Stage 2

For stage 2, the study designed 32 architectural variables for VR settings. Stage 1 looks at the curved boundaries (HB and VB) and space properties (S/L/T/C), while this stage looks at the architectural variables (HB:S/L/T/C and VB:S/L/T/C), which include both curved boundaries and space properties. Consequently, the research examines whether there are any parallels or discrepancies between the initial and subsequent phases of the investigation concerning VR environments. The study also explores whether the presentation of architectural variables affects how participants perceive or interact with a VR environment (IVE and DTVE). Additionally, the study aims to examine how participants' sense of presence is affected by IVE and DTVE. Based on familiarity, excitement, and fascination -aesthetic judgments that are coming from the previous stage- participants rate these spaces. The following RQ are posed for stage 2:

RQ3: What are the aesthetic judgment dimensions associated with VEs and architectural variables of interior spaces?

RQ3a: Is there a difference in aesthetic judgment dimensions based on VEs of interior spaces?

RQ3b: Is there a difference in aesthetic judgment dimensions based on architectural variables of interior spaces?

RQ4: Does interaction between VEs and architectural variables affect the aesthetic judgment dimensions of interior spaces?

RQ5: Is there a difference in presence based on VEs of interior spaces?

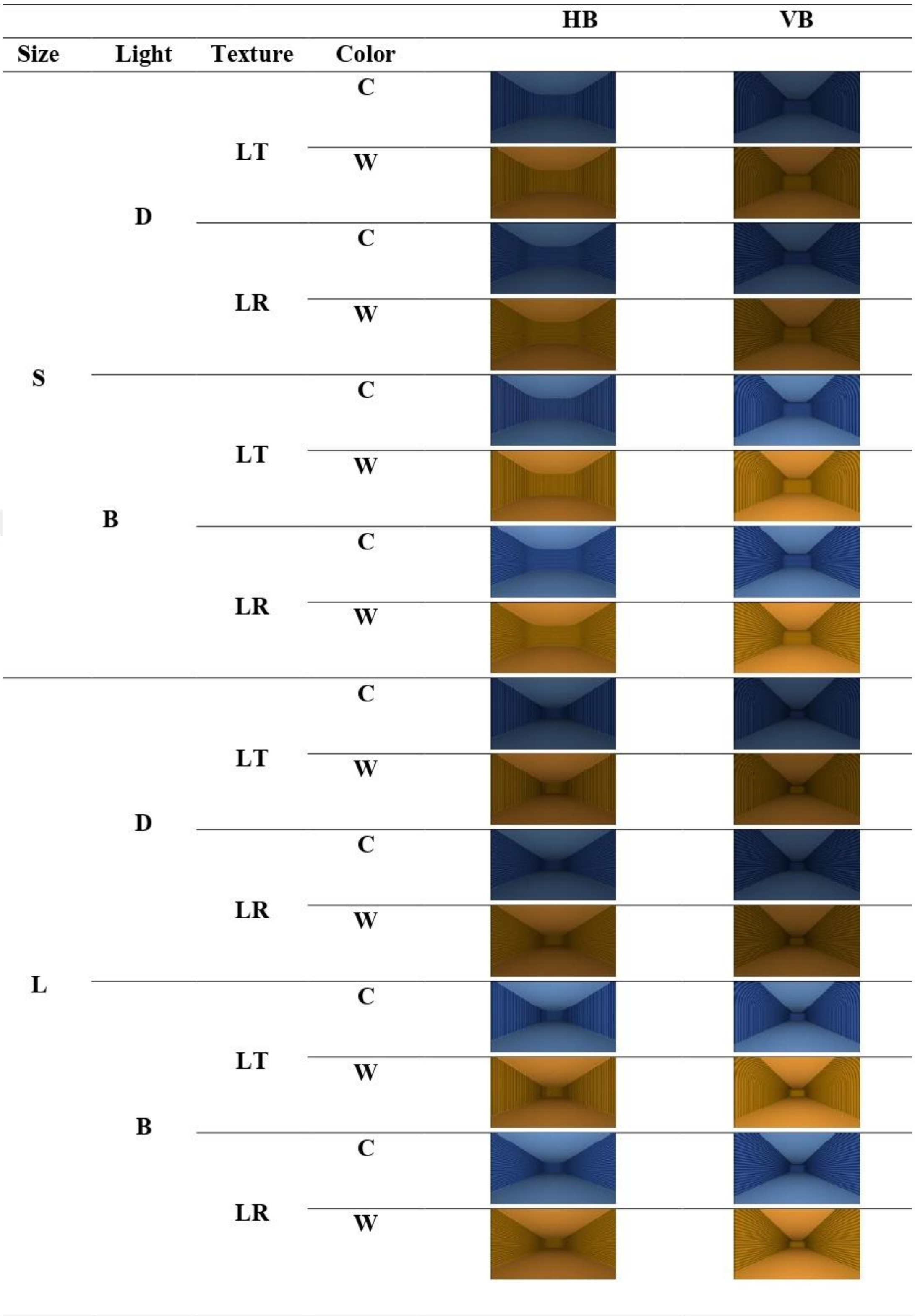
RQ6: Do aesthetic judgment dimensions have an impact on the presence scores in VE?

4.2.1. Participants

The experiment involved 60 graduate and undergraduate students from various departments of Bilkent University, 37 of whom were female and 23 of whom were male. Using an ANOVA and an a priori G* Power F-test analysis (Faul et al., 2009). The study employed repeated measures within factors, with a power level of 0.90 and estimated effect size (f) of 0.25, α=0.05. This suggested that a minimum of 44 participants were needed for each of the 32 visualizations. This study was authorized by the Institutional Ethics Review Board of Bilkent University (No: 2023_10_02_01, see Appendix B2). The informed consent form (see Appendix C2) was signed by each participant. The study consists of two sections (IVE and DTVE), and the same individuals participated in the experiment. Ishihara's electronic color blindness test was used (Color-blindness.com, 2023) to ensure the subjects' complete color perception (see Appendix D).

4.2.2. Environmental Stimuli

Curved boundaries and space properties are two architectural variables that create the experimental stimulus in the VE, and they were examined individually in the 1st stage. In stage 2, these qualities are integrated, and 32 new architectural variables are constructed in a combined way. The participants perceive these zones at eye level. (see Figure 10).



Horizontal Boundary(HB):size(S)/light(L)/texture(T)/color(C) and
Vertical Boundary(VB):size(S)/light(L)/texture(T)/color(C).

Figure 10. Architectural variables visualizations (designed by the author, 2023).

4.2.3. Instruments and Procedures

The study aims to identify the impacts of architectural variables on different VEs and examine the differences in participants' aesthetic judgments of the VEs. Two VEs were used for the study: a DTVE and an IVE. A digital model's stereoscopic images are displayed by an immersive (IVE) high-end VR system, while its monoscopic perspective views are displayed by a non-immersive (DTVE) low-end VR system (Paes et al., 2021).

The three aesthetic judgments of thirty-two 360-degree perceived architectural surroundings are determined using HTC Vive Pro for IVE and IntelI Core i7-7700U CPU @ 3.60GHz computer for DTVE. IVE is a fully immersive environment that comes with two touch controllers and a headset for assessing aesthetic judgments as well as presence questionnaire (PQ) scores. DTVE was a monitor-based VR system that used a computer mouse to facilitate user interaction with the virtual world and a high-performance 32" full HD monitor to display the VR environments. In order to avoid perceptual discrepancies brought on by various computer settings, each participant uses the same desktop computer (Luminance 120; Gamma 2.2; Color temperature 6500K; Color display 24-bit) (EIZO, 2023; Federal Agencies Digital Guidelines Initiative, 2016).

As an egocentric framework in the IVE, participants donned the headgear and rotated 360 degrees to move around the scene. The participant in the DTVE was utilizing a 32" full HD monitor and a mouse while seated in front of a desk. The 32 visualizations in both environments had a total duration of 10 seconds. Depending on the location and customization of the virtual glasses, the IVE experience process took 25-30 minutes, while the DTVE experience process took roughly 15-20 minutes. Every subject underwent two phases in the experiment. Every participant began the experiment in one stage before switching to the other. To avoid the order effect, thirty individuals experienced the IVE first, followed by the DTVE, while the remaining thirty participants experienced the DTVE first, followed by the IVE. The experiment room in the Bilkent University FF building was devoid of windows, color, and furniture for both sessions. The only items present were the VR system and desktop equipment.

Qualtrics survey is conducted in both VEs ("Qualtrics XM - Experience Management Software," 2023). After viewing each space, participants assessed the three aesthetic dimensions on a 7-point Likert scale (1=represent not at all and 7=represent great deal). The visualizations were assigned at random within Qualtrics (see Appendix E2 for survey set). The previous stage 1 findings, which categorized the three dimensions of the aesthetic judgments -familiarity, excitement, and fascination- were used by the participants to rate these visualizations. The PQ was given to participants after they had finished two sections in order to assess how present they felt in the 3D perceptions in the VEs (IVE and DTVE). Most of the PQ are derived from the Slater-Usoh-Steed (SUS) instrument designed by Usoh and colleagues (2000). Table 6 shows the set of VE PQ that Paes (2019) developed, drawing inspiration from Usoh et al., (2000), Witmer and Singer, (1998), and Zikic, (2007). In addition, the participants were asked back to take part in the experiment's second phase a week after finishing the first.

Table 6. VEs Presence questionnaire (adapted from Paes, 2019, pp. 129-130).

Presence questionnaire (PQ)
1. To what extent did you feel present in the space considering your presence experiences in the real world?
2. When you think back about your experience, to what extent do you think of the space as a place in a way similar to when you remember of other places that you have been today?
3. When you think back about your experience, to what extent do you think of the space as somewhere you were at?
4. During the time of the experience, how strong was your sense of being in the space rather than being in the experiment room?
5. To what extent did your visual experience in the space seem consistent with your visual experiences in the real world?
6. To what extent did you feel you could grasp an object in the space?
7. If the space ceiling had started to collapse, what would have been the probability of you dodging in an attempt to not getting hit by falling parts?
8. Were there times during the experience when the space was the reality for you?
9. Were you involved in the experience to the extent that you lost track of time?
10. To what extent have you experienced motion sickness (nausea, dizziness)?

4.2.4. Data Analysis of Stage 2

Based on the ratings of the 60 participants, the 2 architectural variables (HB:S/L/T/C and VB:S/L/T/C) x 2 presentation mode (IVE and DTVE) repeated measures ANOVA and their relationships with the three aesthetic judgment dimensions were conducted. This led to the determination of the main effects of architectural variables, VEs, and the interaction between VE and architectural variables. In addition to these, a pairwise comparison was used to report the VEs' presence score. In order to ascertain the proportion of variation in the dimensions of the architectural variables that affect the presence score, the research also performed a hierarchical multiple regression analysis.

4.2.5. Results of Stage 2

The result of Stage 2 is divided into five categories. The relationship between aesthetic judgments and VEs (IVE and DTVE), the aesthetic judgments and architectural variables, aesthetic judgments and presence score of VEs, and VEs and presence score hierarchical multiple regression analysis were conducted. Using the RStudio (2023), the relationships were calculated (see Figures 11, 12,13, and 14).

Aesthetic Judgment Dimensions and VEs

In Figure 11, the ANOVA on the familiarity dimension showed a main effect of VEs ($F(1,59)=15.81$, $p<0.0001$, $\eta_p^2=0.21$). IVE ($M=3.83$, $SD=0.11$) was more familiar than DTVE ($M=3.36$, $SD=0.11$). The excitement dimension showed a main effect of VEs ($F(1,59)=4.56$, $p<0.05$, $\eta_p^2=0.07$). IVE ($M=3.75$, $SD=0.09$) was more exciting than DTVE ($M=3.56$, $SD=0.09$). The fascination dimension showed no main effect of VEs ($F(1,59)=1.78$, $p=0.18$).

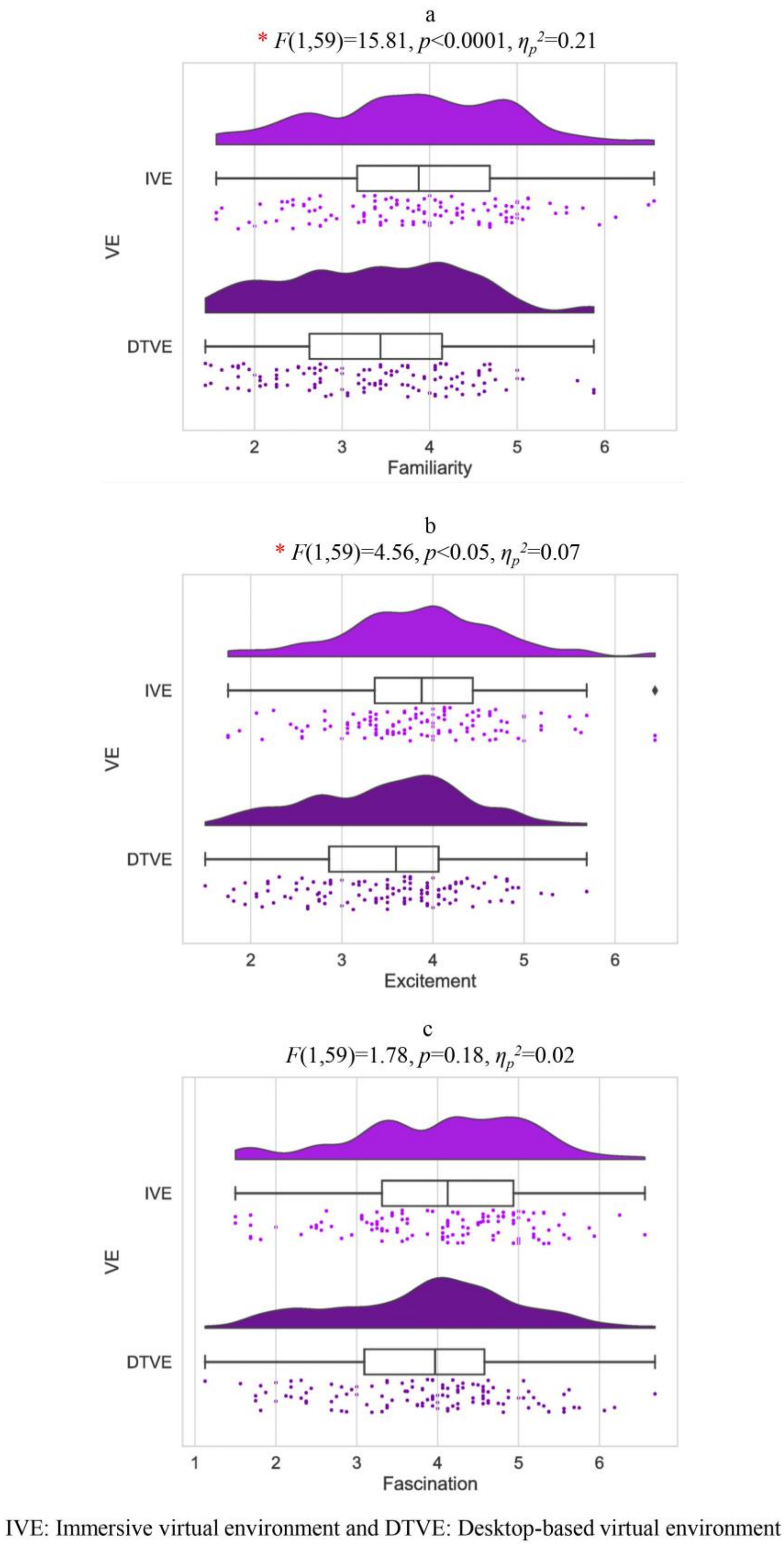


Figure 11. Raincloud plots of aesthetic judgment dimensions (a: Familiarity, b: Excitement, and c: Fascination) and VEs (drawn by the author, 2023).

In Figure 12, the ANOVA on the familiarity dimension showed a main effect of architectural variables ($F(1,59)=97.90$, $p<0.0001$, $\eta_p^2=0.62$). Horizontal boundaries ($M=4.03$, $SD=0.10$) were more familiar than vertical boundaries ($M=3.15$, $SD=0.11$). The excitement dimension showed a main effect of architectural variables ($F(1,59)=6.50$, $p<0.01$, $\eta_p^2=0.10$). Vertical boundaries ($M=3.77$, $SD=0.10$) were more exciting than horizontal boundaries ($M=3.55$, $SD=0.08$). The fascination dimension showed a main effect of architectural variables ($F(1,59)=31.70$, $p<0.0001$, $\eta_p^2=0.35$) as well. Vertical boundaries ($M=4.30$, $SD=0.11$) were more fascinating than horizontal boundaries ($M=3.60$, $SD=0.10$).

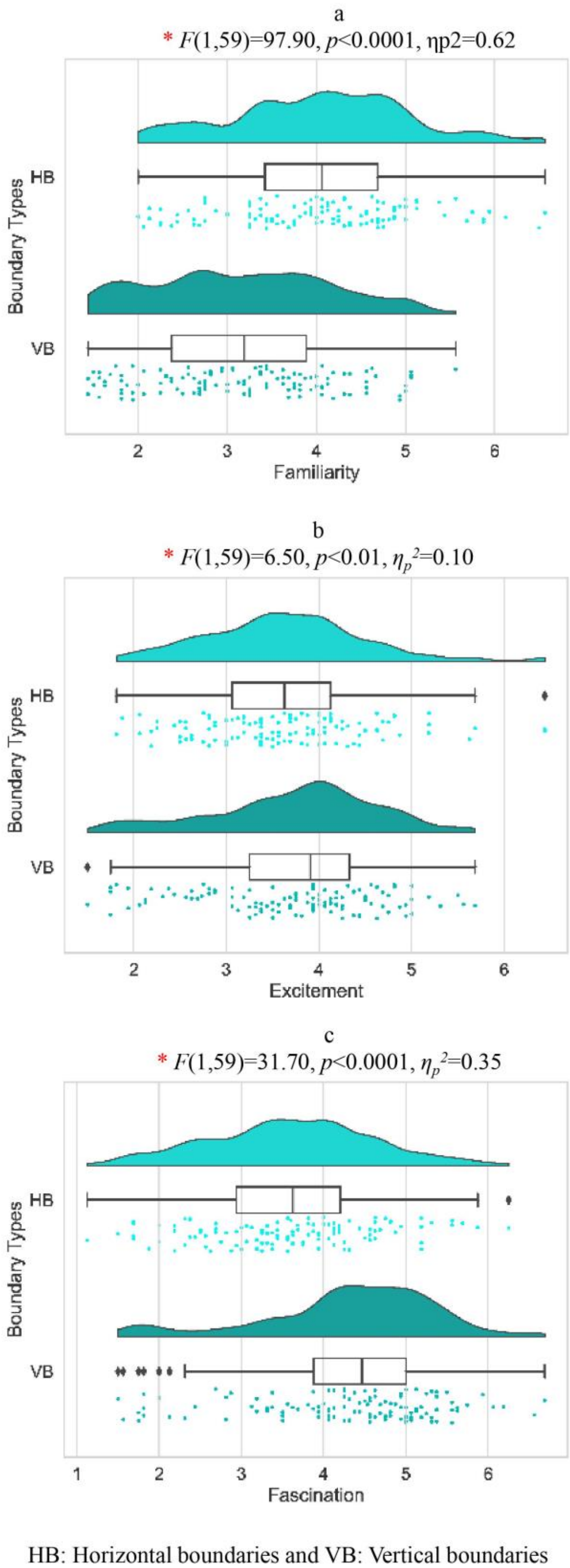
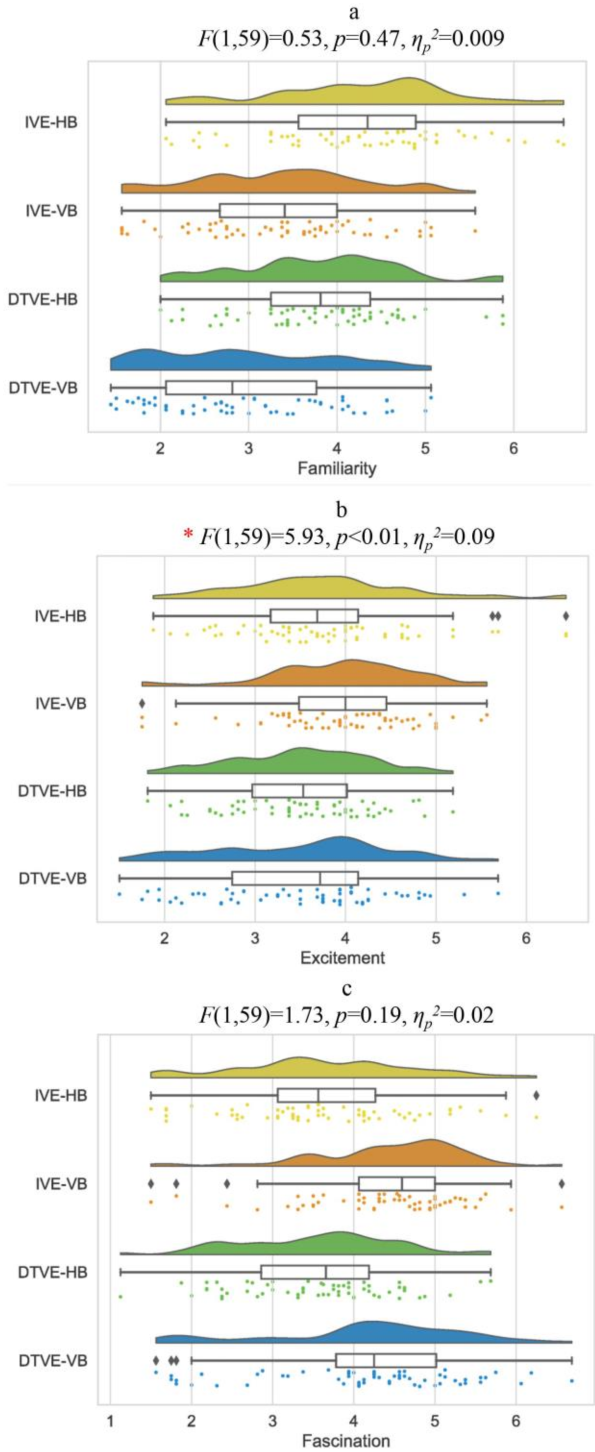


Figure 12. Raincloud plots of aesthetic judgment dimensions (a: Familiarity, b: Excitement, and c: Fascination) and architectural variables (drawn by the author, 2023).

Architectural Variables and VEs Interactions in Aesthetic Judgment Dimensions

In Figure 13, ANOVA on familiarity ($F(1,59)=0.53$, $p=0.47$) and fascination ($F(1,59)=1.73$, $p=0.19$) dimensions showed no significant interaction between architectural variables and VEs. The excitement dimension showed a significant interaction between architectural variables and VEs ($F(1,59)=5.93$, $p<0.01$, $\eta_p^2=0.09$. In contrast, the two architectural variables did not significantly differ in excitement for the DTVE ($t(59)=0.84$, $p=0.40$).



IVE-HB: Immersive virtual environment-Horizontal boundaries, IVE-VB: Immersive virtual environment-Vertical boundaries, DTVE-HB: Desktop-based virtual environment-Horizontal boundaries, and DTVE-VB: Desktop-based virtual environment-Vertical boundaries

Figure 13. Raincloud plots of architectural variables and VEs interactions in each aesthetic judgment dimension (a: Familiarity, b: Excitement, and c: Fascination) (drawn by the author, 2023).

Presence of VEs in Aesthetic Judgment Dimensions

In Figure 14, the ten presence scores differed between IVE and DTVE, with higher values found in IVE. While in the IVE, the density distribution is between 4-6 scores, in the DTVE, the density distribution is between 2-4. The mean number of presences scores at IVE (*M*=4.58, *SD*=1.06) and DTVE (*M*=2.77, *SD*=1.02) differ significantly t=10.97, df=59, two-tailed p<0.0001. The average difference between the paired mean score values IVE and DTVE mean values is 1.81.

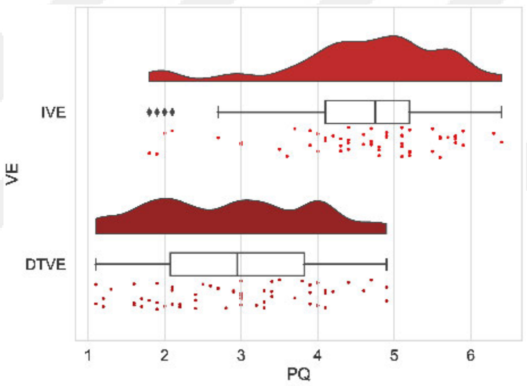


Figure 14. Raincloud plots of presence scores and VEs (drawn by the author, 2023).

Hierarchical Multiple Regression on VE's and Presence Score

Hierarchical multiple regression was used to identify the predictive role of aesthetic dimensions of architectural variables in determining the presence score in IVE and DTVE. Two models were found to be effective in IVE. The first IVE model included the familiarity and excitement dimensions of the architectural variables. The excitement dimension (β=0.53, t=4.37, df=57, p<0.001) is the only predictor that explains 24.34% of the variance of the architectural variables in the presence score of model 1 in IVE. The second model of IVE included the architectural variables' familiarity, excitement, and fascination dimensions. The fascination dimension (β=0.45, t= 2.69, df=56, p=0.009) is the only predictor that explains 8.35% of the variance of the architectural variables in the presence score of model 2 in IVE. However, one model was effective in DTVE, including the familiarity and excitement dimensions of the architectural variables. The excitement dimension (β=0.33, t=2.6, df=57, p=0.012) is the only predictor that explains 10.18% of the architectural variables' variance in the model's presence score, as seen in Table 7. All the aesthetic dimensions were checked for collinearity, and all the predictors had tolerance levels greater than 0.1.

Table 7. Hierarchical multiple regression on VE's and the presence score.

	IVE		DTVE
	Model1 (familiarity, excitement)	Model2 (familiarity, excitement, fascination)	Model1 (familiarity, excitement)
Excitement	0.49**		0.32*
Fascination (Correlations Part)		0.29**	
β	0.53	0.45	0.33
R	0.52	0.60	0.38
R^2	0.27	0.35	0.15
ΔR^2	0.24	0.08	0.10
ΔF	19.06	7.26	6.79
df	57	56	57

*p<0.05
** p<0.001

To summarize the hierarchical multiple regression results, the excitement dimension was the leading predictor in IVE. The fascination dimension was the second effective predictor in IVE. However, the excitement dimension was the only predictor in DTVE. VE’s excitement dimension (wideawake, excited, frenzied, jittery, contended) was the common predictor of the presence score in both environments.

4.2.6. Discussion of Stage 2

The study aims to test the combined architectural variables of IVE and DTVE in different VEs and emphasize how aesthetic judgments influence them. The study also explores how architectural variables (HB:S/L/T/C and VB:S/L/T/C) affect aesthetic judgments. Another aim of the study was to investigate the differences in feelings of presence in different VEs. The effects of VEs on aesthetic judgments, architectural variables on aesthetic judgment, interactions of architectural variables with aesthetic judgment, and effects of presence in VEs on aesthetic judgment are explored in detail. A comparative discussion with the result of the previous study (stage 1) has been given in detail.

Effects of VEs on Aesthetic Judgment

The current study investigates users' presence outcomes and aesthetic judgment within the relevant VEs. The study's findings indicate that the elements of familiarity and excitement components demonstrate major roles in both VEs. The familiarity components of aesthetic judgment include elements such as 'happy, pleased, satisfied, relaxed, like to spend time, prefer to live, enjoy exploring, and others. The 'hominess' element mentioned in Coburn et al.'s (2020) study, which investigated the human aesthetic judgment by varying architectural characteristics, could also be conceptually connected to the familiarity dimension. The dimension of familiarity can signal a sense of connection to a location like being at home. In this study, the familiarity aesthetic judgments in the IVE showed stronger results compared to the DTVE. This could be because the IVE creates a greater feeling of closeness and comfort akin to being at home than the DTVE. The reason for this could be that there are no outside influences or disruptions when the participants are experiencing the locations. A different explanation might be that participants were free to move their heads about in the VE during the IVE. When necessary, they may rotate their heads, just like acts in real-world.

Throughout the experiment, participants had to remain seated and were not permitted to move. Because of this, wandering around a room is a more familiar approach to explore and visualize it than using DTVE. The focus vision of IVE might provide users with a sense of being in a familiar environment. Furthermore, familiarity and excitement aesthetic components yield the same outcome. Excitation was defined in the prior study (stage 1) as "contended (satisfied)". This result is in line with Imamoglu's (2000) theory, which postulates that stimuli that are more familiar to us might seem less complex, more predictable, and satisfying overall. Nevertheless, a previous study (stage 1) demonstrates that fascination with the components of aesthetics is described as 'complex'. There are no significant factors (complex, mysterious, and stimulated) that contribute to the fascination with aesthetic judgment, which is distinct from the other two aesthetic components. The results of this study are consistent with Imamoglu's (2000) earlier research, which found that when individuals become more familiar to a given stimulus, surroundings might seem mysterious, less complex, and more predictable.

The IVE and DTVE have been observed in earlier research employing simulated architectural surroundings settings (Higuera-Trujillo et al., 2017; Paes et al., 2017; Paes et al., 2021; Paes et al., 2023; Shu et al., 2019). This research quantified how users' perceptions of presence and immersion differ across the two VEs. Beyond preference and perception, further research in the field is required to fully understand the VEs' aesthetic judgment. A thorough scoping assessment of human behavioral studies analyzing VR environments in three areas (perception, interaction, and sensing and reconstruction of reality) was carried out by Hepperle and Wölfel (2023). In their research assessment, Verwulgen et al. (2019) noted that there was just one research investigation into the topic of sensing and reconstructing reality connected to aesthetic judgment in VE facade design.

Effects of Architectural Variables on Aesthetic Judgment

Human preferences for curvature are widespread, although they are not always continuous or invariant, according to Chuquichambi et al. (2022). Moreover, Djebbara and Kalantari (2023) showed that curvature preference and potential interactions with an object are negatively related. The previous study (stage 1) examined various curvilinear boundary types and space properties in the built environment.

Nevertheless, none of the architectural factors they studied had an impact on the fascination dimension, one of the aesthetic components. The previous study (stage 1) also suggested that 'fascination' with aesthetic elements that interact with the perception of the built setting can be enabled by integrating different types of boundary and space properties, which translates to a holistic approach.

Consequently, this stage study examines architectural variables collectively rather than analyzing them separately. This outcome is in line with actual architectural characteristics seen in people's living space, such as curved boundaries and SLTC. This study examines how different aesthetic judgments are affected by architectural variables. The research discovered that an individual's experience of their surroundings influenced the three components of aesthetics: familiarity, excitement, and fascination.

Familiarity and complexity are regularly regarded as separate dimensions of the architectural surroundings (Alexander, 2002; Kaplan & Kaplan, 1989; Salingaros, 2007). This study showed that people were more familiar with horizontal boundaries with different architectural variables than with vertical boundaries, and that people perceived vertical boundaries to be more fascinating and exciting than horizontal ones. The previous study (stage 1) also found that investigations into horizontal boundaries were more familiar and exciting than those into vertical boundaries. According to the previous study (stage 1), elements that are both unexpectedly different and familiar are perceptually salient aspects of the built setting that can be independently altered in architectural design methods that run concurrently with the Coburn et al. (2020) study.

Interactions of Architectural Variables and VEs with Aesthetic Judgment

The previous study (stage 1) focused on the one-to-one interactions between boundary types and space properties including SLTC. The previous study (stage 1) discovered the interaction of boundary and size and the interaction of boundary and light in the excitement dimension, the interaction of boundary and texture in the familiarity dimension, and no interaction between boundary and color.

This study also investigates the relationships between VEs and architectural variables in all dimensions of aesthetic judgment. The primary impact of the interaction between the architectural variable and VE was only visible in the excitement dimension. This result makes a significant contribution to the current literature because, as far as aware, no other study has looked at aesthetic judgments in VEs with different architectural variables.

Effects of Presence in VEs on Aesthetic Judgment

The primary focus of this study is on how participants' aesthetic judgments and presence scores are affected when they are around VEs. The study's findings demonstrated that IVE experiences more presence feelings than DTVE. A previous study (stage 1) limits their investigation in the IVE, and further research focusing on space with curved boundaries and different specific properties in VE presence comparison is needed. This study combines the human psychology of aesthetic judgments with the VE's sense of presence. A more thorough examination of what transpires when an individual reports VEs about presence is given by this research. According to the results of the multiple regression analysis, users' feelings of presence are influenced by how exciting the environment is. Table 8 presents a comprehensive overview of the results obtained during stage 2.

Table 8. Summary of the findings of Stage 2.

	Presentation mode	**Architectural variables**	**Presentation mode + Architectural variables**	**PQ**
Familiarity	IVE>DTVE	HB+SLTC >VB+SLTC	ns	IVE>DTVE
Excitement	IVE>DTVE	HB+SLTC <VB+SLTC	IVE-HB+SLTC	
Fascination	ns	HB+SLTC <VB+SLTC	ns	

ns: non-significant

In stage 3, the aesthetic judgment of architectural variables using IVE was carried out with behavioral and neural examinations. Furthermore, the presence results of IVE as a stage 2 output has been a reference for stage 3, and the use of mobile EEG has been determined accordingly. Nowadays, neural measurements can be conducted with various equipment. The EEG device that could be adapted to IVE was used for stage 3. If DTVE became more present among the participants, stage 3 would be conducted from the computer screen (DTVE) adapted to the MR (3 Tesla MRG-Siemens Magnetom) device. In brief, the neural and behavioral data comparison is in phase 3. Are the aesthetic judgments of neural data and responses consistent based on the compilation of the knowledge participants have obtained? Or If differences exist, and what?

4.3. Method of Stage 3

For stage 3, the study utilized the same 32 stimuli to understand the neural correlates of interest for the three aesthetic components, namely familiarity, excitement, and fasincation. The study was conducted in IVE with a mobile EEG equipment. Since the mobile EEG device has no sharp movement restriction, the participants can experience 3D 360-degree simulations with IVE. Stage 3 consisted of three tasks regarding the three aesthetic components to investigate the identification of neural correlates. The following research questions are posed for stage 3:

RQ7: Are theta, alpha, and beta waves sensitive to architectural variables (i.e., HB:S/L/T/C vs. VB:S/L/T/C)?

RQ8: Are theta, alpha, and beta waves influenced by task demands (regarding the specific aesthetic judgment) during the perception of architectural variables?

4.3.1. Participants

The experiment involved 15 graduate and undergraduate students from the various departments of Bilkent University, 7 of whom were female and 8 of whom were male. According to previous research, samples with 12-15 participants are appropriate for neuroimaging studies (Aksoy et al., 2021; Banaei et al., 2017a; Slobounov et al., 2015; Vecchiato et al., 2015a, 2015b). In order to equilibrate the participants' neurocognitive development, participants had to be at least 20 years old, with ages 45 and above not being accepted (Brooks et al., 2011; Rosander & Von Hofsten, 2011; Shemesh et al., 2022). A questionnaire was given to those who met the age requirements so that the studies could ascertain whether or not each participant met the inclusion/exclusion requirements. The subjects were normal or corrected-to-normal vision, no history of neurological disorders, no history of attention deficit hyperactivity disorder, no heart disease, pregnancy, vertigo, or claustrophobia. the Ethics Committee of Bilkent University approved (No: 2023_10_02_01, see Appendix B2), and the informed consent form (see Appendix C2) was obtained from the subjects. Ishihara's electronic color blindness test (see Appendix D) was used to measure participants' color accuracy (Color-blindness.com, 2023).

4.3.2. Environmental Stimuli

As conducted in stage 2, the same 32 interior space visualizations include architectural variables of the surrounding surfaces analyzed. The participants perceived these zones at eye level. (see Figure 10). Since the EEG device was used in the study, the visualizations were shown in the form of 360-degree video simulations in the VE in order to minimize the participant's movement.

4.3.3. Instruments and Procedures

The experiment room (Bilkent University G building psychology lab 1), except for the VR + EEG equipment and data acquisition devices, was vacant, colorless, and devoid of windows. The experimental setting would be similar to the one seen in Figure 15.

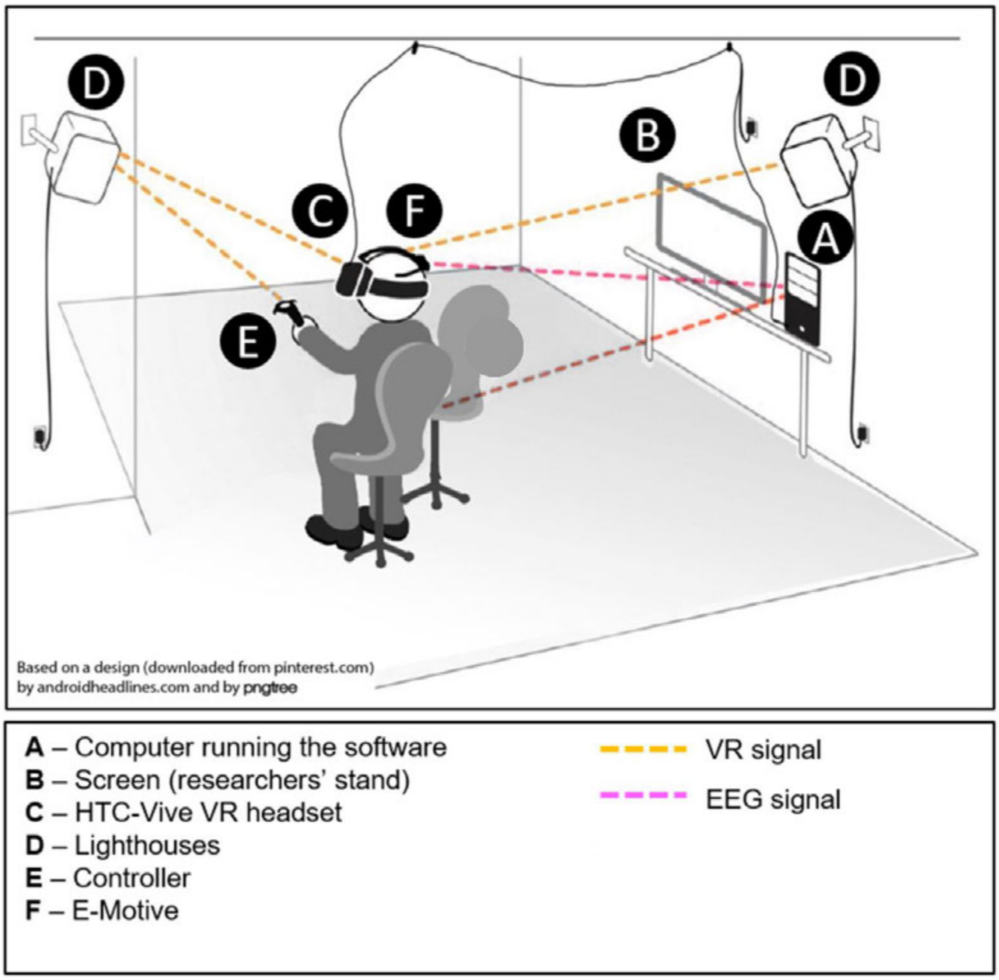


Figure 15. Example of experiment settings (adapted from Shemesh et al., 2022, p.5).

A participant in the experiment wears a VR headset, and there is a controller in order to respond to appropriate aesthetic judgments; a computer, screen, and controller within the room are used by the researcher to run the experiment, along with HTC sensors mounted above the ceiling tracking headsets. The subject has an EEG device placed atop their head and then VR equipment for both sessions. In the right corner, the computer runs the experiment, in which the EEG, the VR, and the programs operating concurrently. In order to make the real-time data easier to follow, the computer simultaneously records it on two screens and gathers it.

The total time for the task section is 60-70 minutes, including electrode placement and VR glasses adaptation on participants' heads, stimulus presentation, and data acquisition. To minimize EEG noise disruptions, participants were asked to move as little as possible throughout the process.

The experiment continued in a VR environment generated by Unity’s real-time engine in conjunction with C# scripts (see Appendix F), experienced by HTC Vive Pro. The integration of HTC Vive VR and the Emotive EEG recorder was the study's primary challenge. The goal was to capture participant behavior and neural responses while presenting a 3D 360-degree visualization of a designed space with different architectural variables using Unity Engine and C# scripts. Opening ports to incorporate the data sent by C# scripts to the EEG recorder helped to preserve the link between the Emotive EEG recorder and VR. Start markers for buffers, space visualizations, and reaction tabs were supplied to the ports linked to the Emotive EEG recorder during the display of the stimuli. A general marker ID was assigned to buffers and response tabs, while a unique marker was assigned to each visualization to serve as an indicator of start and for analytical purposes. Before recordings began, unnecessary channels that accidentally landed in the VR headset were eliminated to guarantee a smooth brain recording (see Figure 16).

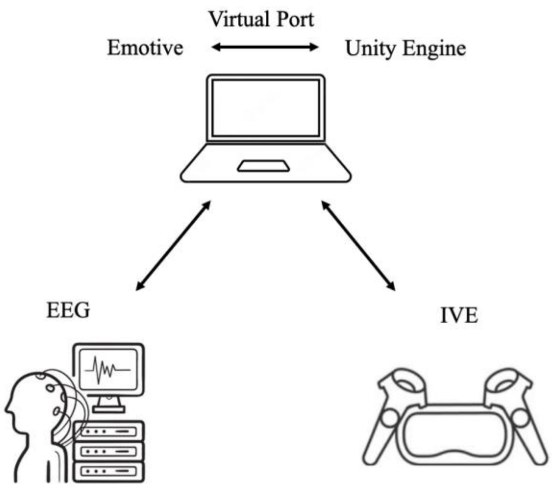


Figure 16. Interplay between EEG and IVE via ports (drawn by the author, 2024).

To understand the effect of architectural variables of the environment on the aesthetic judgment of participants, mixed-method (quantitative and qualitative) data is required to relate neuroscientific measurements with aesthetic judgment. Emotive (EPOC Flex 32-channel mobile brain wear) channels (see Figure 17) obtain physiological data from individuals as they encounter various VE by using HTC Vive Pro (see Figure 18). Channels are Fz, F3, F4, F7, F8, FC1, FC2, FC5, FC6, FT9, FT10, Cz, C3, C4, T7, T8, CP1, CP2, CP5, CP6, Pz, P3, P4, P7, P8, PO3, PO4, Oz, O1, O2, O9, and O10. The sensor wires are color-coded. Blue is utilized on the left side (odd numbers), red on the right side (even numbers), and black for reference points. However, for the electrode coding, ‘F’ represents frontal channels, ‘C’ defines central channels, ‘T’ presents temporal channels, ‘P’ symbolizes parietal channels, and “O” depicts occipital channels.

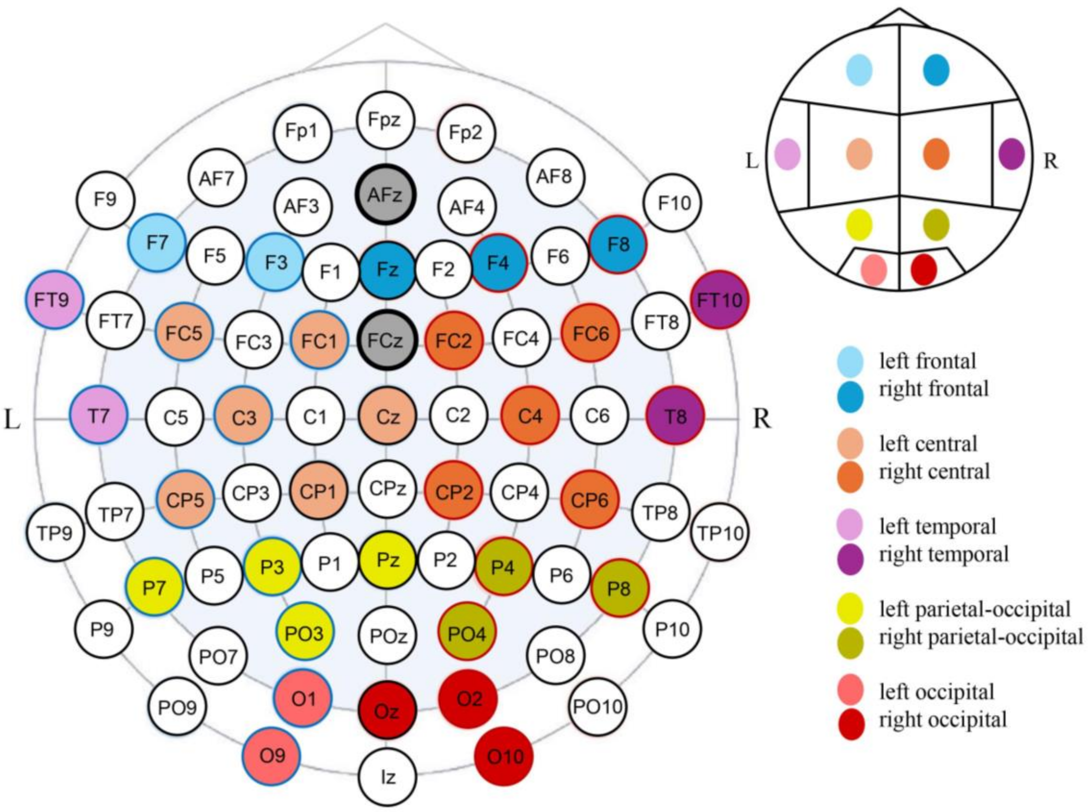


Figure 17. Emotiv 32-channel Epoc Flex EEG headset electrode distribution map and segmentation of 10 brain regions (drawn by the author, 2024).

Figure 18. Participants were wearing the EEG headset and the VR HTC Vive Pro (photo taken by the author, 2024).

As procedure of the study, participants were shown 32 randomized videos throughout the session. During the task, one video was shown at a time, with a question answered following each presentation. The session was separated into three blocks according to the three aesthetic components the stimuli would be assesses with: familiarity, excitement, and fascination. The order of the videos were randomized in each block, and the Likert scale 1 to 7 relating to the block was asked (see Appendix E3 for survey set). Each participant's blocks were assigned at random. Each trial began with a five-second buffer screen displaying a fixation cross, followed by the video presentation. Following the video, participants were asked to rate the space in the video depending on the question posed. Participants had a five-second window to select one of the interactive buttons, with responses thoroughly logged. Missed responses were recorded when there was no response within five seconds. Notably, at the start of each trial, EEG triggers were sent to the Emotive EEG recorder at the start of the buffer, the start of the video, and the start of the question, allowing for synchronous integration of neurophysiological data. The Figure 19. demonstrates the time sequence program.

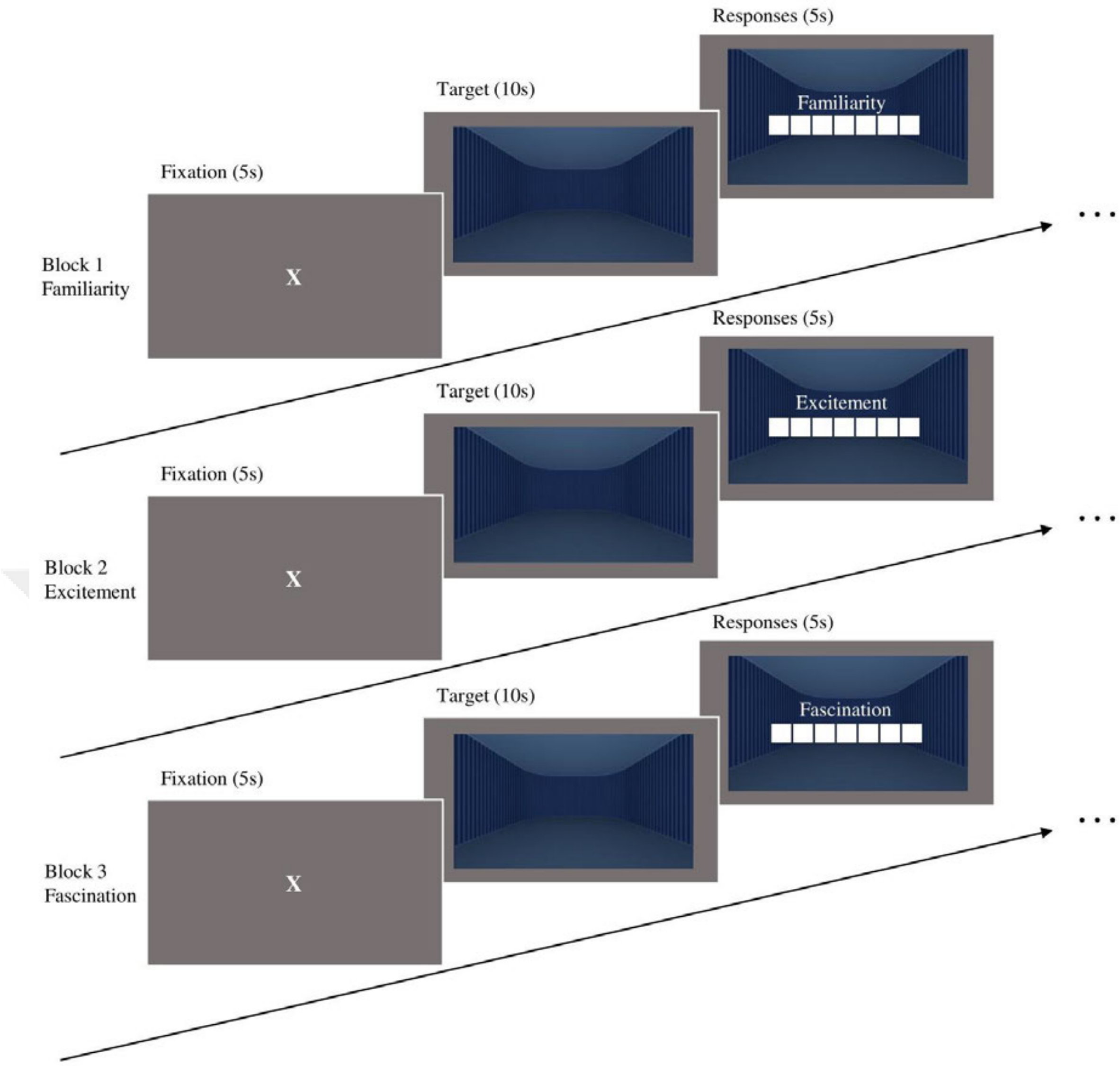


Figure 19. Time sequence programmed for EEG, repeating 32 times in each trial (drawn by the author, 2024).

4.3.4. Data Analysis of Experiment 3

In the behavioral data (participants' responses), based on the ratings of the 15 participants, the t-test was conducted on behavioral data for each aesthetic judgment dimension (familiarity, excitement, and fascination). In the neural data, the same 15 participants' records were collected. Before neural data (participants' neural correlates) were analyzed, a thorough cleaning process took place using Python and the MNE library. EEG recordings of each participant were examined, and muscle movements in the data were discarded. After muscle movements, independent component analysis (ICA) was employed to capture eye movements. ICA components relevant to the eye movements were eliminated, as well. Subsequently, the power spectrum of the clean EEG signals was determined by a Fast Fourier Transform (FFT) using Python and MNE library to calculate the band strength and variance in the frequency range corresponding to frequencies. For this purpose, the FFT was separated into the signal EEG sub-bands (theta, alpha, and beta), and characteristic vectors were created by calculating the energy and variance of each band. The EEG sub-bands are better suited for the aesthetic experiment (in contrast to event-related potentials commonly utilized in EEG studies) since they allow for the observation of a longer period or epoch during which continuous variation is supported (Rui & Gu, 2021). The t-test was conducted on neural data.

4.3.5. Results of Stage 3

The study found that VR is a valuable tool for cognitive and architectural research, with potential integration with neuroscience. The study systematically characterizes human aesthetic judgment in various architectural variables by conducting behavioral and neural data. The relationships were calculated, using the RStudio (2023), (see Figures 20, 21, and 22).

Aesthetic Judgment Dimensions and Architectural Variables in Behavioral Data

The study examined spaces with different architectural variables in three primary aesthetic judgment dimensions. In the familiarity component, the horizontal curvilinear boundaries were more familiar than the vertical curvilinear boundaries ($t(14)=-4.19$, $p<0.0001$). The mean number of HB on familiarity ($M=4.99$, $SD=1.18$) and VB on familiarity ($M=2.94$, $SD=1.21$) differ significantly. The average difference between the paired mean score values familiarity HB and familiarity VB mean values is 2.05.

In the excitement component, the vertical curvilinear boundaries were given higher scores than the horizontal curvilinear boundaries ($t(14)=4.75$, $p<0.0001$). The mean values of VB on excitement ($M=4.53$, $SD=1.13$) and HB on excitement ($M=3.05$, $SD=0.86$) differ significantly. The average difference between the paired mean score values excitement VB and excitement HB mean values is 1.48.

In the fascination components, the vertical curvilinear boundaries were given higher scores than the horizontal curvilinear boundaries ($t(14)=6.43$, $p<0.0001$). The mean number of VB in fascination VB ($M=5.17$, $SD=0.91$) and HB on fascination ($M=3.07$, $SD=0.78$) differ significantly. The average difference between the paired mean score values familiarity VB and familiarity HB mean values is 2.10. The aesthetic judgment dimensions and architectural variables in behavioral data was shown in Figure 20.

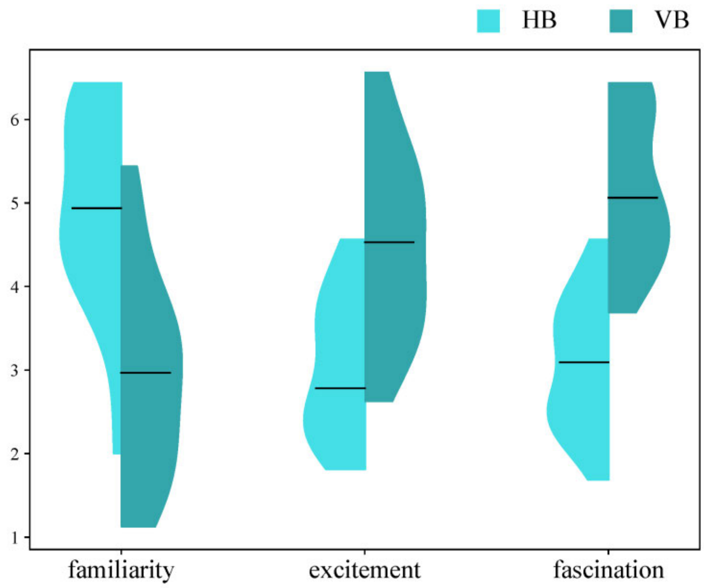


Figure 20. Violin plot of aesthetic judgment dimensions (drawn by the author, 2024).

Aesthetic Judgment Dimensions and Architectural Variables in Neural Data

In order to compare the EEG power differences in theta, alpha, and beta waves in response to architectural variables (HB: S/L/T/C and VB: S/L/T/C) for the three aesthetic measures (familiarity, excitement, fascination), stage 3 ran t-tests between HB and VB in all 32 channels recorded (corrected for multiple comparisons with Bonferroni at $p<0.05$). The channels that showed a significant difference between architectural variables are shown in Table 9.

Table 9. The channels that showed a significant difference between HB and VB in EEG power in theta, alpha, and beta waves for aesthetic judgments.

	Familiarity	**Excitement**	**Fascination**
Theta (4-8Hz)	-	-	-
Alpha (8-12 Hz)	**CP2** (p=0.0014)	**CP2** (p=0.0001)	**CP2** (p=0.0004)
	C4 (p=0.0013)	**C4** (p=0.0010)	**C4** (p=0.0013)
		Cz (p=0.0010)	
Beta (12-30 Hz)	**O2** (p=0.0012)	**O2** (p=0.0008)	**O2** (p=0.0008)
	PO3 (p=0.0008)	**PO3** (p=0.0006)	**PO3** (p=0.0008)
	Cz (p=0.0012)	**Cz** (p=0.0013)	**Cz** (p=0.0015)
	FT9 (p=0.0013)	Oz (p=0.0010)	Oz (p=0.0009)
	P4 (p=0.0005)	P8 (p=0.0002)	P8 (p=0.0014)
			O9 (p=0.0011)

p<0.0015 (Bonferroni corrected)

In related channels that showed a significant difference between the architectural variables (as summarized in Table 9), the power in response to VB was significantly higher than that of the response to HB. Figure 21 and Figure 22 show the bar plots of the power in alpha and beta waves for HB and VB for a selected number of channels (Figure 21 common channels CP2 and C4 and Figure 22 common channels O2, PO3, and Cz). The visualization of other significant channels that are rare is in Appendix G.

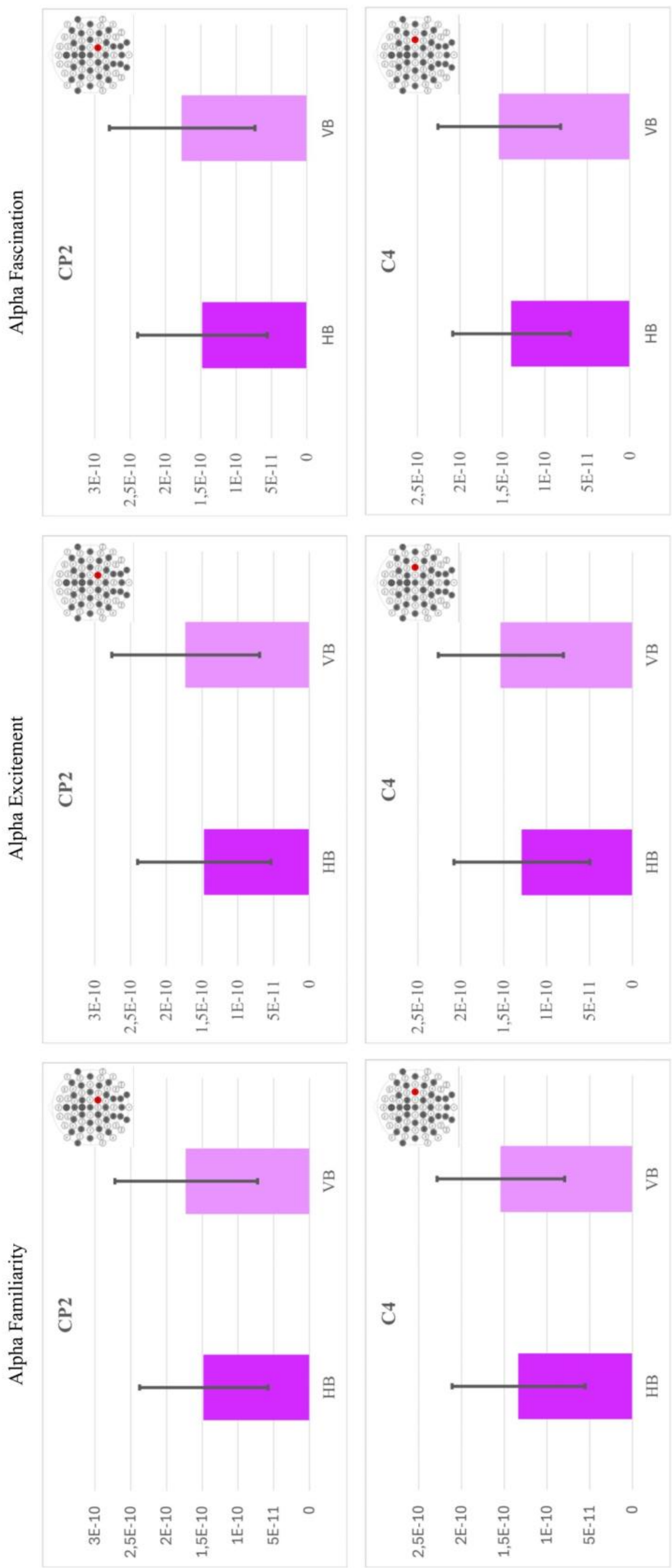


Figure 21. Alpha waves bar plots of aesthetic judgment dimensions (drawn by the author, 2024).

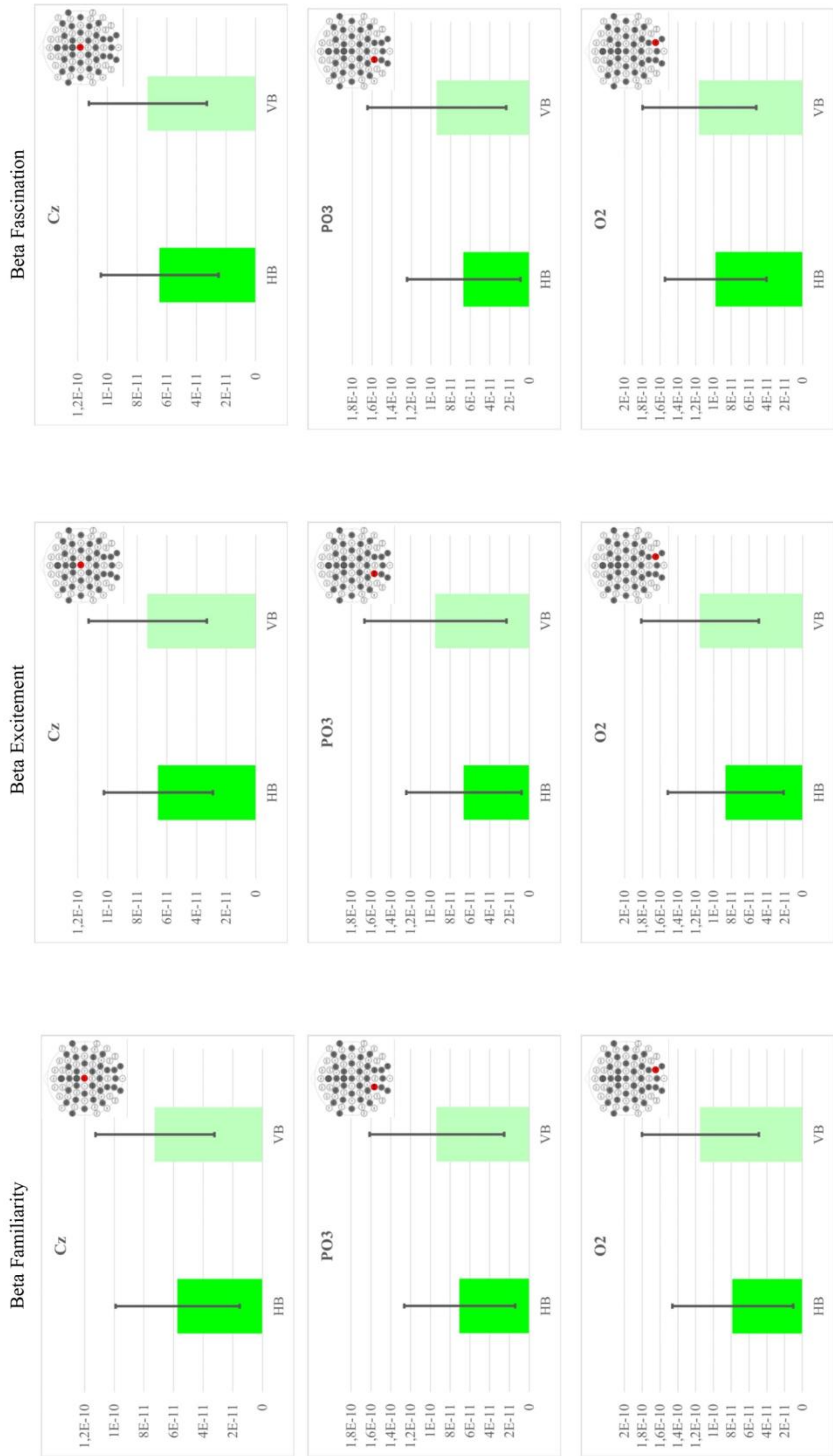


Figure 22. Beta waves bar plots of aesthetic judgment dimensions (drawn by the author, 2024).

4.3.6. Discussion of Stage 3

Aesthetic judgment is one of the most important concepts in studying human mental behavior. Compared to other traditional methods like speech, gestures, and facial expression, brain signals have made it easier to assess changes in humans' aesthetic judgment state in recent years. Brain signals are directly linked to the scalp, making it possible to read the beginning of changes in neural activity to provide more accurate information about changes in emotional state. Brainwaves, also known as neural oscillations, are periodic or rhythmic patterns of neural activity. It provides direct measures of electrocortical activity, with great sensitivity to indicate changes in arousal, perception, and cognitive function (Azzazy et al., 2020; Bell & Cuevas, 2012).

When evaluating aesthetics using brain wave signals, factors such as the time the signals were recorded under specific architectural stimuli, the number of channels and frequency bands, and the characteristics of the statistical feature extraction techniques all matter. The main challenges in this field are selecting the most effective aesthetic induction stimuli, determining the non-linearity of brain signals, and choosing suitable frequency bands.

The neural correlates of the three aesthetic judgment dimensions (found in stage 1) were investigated in this stage. Stage 3 was conducted to test whether there is a similarity or difference between behavior and neural data in response to different architectural variables (HB: S/L/T/C and VB: S/L/T/C).

Effects of Architectural Variables on Aesthetic Judgments in Behavioral Data

A previous study (stage 2) found that people perceived HBs as more familiar and VBs as more exciting and fascinating. In this stage, the behavioral data represented the same result from the previous study (stage 2). So, we replicated the results of the second study and demonstrated the reliability of the findings.

People spend most of their time in interior spaces, and today, the influence of modern architecture has increased familiarity with curved HBs differences. People found these places to be more 'familiar-known spaces' because they were not described differently than the classic 90-degree spaces. Besides, the curved VBs are still barely visible in modern architecture or represent signature structures such as the buildings designed. For this reason, curved VBs are perceived by people as ‘exciting’ and ‘fascinating.’ The main emphasis at this stage was the relationship between behavioral data and neural data (see the next section).

Effects of Architectural Variables on Aesthetic Judgments in Neural Data

Aesthetic judgment dimensions were related to the alpha waves in the central channels and beta waves in the occipital, parietal, and central channels as a result of the neural (EEG) data analysis. In other words, alpha in central channels and beta in occipital, parietal, and central channels provide informative information about aesthetic judgment dimensions. However, theta is not an informative measure in assessing aesthetic judgment dimensions.

This study’s findings predominantly indicate that alpha and beta wave powers are higher for VBs, showing more proficiency in VBs processing than HBs processing. Collected wave bands and channel locations provide insights into how specific regions relate to different visual processing components for different dimensions.

For CP2, C4 channels' VBs elicited higher alpha power for all three aesthetic judgment dimensions. Cz channel elicited higher alpha power for the excitement aesthetic judgment dimension only. These channels read electrical signals over the central region of the skull, CP reads signals over central-parietal regions, C4 reads signals over the right-hand side of the central region, and Cz reads signals over the midline center region. The readings from the channels suggest that the right-hand and parietal central regions are more involved in processing VBs than the HBs for each aesthetic dimension. Given the role of the alpha waves’ involvement in the suppression of unnecessary sensory input and visual attention, central and parietal central regions tend to assist in visual attention for VBs. Higher activation of Cz for VBs only in the context of excitement implies more specific processing of VBs related to emotional responses. Figure 23 highlights the common region of the brain associated with the familiarity, excitement, and fascination aesthetic judgment dimension of the alpha wave.

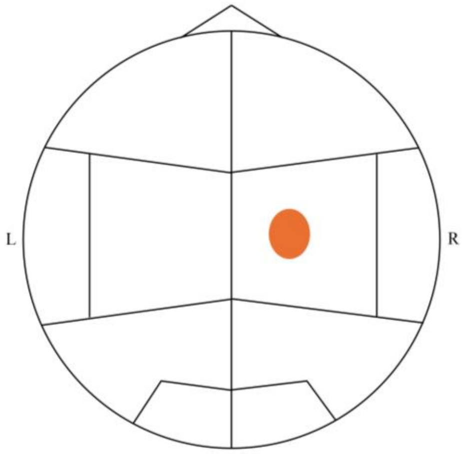


Figure 23. The three aesthetic judgment dimensions in common brain regions of alpha waves (drawn by the author, 2024).

O2, PO3, and Cz channels yielded higher beta power for all three aesthetic judgment dimensions for VBs. For Oz, P8 channels VBs elicited higher beta power for excitement and fascination, whereas FT9 and P4 elicited higher beta power in only the familiarity dimension for VBs. For the O9 channel, VBs elicited higher beta power for the fascination dimension. O channels collect signals over the occipital, P channels collect signals over the parietal, and the PO channel collects signals over the parietal-occipital region. The readings over the channels of the right occipital, parietal-occipital, and central regions are specialized more in the visual processing of VBs in all three dimensions. However, the right parietal and occipital regions show specialization in the visual processing of the exciting and fascinating dimensions of VBs. The left frontal-temporal and right parietal regions visualize familiar vertical boundaries. The left-occipital region processes VBs more in the context of fascination judgment. Figure 24 highlights the common region of the brain associated with the familiarity, excitement, and fascination aesthetic judgment dimension of the beta wave.

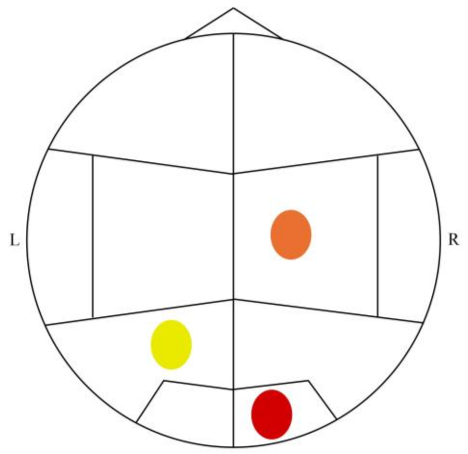


Figure 24. The three aesthetic judgment dimensions in common brain regions of beta waves (drawn by the author, 2024).

In this chapter of the thesis, three separate stages were analyzed. The participant information, environmental stimuli, instruments and procedures, data analysis, results, and discussion points for each stage were specified. In addition, the interrelationship of the stages was highlighted. Table 10 presents a comprehensive overview of the results obtained during stage 3. Each stage was a reference to the next chapter. At the end of each stage, there was a detailed discussion of the related topic. The next chapter of the thesis discusses these three stages using general terms.

Table 10. Summary of the findings of Stage 3.

Behavioral Data		**Neural Data**		
		Theta	**Alpha**	**Beta**
		ns	HB<VB	HB<VB
Familiarity	HB>VB	ns	CP2, C4	O2, PO3, Cz, FT9, P4
Excitement	HB<VB	ns	CP2, C4, Cz	O2, PO3, Cz, Oz, P8
Fascination	HB<VB	ns	CP2, C4	O2, PO3, Cz, Oz, P8, O9

ns: non-significant

CHAPTER 5

DISCUSSION

Since the thesis contains three main stages, a detailed discussion of each stage was identified in the related stage (sections 4.1.6., 4.2.6., and 4.3.6.). The general discussion framework of the thesis in this section was presented in 3 stages of the study in parallel with the research questions. The methodical contribution was also covered. It was also studied based on two disciplines, the practical contribution to architecture and psychology.

5.1. General Discussion

Since people spend many hours daily indoors, researchers need to investigate the influences of indoor environments on people and provide design information to interior designers. Therefore, this extensive study was conducted to improve people's indoor quality of life, raise their aesthetic values, and indirectly contribute to psychology while proposing certain questions in three stages.

Can aesthetic judgments be grouped into psychological dimensions in an architectural space? Are aesthetic judgments sensitive to curved boundaries and space properties? Earlier literature noted that many aesthetic classifications were carried out with one or a few aesthetic adjectives as noncomprehensive studies. As the relevant literature pointed out, different specific architectural properties were responsible for determining the aesthetic responses of users in an environment (Bokharaei & Nasar, 2016; Durak et al., 2007; Franz & Wiener, 2005; Franz et al., 2005; Franz, 2006; Knez, 2001; Kuller et al., 2006; Odabasioglu & Olgunturk, 2015; Stamps, 2007) with various boundary types (Banaei et al., 2017a, 2017b; Banaei et al., 2020; Elver, 2018; Shemesh et al., 2016; Vartanian et al., 2019), and environments with various architectural characteristics need to be tested.

Therefore, a systematic, comprehensive aesthetic evaluation scale needed to be included in the literature. This study's objective was to develop a comprehensive aesthetic scale. The adjectives for aesthetic judgment were compiled from the relevant literature sources to answer the first two research questions (RQ1 and RQ2). Furthermore, the aesthetic judgments influenced by certain specific properties and different space boundaries were experienced in architectural spaces with curved boundaries, which were explored. In the literature, more precise results were achieved in areas that were over-controlled (Carreiro et al., 2017; Shemesh et al., 2016; Simpson et al., 2018; Von Castell et al., 2020; Von Castell et al., 2014; Wang et al., 2020), and strong steps could accompany the next phase. Therefore, this study stage was conducted in controlled architectural surroundings, and it was found that the aesthetic experience is composed of familiarity, excitement, and fascination. Stage 1 of this study indicated that only familiarity and excitement dimensions were associated with the environment's boundary types and three specific properties (SLC) and did not involve texture characteristics.

What if these architectural variables were investigated in a combined way? How would aesthetic judgment affect architectural surroundings? Do different VEs affect these results? If these research questions (RQ3a, RQ3b, RQ4, RQ5, and RQ6) were to be answered, the dimensions of aesthetic judgments in the different VEs of interior spaces would be different. Furthermore, the different architectural variables of interior spaces have different dimensions of aesthetic judgment. However, the interactions between VEs and architectural variables could affect the aesthetic judgment dimensions of interior spaces. Moreover, there is a difference in the presence score based on VEs of interior spaces. Stage 2 was conducted and proven by the participants' answers to these questions. Consequently, the study also analyzed architectural variables in a combined way on aesthetic judgment dimensions and examined different VE conditions.

In stage 2, the study investigated, through a controlled step-by-step process, the spaces with various architectural variables (specific properties + boundary type) in VEs (IVE and DTVE) and was assessed using the aesthetic judgment scale. Since the fascination dimension did not have a significant value in the first stage, it could result from exploring the spaces with one specific property. Consequently, combined architectural variables for evaluating aesthetic judgment dimensions (familiarity, excitement, and fascination) could be significant at this stage. However, these VEs, which contain various features, produced different outcomes for the research in stage 2. For this reason, it is necessary to examine which VE was more suitable for using the behavioral and neural foundations of aesthetic judgments.

Can the study analyze the momentary changes in emotions as participants give these answers, the factors they are affected by, and whether a state raises or lowers them during the day? Depending on these circumstances, what is the validity of this kind of question-answer study? The study also examines aesthetic judgments of architectural variables based on behavioral and neural foundations in stage 3. This thesis presents three methodologies that involve interconnection and causal relationships.

Therefore, studying human brain dynamics as they relate to behavior in and interaction with the built environment is the focus of the newly developing field known as 'neuro-architecture,' which brings together environmental psychology, neuroscience, and architecture. The findings found and proven in the previous studies (stages 1 and 2) were studied based on neural data (stage 3). If these research questions (RQ7 and RQ8) were to be answered by the hypothesis. The alpha and beta waves are sensitive to architectural variables during the perception of architectural variables. Also, alpha and beta waves are influenced by task demands during the perception of architectural variables.

5.2. Methodological Contribution

This thesis adds substantial value by examining the present status of the architectural literature explored. The study provided a comprehensive evaluation of human aesthetics. The study developed an aesthetic judgment scale that did not exist in the previous literature. This proven aesthetic judgment scale became a reference to a subsequent study (Diker & Demirkan, 2023). In stage 1 of the thesis, the curved boundaries and specific properties were analyzed and concluded separately.

In stage 2, it was supported that the dimensions of aesthetic evaluation are effective with the resemblance of places to REs with combined architectural variables. Also, evaluation of the dimensions of aesthetic evaluations and extent of presence showed differences in the two VEs (DTVE and IVE). With today's advanced technology, spaces close to reality were tested and analyzed in two VEs.

The study summarizes these findings and concludes that question-answer and behavioral studies differ from neural studies. Various parameters influence human behavioral responses, while neural data analysis conveys precise information.

5.3. Practical Contribution

The practical contribution of the study's results serves as a connection between the study’s research and real practice. The study, from an architectural and psychological point of view, is based on two main ideas. This part analyses how the thesis contributes to architectural surroundings and psychological science.

Architectural aspects:

• The study systematically characterized human aesthetic judgment in architectural spaces with curvilinear boundaries and the effects of specific architectural properties on aesthetic judgments. The study proposed three primary aesthetic dimensions for the built environment. Researchers interested in aesthetic judgments in the built environment could manipulate these dimensions in their research (Stage 1).

• The aesthetic judgment level increases as the curved boundaries become horizontal, as the size of the space gets larger, as the level of the lighting increases, and as the colors become cool. In line with this result, to increase aesthetic feeling and contribute to human well-being, the design of built environments, especially in living environments, could be created in this respect by the designers (Stage 1).

• To design spaces more familiar in terms of aesthetic assessment, the designer should consider the following adjectives: pleased, happy, satisfied, pleasant, relaxed, like to spend time, prefer to live, enjoy exploring, hopeful, relaxing, feel friendly and talkative, exciting, safe, aroused, arousing, and coherent. To design spaces more exciting in terms of aesthetic assessment, the designer should consider the following adjectives: wide-awake, excited, frenzied, jittery, and contended. To design spaces more fascinating in terms of aesthetic assessment, the designer should consider the following adjectives: mysterious, complex, and stimulated (Stage 1).

• When the architectural variables are combined (like in a RE), the familiarity experience level increases in horizontal curved boundaries (HB:S/L/T/C), and excitement and fascination levels increase in vertical curved boundaries (VB:S/L/T/C). In line with these findings, designers could manipulate this idea in the existing spaces that include different architectural variables. While stage 1 effects can be significant for the new constructions of the built environment, stage 2 results can be substantial for renovating the built environment (Stage 2).

• The study provided immersive and non-immersive VE relations regarding architectural variables. As a result, virtual worlds presented in an IVE are more similar to real-world situations than to computer screens (DTVE). This finding supports the study that an immersive environment is more suitable than a non-immersive one for conducting experiments in human behavioral studies. This finding is useful information for designers and researchers looking to design more immersive and realistic virtual experiences (Stage 2).

Psychological aspects:

• The study would be helpful for architects to test the psychological and neural impacts of the proposed design schemes along the dimensions of the relevant PCs presented in the study. These dimensions propose a specific framework for incorporating behavioral feedback into design iterations before designing an environment.

• The general concern of psychology was human behavior and the mechanisms underlying these behaviors. Behavioral studies do not directly test and identify mechanisms (Urgen et al., 2014). In addition to the explicit behavioral (Stage 1) studies, the aim was to provide complementary studies (Stage 3) to identify mechanisms. The reasons for using explicit and implicit studies are (1) unawareness in occurring of humans' subjective states, (2) difficulty in characterizing a complex phenomenon with a single measurement such as familiarity, excitement, or fascination, (3) only providing the output of the system, and do not address what kind of information processing underlies in behavioral studies' phenomenon.

• Neuroimaging techniques such as EEG help "demystify" the knowledge (Urgen et al., 2014, p.2). The study collected overt responses (Stage 1) and covert responses (Stage 3) from the participants. Neuroimaging does not require overt responses since brain activity can be monitored continuously. Using overt and covert responses expresses the aesthetic judgment more clearly and temporally sensitive results. Neuroimaging provides a rich set of data, which can be more informative than behavioral measures.

In this chapter of the thesis, the general lines of discussion for the three stages were addressed together with related literature and given hypotheses. Methodological and practical contributions were also detailed in that chapter. In the final chapter of the thesis that was the conclusion involved the limitations and further studies were discussed.

CHAPTER 6

CONCLUSION

In the thesis, the study provided a systematic characterization of aesthetic judgment in curvilinear boundaries with space properties and how various properties of architecture influenced aesthetic judgments. The three primary aesthetic scales, familiarity, excitement, and fascination, were demonstrated in this study and contributed a new light to the aesthetic and built environment literature. This study adds substantial value by examining the present status of architectural aesthetics (stage 1).

Also, the study proves that, in IVE, the level of familiarity and excitement increases. Furthermore, the familiarity experience increases in horizontal curved boundaries, whereas excitement and fascination dimensions increase in vertical curved boundaries (stage 2). The virtual worlds in an IVE are more like real-world circumstances than computer displays (DTVE). This outcome lends weight to the study's conclusion that an immersive setting is preferable than a non-immersive one for performing human behavioral research. This study adds substantial value by examining the present status of VE literature.

However, the neural data revealed aesthetic judgment dimensions in central channels for alpha waves and occipital, parietal, and central channels for beta waves. In this study, alpha in central channels and beta in occipital, parietal, and central channels give useful information regarding aesthetic judgment dimensions. However, theta does not (stage 3). Augmenting behavioral responses with EEG underlines the neural correlates of VB and HB processing in three aesthetic judgments and provides insights about which aspects of the EEG are involved in visual attention via alpha waves and visual processing via beta waves. This stage is an exploratory study, and there is no research in the literature on neural correlates of architectural variables. For this reason, the study's findings reference the neuro-architectural studies.

There are various limitations to this study. First, the study employed simple and well-controlled stimuli to isolate the effects of space properties (SLTC) and curved boundaries for stage 1 and architectural variables for stages 2 and 3 on aesthetic judgment while controlling for other visual factors. Given that the constructed world we perceive daily is far more complex, future research might expand on this work by developing more complex and lifelike stimuli and assessing aesthetic perception. This finding will allow people to determine which space properties may interact with people's perception of the built environment. Second, using a head-mounted display is another limitation of the study for both three stages. Technological gadgets are evolving daily, and this study did not include using newer versions of these devices.

Additional studies might be undertaken using more immersive display equipment, such as augmented reality, to examine three aesthetic judgments. The third limitation is that the study only employed visual stimulation for both stages in the current investigation since VR limits people's ability to excite other sensory modalities, such as touch or smell. Future work can expand on this study in more realistic architectural surroundings by manipulating the texture or odor of the environments to assess their influence on aesthetic judgment. The final limitation is that electroencephalography comes with its drawbacks and limitations. EEG is flawed in spatial resolution; even though it can capture rapid changes in brain activity and provides coarse information to locate the source of the activity, study can only approximate the regions (Buzsáki & Draghun, 2004; Michel & Murray, 2012).

Further fMRI studies should elicit anatomical information that cannot be acquired via EEG to elucidate the brain regions involved in boundary processing within the aesthetic dimensions' scope (Michel & Murray, 2012; Herrmann et al., 2016). EEG data are sensitive to various artifacts, such as muscle movements, eye blinks, and electrical noise (Fatourechi et al., 2007). Several data-cleaning steps were employed in the study, yet integrating EEG and VR may require more clarification in interpreting the neural data.

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APPENDICES

Appendix A. TÜBİTAK Approval

T.C.
TÜRKİYE BİLİMSEL VE TEKNOLOJİK ARAŞTIRMA KURUMU BAŞKANLIĞI
Araştırma Destek Programları Başkanlığı

Sayı : E-53305490-115.02-203429 18/08/2023
Konu : 123K937 Numaralı Proje Karar Yazısı

Sayın Tuğçe ELVER BOZ

"1002-A Hızlı Destek Modülü" kapsamında Kurumumuza sunulan 123K937 numaralı ve "Mimaride Nöro-Estetik: Kavisli Sınırları Olan İç Mekanların Estetik Olarak Değerlendirilmesi Ve Nöral Temellerinin İncelenmesi" başlıklı projenize ilişkin bilimsel değerlendirme süreci tamamlanmıştır.

Konunun uzmanı danışmanlar tarafından yapılan değerlendirmeler sonucunda proje önerinize destek verilmesine karar verildiğini bildirmekten memnuniyet duyarım (*).

Desteklenmesine karar verilen proje önerinizin ilgili mevzuat çerçevesinde, mali ve benzeri konularda değerlendirme çalışmalarına başlanmıştır. Süreç tamamlandığında projelere ait sözleşme ve diğer belgeler imzalanmak üzere tarafınıza gönderilecektir.

Başarınızı tebrik eder, saygılar sunarım.

Alperen Zekeriya KARATAŞ
Sosyal ve Beşeri Bilimler
Araştırma Destek Grubu
Grup Koordinatörü V.

PUAN SEVİYESİ: B

A: Çok İyi B: İyi C: Orta D: İyi Değil E: Yetersiz F: Özgün Değeri Yetersiz

Panel puanı A ve B seviyesinde olan projeler desteklenmiştir.

* Bir kişi kariyer hayatı boyunca 1002-A Hızlı Destek Modülü ve 1002-B Acil Destek Modülü kapsamında toplamda en fazla beş kez proje yürütücüsü olarak görev alabilir.

Belge Doğrulama Kodu: FHADQU/AolwvNVYu06tOYbx7xJc= Bu belge elektronik olarak imzalanmıştır. Belge Doğrulama Adresi: https://pys.tubitak.gov.tr/belgeSorgula.htm

Araştırma Destek Programları Başkanlığı (ARDEB)
İşçi Blokları Mahallesi, Muhsin Yazıcıoğlu Caddesi, No:51/C, 06530, Çankaya/ANKARA
Telefon No: (0312) 468 53 00 Faks No: (0312) 427 74 89
eposta:iletisim@tubitak.gov.tr İnternet Adresi:www.tubitak.gov.tr

Panel Yönetim Sistemi(PYS)
https://pys.tubitak.gov.tr/

Appendix B. Ethics Committee Approval

B1. Stage 1

Bilkent Üniversitesi
Akademik İşler Rektör Yardımcılığı

Tarih: 18 Ocak 2018

Gönderilen: Prof. Dr. Halime Demirkan, Tuğçe Elv[redacted]

Gönderen: Doç. Dr. Fatma Taşkın
İnsan Araştırmaları Etik Kurulu Başkanı

Konu: *"MFA student of ..."* çalışması etik kurul onayı

Üniversitemiz İnsan Araştırmaları Etik Kurulu, 18 Ocak 2018 tarihli görüşme sonucu, "*MFA student of the Department of Interior Architecture and Environmental Design*" isimli çalışmanız kapsamında yapmayı önerdiğiniz etkinlik için etik onay vermiş bulunmaktadır. Onay, ekte verilmiş olan çalışma önerisi, çalışma yürütücüleri, ve bilgilendirme formu için geçerlidir.

Bu onay, yapmayı önerdiğiniz çalışmanın genel bilim etiği açısından bir değerlendirmesine karşı gelmektedir. Çalışmanızda, kurulumuzun değerlendirmesi dışında kalabilen özel etik ve yasal sınırlamalara uymakla ayrıca yükümlüsünüz.

Etik Kurul Üyeleri:

Ünvan / İsim	**Bölüm / Uzmanlık**	**İmza**
1. Doç.Dr. Fatma Taşkın	İktisat	[redacted]
2. Prof.Dr. Erdal Onar	Hukuk	
3. Prof.Dr. Haldun Özaktaş	Elektrik ve Elektronik Müh.	
4. Doç.Dr. Işık Yuluğ	Moleküler Biyoloji ve Genetik	
5. Yrd.Doç.Dr. Gül Günaydın	Psikoloji	
Yd.1.Doç.Dr. Çiğdem Gündüz Demir	Bilgisayar Mühendisliği	
Yd.2. Yrd.Doç.Dr. A.Barış Özbilen	Hukuk	

Kurul karar/toplantı No: 2018_01_18_04

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B2. Stages 2 and 3

Bilkent Üniversitesi
Akademik İşler Rektör Yardımcılığı

Tarih	: 2 Ekim 2023
Gönderilen	: Tuğçe Elver Boz
Danışman	: Halime Demirkan, Burcu A. Ürgen
Gönderen	: H. Altay Güvenir İnsan Araştırmaları Etik Kurulu Başkanı
Konu	: *"Architecture ..."* çalışması etik kurul ona[redacted]

Üniversitemiz İnsan Araştırmaları Etik Kurulu, 2 Ekim 2023 tarihli görüşme sonucu, *"Architecture with Aesthetics: Measuring Psychological and Neural Responses to Curved Architectural Boundaries (Mimaride Nöro-Estetik: Kavisli Sınırları Olan İç Mekanların Estetik Olarak Değerlendirilmesi ve Nöral Temellerinin İncelenmesi)"* isimli çalışmanız kapsamında yapmayı önerdiğiniz etkinlik için etik onay vermiş bulunmaktadır. Onay, ekte verilmiş olan çalışma önerisi, çalışma yürütücüleri ve bilgilendirme formu için geçerlidir.

Bu onay, yapmayı önerdiğiniz çalışmanın genel bilim etiği açısından bir değerlendirmedir. Çalışmanızda, kurulumuzun değerlendirmesi dışında kalabilen özel etik ve yasal sınırlamalara uymakla ayrıca yükümlüsünüz.

Kovid-19 salgını nedeniyle konulmuş olan kısıtlamaların yürürlükte olduğu süre içinde, tüm komite toplantıları elektronik ortamda yapılmaktadır; aşağıda isimleri bulunan Bilkent Üniversitesi Etik Kurulu Üyeleri adına bu yazıyı imzalama yetkisi kurul başkanındadır.

Etik Kurul Üyeleri:

Ünvan / İsim	**Bölüm / Uzmanlık**	
Prof.Dr. H. Altay Güvenir	Bilgisayar Mühendisliği	Başkan
Prof.Dr. Haldun Özaktaş	Elektrik ve Elektronik Müh.	Üye
Doç.Dr. Işık Yuluğ	Moleküler Biyoloji ve Genetik	Üye
Dr. Öğr. Üyesi Burcu Ayşen Ürgen	Psikoloji	Üye
Dr. Öğr. Üyesi A.Barış Özbilen	Hukuk	Yedek Üye
Dr. Öğr. Üyesi Didem Özkul McGeoch	İletişim ve Tasarımı	Yedek Üye
Dr. Öğr. Üyesi A.Barış Özbilen	Hukuk	Yedek Üye

Kurul karar/toplantı No: 2023_10_02_01

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Appendix C. Consent Form

C1. Stage 1

CONSENT FORM TO PARTICIPATE AS A RESEARCH SUBJECT

Research project: Perception of spatial enclosure as a function of different space boundaries.

İ.D. Bilkent University

Principal Investigator: Tugce Elver
Email: tugce.elver@bilkent.edu.tr Tel: (530) 1550971

Academic Advisor: Halime Demirkan (demirkan@bilkent.edu.tr)

Background Information and Purpose of the Study: The purpose of this research is to examine the relationship between the perception of curvilinear boundaries with different physical properties of the environment such as size, light, texture and color. This research relates to the master thesis of Tuğçe Elver who is a graduate student of the Department of Interior Architecture and Environmental Design at Bilkent University. In this study, approximately 128 undergraduate and graduate students at Bilkent University who are over 18 years old, experience spatial 360-degree spaces with Gear Virtual Reality (VR) equipment.

Eligibility to participate in the study: If you agree to participate, you will be asked to fill out a pre-screening questionnaire about your health status. If no medical reason is found to exclude you from the study, you will be asked to participate in the research study.

Procedures: Each participant is responsible for only one set of survey that consists of four spaces with different curvilinear boundaries associated with only one of the environmental properties. Boundaries are related to the way how the surfaces are connected with each other in the space. The perception of four 360-degree spaces is determined using a Gear VR. This equipment creates realistic virtual environment simulations. After the analysis of spaces, a survey consisting of aesthetic judgements and emotional responses of the participants is completed; the participants will be asked to assess how much they perceived the environment and how they felt in the spaces after experiencing the environment.

Risks and Benefits: This research aims to guide architects and interior architects to design better quality and spacious living environments. The result of the research may enhance the aesthetic judgements of the users of space and increase the emotional well-beings of the individuals. Moreover, I understand that the current research does not entail any physical or emotional risks other than those encountered in everyday life. There is no personal benefit to me.

Compensation: I will not be compensated for my participation in this research.

Confidentiality/ Privacy: Any information obtained in this research will only be reported and published for scientific purposes. As a participant, any information about my identity remain confidential and placed in investigator's locked secure storage for three years after the completion of the research study.

Participation: I am one of approximately 128 participants who will participate in this research study. My participation is voluntary. If I feel uncomfortable as a participant, I can decide to withdraw from participation in this research study by informing the researcher at any time or I can be excluded from the research study if it is deemed necessary by the researcher. I understand that my final decision will not positively or negatively influence my academic evaluation, or the service provided to me. In addition, if I have question regarding this research study, I can contact the investigator, advisor of the investigator or Bilkent University Local Ethics Committee. Research study has been reviewed and approved by Local Ethics Committee of Bilkent University.

I have read and understood the information provided to me. I voluntarily participate in this study. I have been given a copy of this consent form.

Participant	**Investigator**
Name-Last Name:	Name-Last Name:
Email:	Email:
Phone:	Phone:
Date:	Date:
Signature:	Signature:

C2. Stages 2 and 3

CONSENT FORM TO PARTICIPATE AS A RESEARCH SUBJECT

Research project: The aesthetic experience of interior spaces with curvilinear boundaries and various space properties in immersive and desktop-based virtual environments

İ.D. Bilkent University

Principal Investigator: Tugce Elver Boz
Email: tugce.elver@bilkent.edu.tr Tel: (530) 1550971

Academic Advisors: Halime Demirkan (demirkan@bilkent.edu.tr)
Burcu A. Ürgen (burcu.urgen@bilkent.edu.tr)

This research relates to the doctorate thesis and TÜBİTAK 1002 project of Tugce Elver Boz, a doctorate student of the Department of Interior Architecture and Environmental Design at Bilkent University.

Background Information and Purpose of the Study: The study mainly contributes to the interdisciplinary work between neuroscience and architecture. The study aims to understand the neural mechanisms that underlie how people perceive and process visual architectural features. During the experiment, we will record the electrical activity of your brain with EEG as you are presented with visual and/or auditory stimuli. EEG is a non-invasive technique routinely used in clinical and research settings to understand the neural processing in the human brain.

Eligibility to participate in the study: If you agree to participate, you will be asked to fill out a pre-screening questionnaire about your health status. If no medical reason is found to exclude you from the study, you will be asked to participate in the research study.

Procedures: This study provides an efficient evaluation of the aesthetic perception of 32 different spaces with varied architectural features (curved edges, size, lighting, texture, or color) in a virtual reality environment and investigates the neurological bases of aesthetic perception. The project will consist of three behavioral sessions and two electroencephalograms (EEG). (A) In the behavioral session, the participants will wear virtual reality head-mounted display (HMD) glasses (HTC Vive pro) to evaluate the similarities between different pairs of spaces. (B) The EEG sessions will consist of a passive (only spatial experience) and an active (spatial experience and the evaluation of related aesthetic concepts) session.

If you agree to participate in this study and are eligible to participate;

(A) You must wear head-mounted display virtual reality glass (HTC Vive Pro). The high-resolution HMD will be placed onto your head and stabilized, squeezing the back part until the visualization is clear.

(B) You will need to remove any metallic items (e.g., keys, watches, coins, glasses, jewelry, hair pins) or items with magnetic data (credit cards) from your body before entering the EEG room. The 32-channel and most flexible wireless EEG Brain wear will be placed onto your head and stabilized using an elastic band under your chin. A conductive saline sensor will be applied to the space between each EEG electrode and your head skin.

We will start the experiment once the HMD or EEG electrodes are placed. We will present visual stimuli on an HMD virtual reality glass (HTC Vive Pro) and a computer screen. You will be asked to passively observe or make simple judgments about the stimuli and respond using a button press.

Before the experiment, Elver Boz will inform you about the details you will see. The behavioral session (A) will be approximately 40 min, including the placement of the HMD (5 minutes). The EEG session (B) will typically last about 1 hour, including the placement of the cap (10-15 minutes) and removal (5-10 minutes) after the experiment.

You should inform the investigator anytime if you feel uncomfortable during the experiment.

Risks and Benefits: The current research on HMD does not entail any physical or emotional risks other than those encountered daily. Also, EEG recording requires the placement of a cap on the human scalp. There are some minimal risks associated with this procedure. The saline sensors that are used to improve conduction between the skin and the electrodes may temporarily cause redness on the skin. However, this condition will go away as soon as the experiment is over. The electrodes used in the experiment do not have any risk of electro-shock. The current within the wires inside the cap and the electromagnetic fields it will create is minimal and is not higher than that of the earphones commonly used. There is no evidence that this current will harm health. However, there is no guarantee to discover unforeseeable negative effects. Many research institutes worldwide have used the methods used to stabilize the electrodes for a long time. There has been no side effect so far.

Participation in this study does not have any rehabilitation or diagnosis purpose. If you have any brain disorder or abnormality, this study will not reveal it.

Direct benefit to you is expected only by learning about how research in cognitive neuroscience is conducted in a highly-regarded research university. If you want, the investigator can show you the recorded EEG data after the experimental session.

Research-related injury: If this research activity results in an injury, treatment will be available at the Bilkent University Health Center, including first aid, emergency treatment, and follow-up care as needed. This period covers the entire duration of the study. Care for such injuries will be limited to the care provided to Bilkent students. The coverage does **not** include hospital stays, surgical operations, and treatment of chronic diseases or prolonged injuries. If you think you have suffered a research-related injury, let the study investigators know immediately.

Confidentiality: The research records of this study will be kept confidential. All files associated with this study, physical or digital, will be kept secure. Only authorized personnel from the lab will have access to the data. We will use a special coding system, making associating your personal information with the collected data impossible. We may report your data in scientific publications but only with coded numbers.

Voluntary Nature of the Study: Participation in the current study is voluntary. If you decide to participate, you may withdraw from the study at any time and request that your data be destroyed. Your decision whether or not to participate will not affect your current or future relations with Bilkent University in any way.

Contacts and Questions: If you have any questions regarding this study, you may talk to Elver Boz. If you have questions, contact us via email or phone at Elver Boz.

You will be given a copy of this consent form to keep for your records upon request.

Statement of Consent: I have read and understand the above information. I have asked questions and received answers. I consent to participate in the study.

Participant	**Investigator**
Name-Last Name:	Name-Last Name:
Email:	Email:
Phone:	Phone:
Date:	Date:
Signature:	Signature:

Appendix D. Ishihara Electronic Color Blindness Test

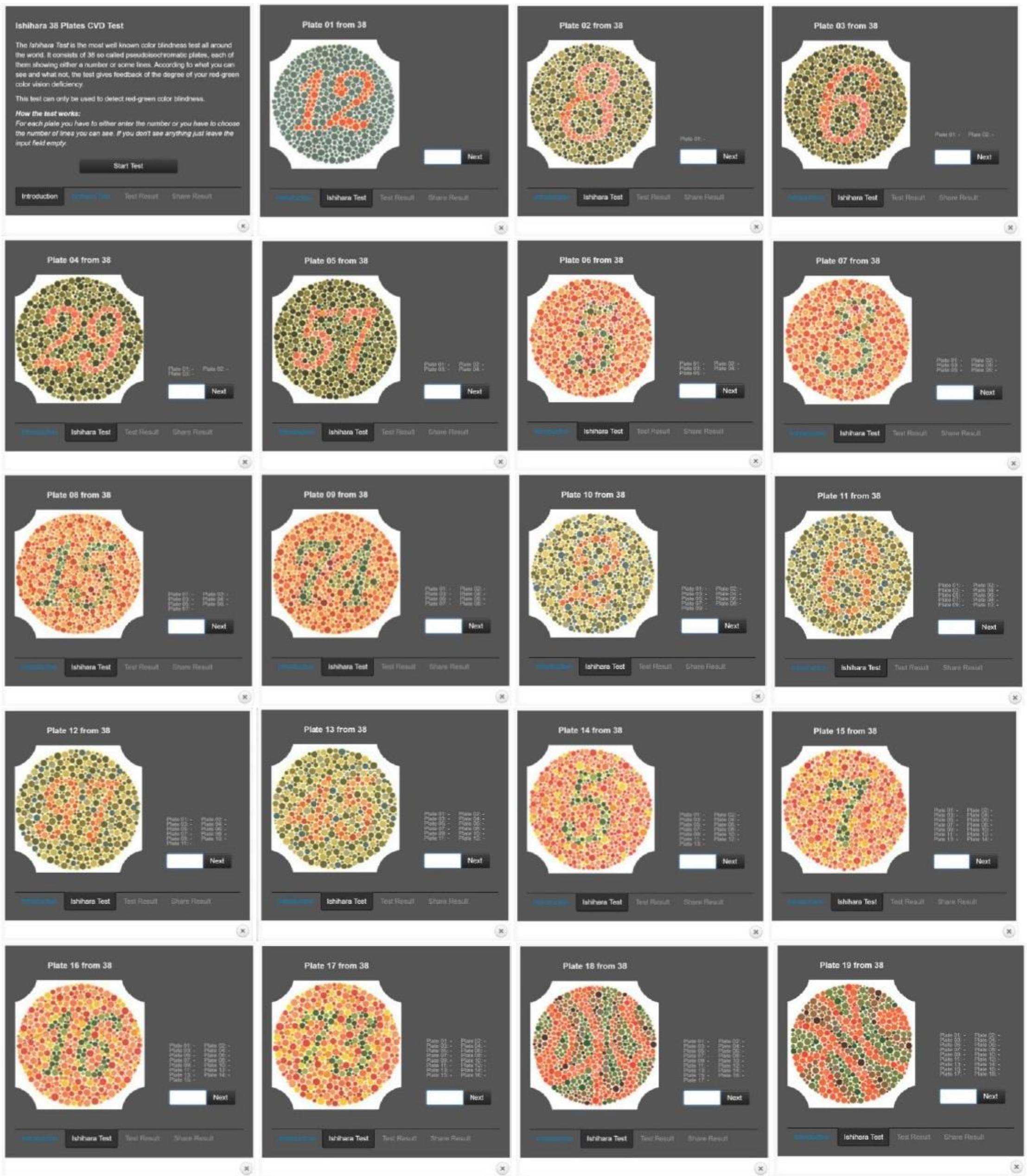



Plate 20 from 38
Plate 21 from 38
Plate 22 from 38
Plate 23 from 38
Plate 24 from 38
Plate 25 from 38
Plate 26 from 38
Plate 27 from 38
Plate 28 from 38
Plate 29 from 38
Plate 30 from 38
Plate 31 from 38
Plate 32 from 38
Plate 33 from 38
Plate 34 from 38
Plate 35 from 38
Plate 36 from 38
Plate 37 from 38
Plate 38 from 38
Ishihara 38 Plates CVD Test
The Ishihara Test is the most well known color blindness test all around the world. It consists of 38 so called pseudoisochromatic plates, each of them showing either a number or some lines. According to what you can see and what not, the test gives feedback of the degree of your red-green color vision deficiency.
This test can only be used to detect red-green color blindness.
How the test works:
For each plate you have to either enter the number or you have to choose the number of lines you can see. If you don't see anything just leave the input field empty.
Start Test
Introduction
Ishihara Test
Test Result
Share Result

Appendix E. The Survey Instrument

E1. Stage 1

SURVEY SET

Visual Perception of the Built Environment in Virtual Reality: A Systematic Characterization of Human Aesthetic Experience in Spaces with Curved Boundaries

SET NO : Size / Light / Texture / Color _______ HB / VB - 1.... 2.... HB / VB - 3... 4...

Participant Information

Participant No: _________

Age: _____

Sex: ☐ Female ☐ Male

Faculties and Departments: _________________

Education Level: ☐ Undergraduate ☐ Graduate

Space 1

Please mark your cognitive responses elicited by related space on each scale.

	-2	-1	0	1	2	
Sleepy						Arousing
Unpleasant						Pleasant
Gloomy						Exciting
Distressing						Relaxing
Simple						Complex
Incoherent						Coherent
Unsafe						Safe
Not mysterious						Mysterious
Masculine						Feminine

Please mark your emotional responses elicited by related space settings on each scale. You should respond quickly (quick responses are important).

	-2	-1	0	1	2	
Annoyed						Pleased
Unaroused						Aroused
Unhappy						Happy
Bored						Relaxed
Unsatisfied						Satisfied
Calm						Excited
Sluggish						Frenzied
Dull						Jittery
Sleepy						Wide-awake
Melancholic						Contended
Relaxed						Stimulated
Despairing						Hopeful

Please fill in the behavioral responses elicited by related space on each question.

Are there any other feelings/ emotions that you'd like to describe about related space setting?
____

What have you liked/ disliked about this room? Please explain_________________________

How much time would you like to spend in this room?

☐ Never ☐ Almost never ☐ A few minutes ☐ An hour ☐ A few hours

Once in this room, how much would you enjoy exploring around?

☐ Not at all ☐ Slightly ☐ Moderate ☐ Much ☐ Very much

To what extent does this place make you feel friendly and talkative to a stranger who happens to be near you?

☐ Not at all ☐ Slightly ☐ Moderate ☐ Much ☐ Very much

Space 2

Please mark your cognitive responses elicited by related space on each scale.

	-2	-1	0	1	2	
Sleepy						Arousing
Unpleasant						Pleasant
Gloomy						Exciting
Distressing						Relaxing
Simple						Complex
Incoherent						Coherent
Unsafe						Safe
Not mysterious						Mysterious
Masculine						Feminine

Please mark your emotional responses elicited by related space settings on each scale. You should respond quickly (quick responses are important).

	-2	-1	0	1	2	
Annoyed						Pleased
Unaroused						Aroused
Unhappy						Happy
Bored						Relaxed
Unsatisfied						Satisfied
Calm						Excited
Sluggish						Frenzied
Dull						Jittery
Sleepy						Wide-awake
Melancholic						Contended
Relaxed						Stimulated
Despairing						Hopeful

Please fill in the behavioral responses elicited by related space on each question.

Are there any other feelings/ emotions that you'd like to describe about related space setting?

____

What have you liked/ disliked about this room? Please explain________________________

How much time would you like to spend in this room?

☐ Never ☐ Almost never ☐ A few minutes ☐ An hour ☐ A few hours

Once in this room, how much would you enjoy exploring around?

☐ Not at all ☐ Slightly ☐ Moderate ☐ Much ☐ Very much

To what extent does this place make you feel friendly and talkative to a stranger who happens to be near you?

☐ Not at all ☐ Slightly ☐ Moderate ☐ Much ☐ Very much

Space 3

Please mark your cognitive responses elicited by related space on each scale.

	-2	-1	0	1	2	
Sleepy						Arousing
Unpleasant						Pleasant
Gloomy						Exciting
Distressing						Relaxing
Simple						Complex
Incoherent						Coherent
Unsafe						Safe
Not mysterious						Mysterious
Masculine						Feminine

Please mark your emotional responses elicited by related space settings on each scale. You should respond quickly (quick responses are important).

	-2	-1	0	1	2	
Annoyed						Pleased
Unaroused						Aroused
Unhappy						Happy
Bored						Relaxed
Unsatisfied						Satisfied
Calm						Excited
Sluggish						Frenzied
Dull						Jittery
Sleepy						Wide-awake
Melancholic						Contended
Relaxed						Stimulated
Despairing						Hopeful

Please fill in the behavioral responses elicited by related space on each question.

Are there any other feelings/ emotions that you'd like to describe about related space setting?

____

What have you liked/ disliked about this room? Please explain_________________________

How much time would you like to spend in this room?

☐ Never ☐ Almost never ☐ A few minutes ☐ An hour ☐ A few hours

Once in this room, how much would you enjoy exploring around?

☐ Not at all ☐ Slightly ☐ Moderate ☐ Much ☐ Very much

To what extent does this place make you feel friendly and talkative to a stranger who happens to be near you?

☐ Not at all ☐ Slightly ☐ Moderate ☐ Much ☐ Very much

Space 4

Please mark your cognitive responses elicited by related space on each scale.

	-2	-1	0	1	2	
Sleepy						Arousing
Unpleasant						Pleasant
Gloomy						Exciting
Distressing						Relaxing
Simple						Complex
Incoherent						Coherent
Unsafe						Safe
Not mysterious						Mysterious
Masculine						Feminine

Please mark your emotional responses elicited by related space settings on each scale. You should respond quickly (quick responses are important).

	-2	-1	0	1	2	
Annoyed						Pleased
Unaroused						Aroused
Unhappy						Happy
Bored						Relaxed
Unsatisfied						Satisfied
Calm						Excited
Sluggish						Frenzied
Dull						Jittery
Sleepy						Wide-awake
Melancholic						Contended
Relaxed						Stimulated
Despairing						Hopeful

Please fill in the behavioral responses elicited by related space on each question.

Are there any other feelings/ emotions that you'd like to describe about related space setting?

____

What have you liked/ disliked about this room? Please explain_________________________

How much time would you like to spend in this room?

☐ Never ☐ Almost never ☐ A few minutes ☐ An hour ☐ A few hours

Once in this room, how much would you enjoy exploring around?

☐ Not at all ☐ Slightly ☐ Moderate ☐ Much ☐ Very much

To what extent does this place make you feel friendly and talkative to a stranger who happens to be near you?

☐ Not at all ☐ Slightly ☐ Moderate ☐ Much ☐ Very much

E2. Stage 2

IVE-SURVEY SET

The Aesthetic Experience of Interior Spaces with Curvilinear Boundaries and Various Space Properties in Immersive and Desktop-Based Virtual Environments

Participant Information

Participant No: _________

Age: _____

Sex: ☐ Female ☐ Male

Faculties and Departments: _________________

Education Level: ☐ Undergraduate ☐ Graduate

Please mark your aesthetic judgement elicited by related space after each immersive virtual environment simulations.

The **familiarity** dimension includes assessments such as how pleased, satisfied or relaxed one feels in an environment, how safe and coherent they think the environment looks, and how they would like to behave in this environment such as whether they would like to spend time or enjoy exploring.

The **excitement** dimension includes assessments such as how excited, frenzied, jittery or contended one feels in an environment. In other words, this dimension characterizes how one feels in an architectural space.

The **fascination** dimension includes assessment such as how mysterious or complex an environment looks or how stimulated one feels in that environment

Space 1 **Familiarity** (Pleased, Happy, Satisfied, Pleasant, Relaxed, Like to spend time, Prefer to live, Enjoy exploring, Hopeful, Relaxing, Feel friendly and talkative, Exciting, Safe, Aroused, Arousing, Coherent)

1-not familiar	2	3	4-netural	5	6	7-familiar

Excitement (Wideawake, Excited, Frenzied, Jittery, Contended)

1-not excited	2	3	4-netural	5	6	7-excited

Fascination (Mysterious, Complex, Stimulated)

1-not fascinated	2	3	4-netural	5	6	7-fascinated

-
-
-

Space 32 **Familiarity** (Pleased, Happy, Satisfied, Pleasant, Relaxed, Like to spend time, Prefer to live, Enjoy exploring, Hopeful, Relaxing, Feel friendly and talkative, Exciting, Safe, Aroused, Arousing, Coherent)

1-not familiar	2	3	4-netural	5	6	7-familiar

Excitement (Wideawake, Excited, Frenzied, Jittery, Contended)

1-not excited	2	3	4-netural	5	6	7-excited

Fascination (Mysterious, Complex, Stimulated)

1-not fascinated	2	3	4-netural	5	6	7-fascinated

DTVE-SURVEY SET

The Aesthetic Experience of Interior Spaces with Curvilinear Boundaries and Various Space Properties in Immersive and Desktop-Based Virtual Environments

Participant Information

Participant No: _________

Age: _____

Sex: ☐ Female ☐ Male

Faculties and Departments: _________________

Education Level: ☐ Undergraduate ☐ Graduate

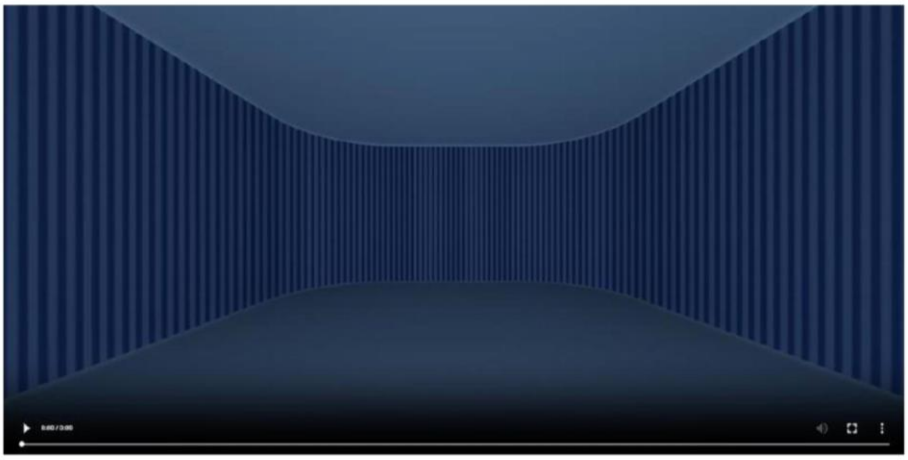
Please mark your aesthetic judgement elicited by related space after each desktop-base virtual environment video simulations.

The **familiarity** dimension includes assessments such as how pleased, satisfied or relaxed one feels in an environment, how safe and coherent they think the environment looks, and how they would like to behave in this environment such as whether they would like to spend time or enjoy exploring.

The **excitement** dimension includes assessments such as how excited, frenzied, jittery or contended one feels in an environment. In other words, this dimension characterizes how one feels in an architectural space.

The **fascination** dimension includes assessment such as how mysterious or complex an environment looks or how stimulated one feels in that environment

Space 1



Familiarity (Pleased, Happy, Satisfied, Pleasant, Relaxed, Like to spend time, Prefer to live, Enjoy exploring, Hopeful, Relaxing, Feel friendly and talkative, Exciting, Safe, Aroused, Arousing, Coherent)

1-not familiar	2	3	4-netural	5	6	7-familiar

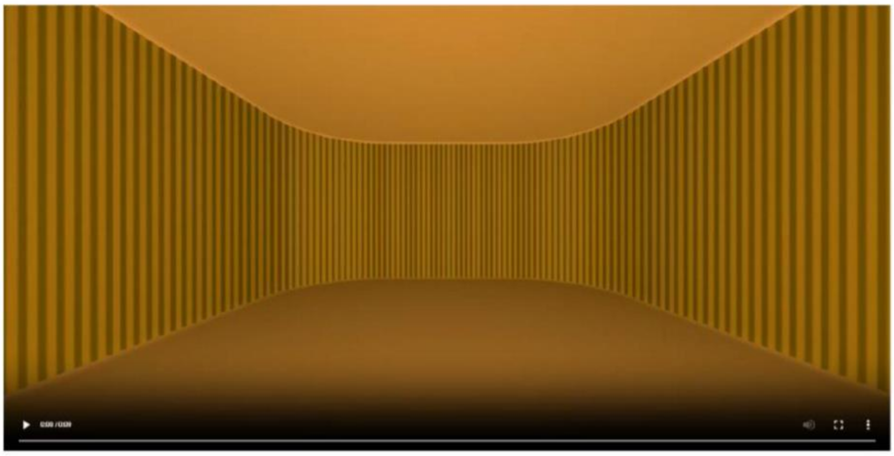
Excitement (Wideawake, Excited, Frenzied, Jittery, Contended)

1-not excited	2	3	4-netural	5	6	7-excited

Fascination (Mysterious, Complex, Stimulated)

1-not fascinated	2	3	4-netural	5	6	7-fascinated

Space 32



Familiarity (Pleased, Happy, Satisfied, Pleasant, Relaxed, Like to spend time, Prefer to live, Enjoy exploring, Hopeful, Relaxing, Feel friendly and talkative, Exciting, Safe, Aroused, Arousing, Coherent)

1-not familiar	2	3	4-netural	5	6	7-familiar

Excitement (Wideawake, Excited, Frenzied, Jittery, Contended)

1-not excited	2	3	4-netural	5	6	7-excited

Fascination (Mysterious, Complex, Stimulated)

1-not fascinated	2	3	4-netural	5	6	7-fascinated

E3. Stage 3

EEG PRE-SCREENING FORM TO PARTICIPATE AS A RESEARCH SUBJECT

Research project: The aesthetic experience of interior spaces with curvilinear boundaries and various space properties in immersive and desktop-based virtual environments

İ.D. Bilkent University

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Name-Last name:
Date of birth:
Gender:

GENERAL QUESTIONS:

Right handed: yes / no

Normal hearing: yes / no

Normal vision / wear contacts: yes / no

If you wear glasses, your prescription (if known):

Native language:

Other languages you are fluent:

EEG COMPATIBILITY QUESTIONS

Do you have any psychiatric or neurological disorder (e.g. epilepsy)?

Do you use psychiatric medication?

Do you have any metallic implants around your neck or head?

For female volunteers: Are you pregnant or could you possibly be pregnant?

How many hours do you usually sleep?

How many hours did you sleep last night?

I inform that the above information is correct.

Participant name:

Participant signature:

SURVEY SET

Architecture With Aesthetics:

Measuring Psychological and Neural Responses to Curved Architectural Boundaries

Participant Information

Participant No: _________

Age: _____

Sex: ☐ Female ☐ Male

Faculties and Departments: _________________

Education Level: ☐ Undergraduate ☐ Graduate

Please mark your aesthetic judgment elicited by related space after each virtual environment video simulation.

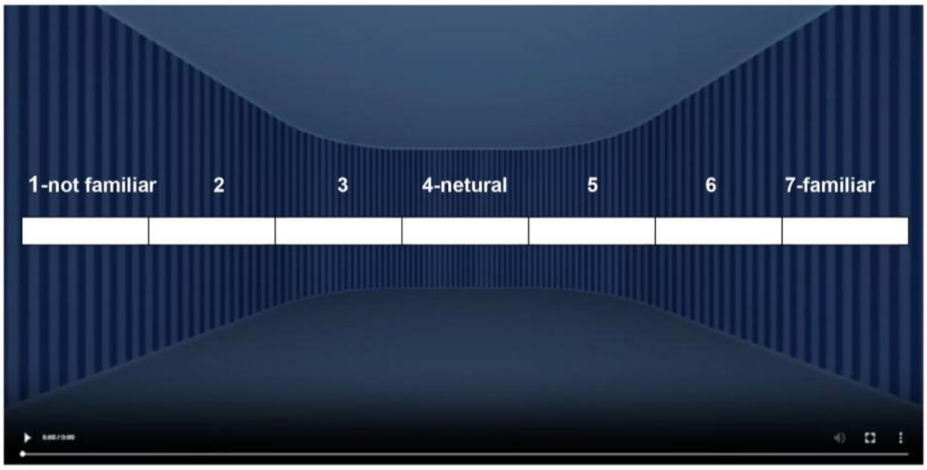
The **familiarity** dimension includes assessments such as how pleased, satisfied or relaxed one feels in an environment, how safe and coherent they think the environment looks, and how they would like to behave in this environment such as whether they would like to spend time or enjoy exploring.

The **excitement** dimension includes assessments such as how excited, frenzied, jittery or contended one feels in an environment. In other words, this dimension characterizes how one feels in an architectural space.

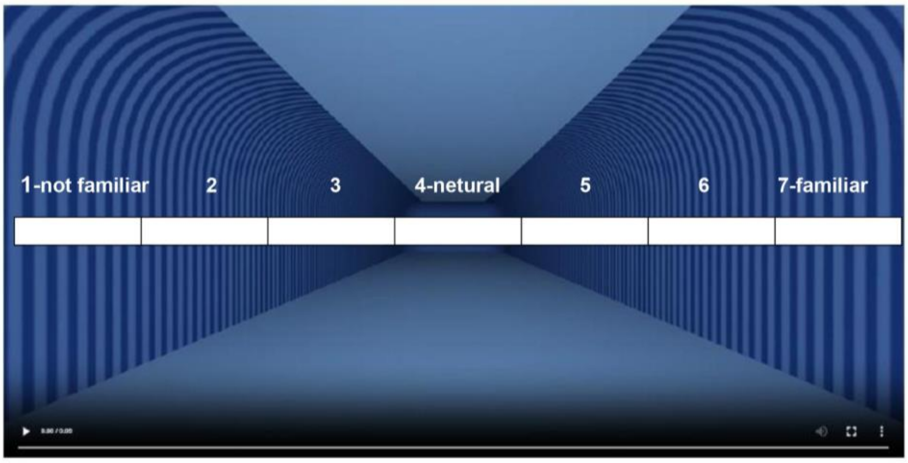
The **fascination** dimension includes assessment such as how mysterious or complex an environment looks or how stimulated one feels in that environment

Block 1 Familiarity

Space 1

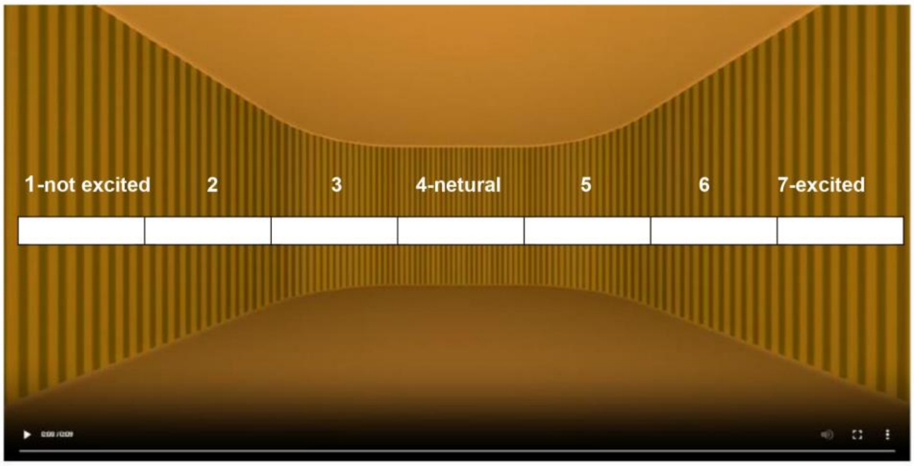


Space 32



Block 2 Excitement

Space 1

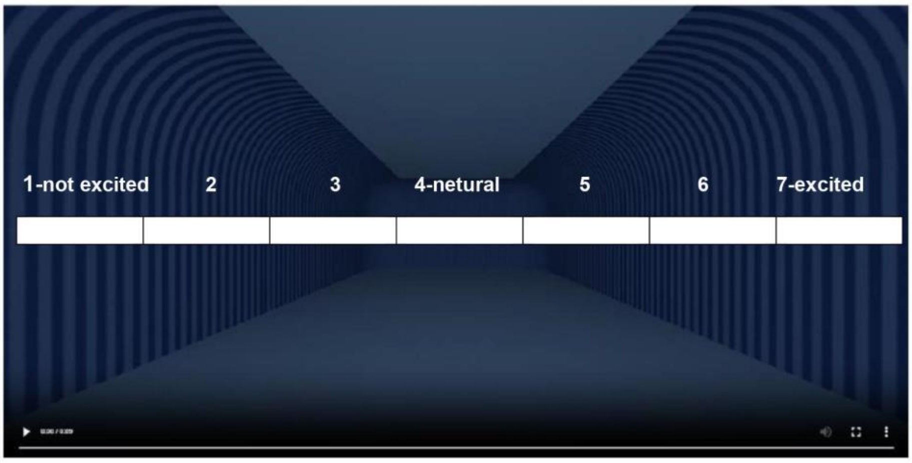


▪

▪

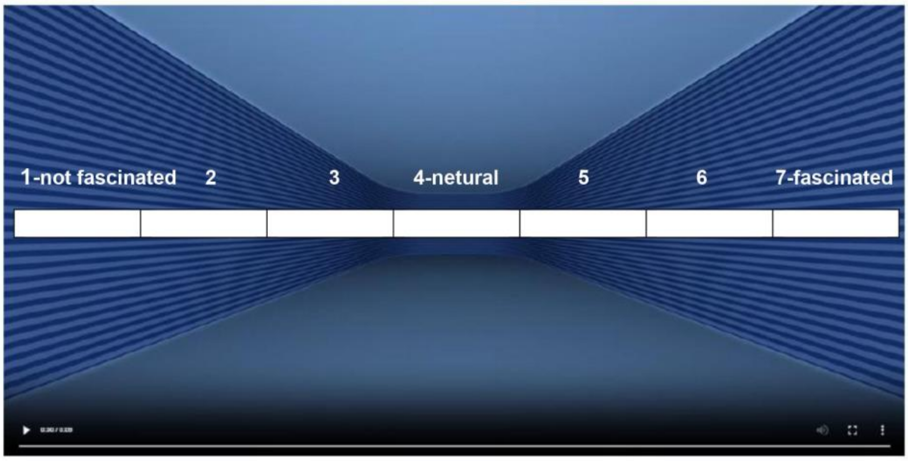
▪

Space 32

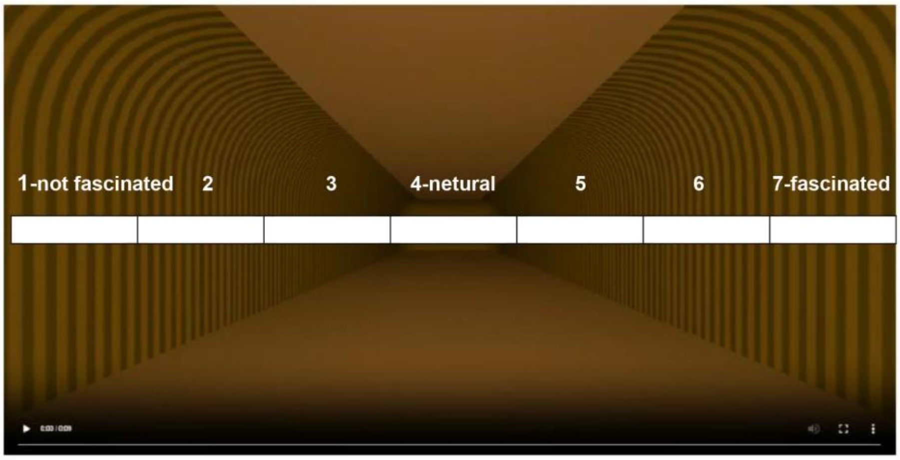


Block 3 Fascination

Space 1



Space 32



Appendix F. C# for Stage 3

```
using System;
using System.Collections;
using System.Collections.Generic;
using System.Drawing.Text;
using System.IO;
using System.IO.Ports;
using TMPro;
using UnityEditor;
using UnityEditor.Callbacks;
using UnityEngine;
using UnityEngine.Rendering.VirtualTexturing;
using UnityEngine.UI;
using UnityEngine.Video;

public class PlayScenesWithoutQuestions : MonoBehaviour
{
    public static string port = "COM21";
    public static int baudrate = 9600;
    public static bool isStreaming = false;
    public static SerialPort sp;
    private int currentIndex=-1;

    public VideoPlayer videoPlayer;
    public VideoClip[] videoArray;
    public TMP_Text fixationCross;
    public TMP_Text text;

    public RawImage overlayImage;
    public RawImage background;
    public List<DataObject> dataObjects = new List<DataObject>();

    private UInt16[,] marker_array = new UInt16[32,3] {
        {1, 2, 3}, {4, 5, 6}, {7, 8, 9}, {10, 11, 12}, {13, 14, 15}, {16, 17, 18}, {19, 20, 21}, {22, 23, 24},
        {25, 26, 27}, {28, 29, 30}, {31, 32, 33}, {34, 35, 36}, {37, 38, 39}, {40, 41, 42}, {43, 44, 45}, {46, 47, 48},
        {49, 50, 51}, {52, 53, 54}, {55, 56, 57}, {58, 59, 60}, {61, 62, 63}, {64, 65, 66}, {67, 68, 69}, {70, 71, 72},
        {73, 74, 75}, {76, 77, 78}, {79, 80, 81}, {82, 83, 84}, {85, 86, 87}, {88, 89, 90}, {91, 92, 93}, {94, 95, 96}};


    private string[] typeList = {
        "The familiarity dimension includes assessments such as how pleased, satisfied or relaxed one feels in an environment, how safe and coherent they think the environment looks, and how
        "Excitement dimension includes assessments such as how excited, frenzied, jittery or contended one feels in an environment.",
        "Fascination dimension includes assessment such as how mysterious or complex an environment looks or how stimulated one feels in that environment."

    };

    private string[] types =
    {
        "Familiarity",
        "Excitement",
        "Fascination"
    };

    void Start()
    {

        overlayImage.enabled = true;
        fixationCross.enabled = false;
        text.enabled = false;

        Open();

        StartCoroutine(PlayVideos());

    }
    void OnDestroy()
    {
        WriteDataToCSV("output.csv", dataObjects);
        sp.Close();
    }
```

```
        text.enabled = true;
        yield return new WaitForSeconds(10f);
        text.enabled = false;

        ShuffleArray(videoArray);
        foreach (var videoClip in videoArray)
        {
            currentIndex++;
            int.TryParse(videoClip.ToString().Split(".")[0], out int videoCode);

            DataObject data = new();
            UInt16 eegCode = marker_array[videoCode - 1, var];


            data.code = videoCode;
            data.code_eeg = eegCode;
            data.name = videoClip.ToString().Split(".")[1];
            data.blockName = type;

            dataObjects.Add(data);


            Debug.Log("Showing Overlay Image");
            overlayImage.enabled = true;
            fixationCross.enabled = true;

            videoPlayer.clip = videoClip;

            videoPlayer.Play();
            yield return new WaitForSeconds(0.001f);
            videoPlayer.Pause();

            Debug.Log("------------- CALLING THE TRIGGER FUNCTION -----------------");
            sendTriggers(150);
            Debug.Log("Trigger_step1 function executed succesfully on " + currentIndex);

            yield return new WaitForSeconds(5f);

            overlayImage.enabled = false;
            fixationCross.enabled = false;

            Debug.Log("Hiding Overlay Image");

            // Wait for the overlay image to be hidden before playing the video
            while (overlayImage.enabled)
            {
                yield return null;
            }

            Debug.Log("------------- VIDEO BEGINS -----------------");
            Debug.Log("------------- CALLING THE TRIGGER FUNCTION -----------------");
            sendTriggers(eegCode);
            Debug.Log("Trigger_step2 function executed succesfully on " + currentIndex);

            videoPlayer.Play();

            yield return new WaitForSeconds((float)videoClip.length);
            videoPlayer.Pause();
            sendTriggers(100 );
        }

        overlayImage.enabled = true;

        text.text = "Block Complete";
        text.enabled = true;
        yield return new WaitForSeconds(5f);
        text.enabled = false;
    }

}
```

```
void Open()
{
    sp = new SerialPort(port, baudrate);
    sp.ReadTimeout = 100;
    sp.DataBits = 8;
    sp.Open(); // open the port
    if (sp.IsOpen)
    {
        isStreaming = true;
        Debug.Log("Succesfully opened a serial port at " + port);
       // sendTriggers(200);

    }

}

void sendTriggers(UInt16 eventcode)
{
    Debug.Log("PORT CHECK sp.PortName : " + sp.PortName);
    Debug.Log("PORT CHECK port : " + port);
    Debug.Log("Is port open: " + sp.IsOpen);


    if (sp.IsOpen)
    {
        Debug.Log("Inside the send function: Sending an event code from port: " + sp.PortName);
        byte[] intbytes = BitConverter.GetBytes(eventcode);
        sp.Write(intbytes, 0, 1);
        sp.BaseStream.Flush();
        System.Threading.Thread.Sleep(200);
        Debug.Log("SENT! The streamed eventcode: " + eventcode);
    }

    //


}
IEnumerator PlayVideos()
{
    text.text = "The experiment is about to start.";
    text.enabled = true;
    yield return new WaitForSeconds(3f);

    ShuffleArray(types);

    foreach(var type in types)
    {
        int var;
        string intro;

        if (type.Equals("Fascination"))
        {
            intro = typeList[2];
            var = 0;
        }
        else if (type.Equals("Excitement"))
        {
            intro = typeList[1];
            var = 1;
        }
        else
        {
            intro = typeList[0];
            var = 2;
        }

        text.text = intro.ToString();
```

```
using System;
using System.Collections;
using System.Collections.Generic;
using System.IO;
using System.IO.Ports;
using TMPro;
using UnityEngine;
using UnityEngine.UI;
using UnityEngine.Video;

public class DataObject
{
    public static DataObject instance;

    private string videoName;
    private string questionType;
    private int buttonResponse;
    private int no;

    public DataObject(int no, string videoName, string questionType, int buttonResponse)
    {
        this.videoName = videoName;
        this.questionType = questionType;
        this.buttonResponse = buttonResponse;
        this.no = no;
    }

    public string getVideoName()
    {
        return videoName;
    }

    public string getQuestion()
    {
        return questionType;
    }

    public int getButtonResponse()
    {
        return buttonResponse;
    }

    public int getNo()
    {
        return no;
    }

}

public class PlayScenesWithEachQuestion : MonoBehaviour
{
    // Port spesifications

    /*public string port = "COM3"; // name
    public int baudrate = 9600; // baudrate
    public static SerialPort sp;
    public bool isStreaming = false; // default value, will be changed to true as the port is open
    public int tmp = 0;*/

    public static SerialPort sp;
    public static bool x = false;

    public static bool isStreaming = false; // default value, will be changed to true as the port is open
    public string port = "COM3"; // name
    public int baudrate = 9600; // baudrate

    public VideoPlayer videoPlayer;
    public VideoClip[] videoArray;
    private int currentIndex;
    public CanvasGroup[] buttonCanvasGroups;
    public Button[] optionButtons;
    public string currentButtonText;
    public TMP_Text textMeshProText;
```

```
public RawImage overlayImage;
public RawImage background;

public string[] videoName;
public string questionType;
public int buttonResponse;
public List<DataObject> dataList;

private string[] questions = {
    "Familiarity",
    "Excitement",
    "Fascination"
};

void Start()
{
    dataList = new List<DataObject>();
    overlayImage.enabled = false;
    sp = new SerialPort(port, baudrate); // create a serialport object
    sp.ReadTimeout = 100; // wait for 100 seconds
    sp.DataBits = 8; // number of databits
    sp.Open(); // open port
    isStreaming = true;
    Debug.Log("Succesfully opened a serial port.");

    Debug.Log("printing");



  //  StartCoroutine(PlayScenes());
}


void OnDestroy()
{
    // Call the method to write the CSV file when the script is being destroyed
    WriteDataToCSV("output.csv", dataList);
}

IEnumerator PlayScenes()
{
    ShuffleArray(questions);

    foreach (string question in questions)
    {
        questionType = question;
        currentIndex = 0;
        ChangeTextMeshContent(textMeshProText, question);
        ShuffleArray(videoArray);
        yield return StartCoroutine(PlayNextVideo());
    }
}

IEnumerator PlayNextVideo()
{
    while (currentIndex < videoArray.Length)
    {
        yield return StartCoroutine(OverlayImageForFiveSeconds());
        // Play the video
        ShowButtons();

        // Wait for button response or 5 seconds timeout
        yield return StartCoroutine(WaitForButtonResponse());

        HideButtons();

        currentIndex++;
    }

    Debug.Log("No more videos in the array.");
}
```

```
    void ShuffleArray<T>(T[] array)
    {
        int n = array.Length;
        for (int i = n - 1; i > 0; i--)
        {
            int j = UnityEngine.Random.Range(0, i + 1);
            T temp = array[i];
            array[i] = array[j];
            array[j] = temp;
        }
    }

    void WriteDataToCSV(string filePath, List<DataObject> dataList)
    {
        // Create and write to the CSV file
        using (StreamWriter sw = new StreamWriter(filePath))
        {
            // Write header
            sw.WriteLine("BlockName,VideoName,VideoNo,BegMarker");

            // Write data
            foreach (var dataObject in dataList)
            {
                sw.WriteLine($"{dataObject.blockName},{dataObject.name},{dataObject.code},{dataObject.code_eeg}");
            }
        }
    }
}

public class DataObject
{
    public static DataObject instance;

    public int code;
    public string name;
    public string blockName;
    public UInt16 code_eeg;

    public DataObject()
    { }
}
```

Appendix G. Alpha and Beta Bar Plots of Aesthetic Judgment Dimensions